News and Information:

Glue Technologies for Space Systems: An Introduction to a New AESS Technical Panel

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INTRODUCTION AND MOTIVATIONS

The recent change of perspective of aerospace communications, also known as "Space 2.0" [1], straightforwardly introduced the concept of "space intelligence," meaning the capability of building a networked cognitive space

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environment, able to support the endeavors of researchers and developers working in the field of space technology. As shown in Figure 1, the space environment becomes a kind of ecosystem where surface networks (in the figure, terrestrial networks are indicated, but the same scenario could be conceived, e.g., for Martian networks) and space networks will form together a unique integrated infrastructure targeting the global, ubiquitous, resilient, and broadband coverage of Information and Communication Technology (ICT) services. Space network intelligence is actually the capability of the space segment of dynamically configuring itself on the basis of the connectivity requirements coming from the surface network infrastructures.

It is evident that such a renewed vision involves the necessity of a superior level of integration among heterogeneous networked processing entities. "Glue technologies" will offer the necessary support to fulfill such a fundamental requirement. Glue technology, as with global enterprises, integrates the subsidiaries and other producing units, saving their own need of autonomy [2]. In the specific space framework, "Glue technologies" constitutes the necessary common platform for the innovative systems based on space components (satellites, UAV, rover, landers, orbiters, etc.) that will be deployed in the near future in various application fields (satellite and aerospace communications, interplanetary communications, planet exploration, Internet of Space Things (IoST), etc.). This is the reason why AESS decided in April 2019 to constitute a new panel called "Glue Technologies for Space Systems." Rather than more

"technologies," the panel will consider "technological tools" that will be used (and reused) in different and heterogeneous sectors of space science and engineering.

The most important "glue" in space ICT is the exchange of data among different entities that should work in seamless networked manner. But, also data and signal processing constitutes another form of glue that is essential to connect the remote processing machines to the human comprehension and investigation of what happens in the space.

In this article, the various glue technologies for space systems will be briefly introduced (see "Overview of Glue Technologies for Space Systems" section) and, then, the founder members will share their own vision of the panel in terms of motivations and future achievements to be pursued (see "Panel Vision (From the Panel Founder Members)" section). Sections "Updated List of the Adjunct Panel Members" and "Panel Meetings and Participation Rules" will conclude the article with the updated list of the panel adjunct members and some other useful information (panel meeting organization, panel participation rules, etc.)

OVERVIEW OF GLUE TECHNOLOGIES FOR SPACE SYSTEMS

In the following, a brief overview of the technical areas of the panel is provided, along with some reference to relevant works published in the literature, highlighting developments, potentials, open issues, and applications of the "glue" technologies.

BROADBAND SPACE TRANSMISSIONS

The most recent trends in broadband satellite data transmissions are considering the exploitation of extremely high frequency (EHF) bandwidth portions in order to boost link capacity (see, e.g., ESA Alphasat experiment concerning a Q/V band payload [3]). The synergy between EHF transmission and multibeam satellites could break the wall of terabit capacity in the sky, paving the road to a plethora of applications, from UHDTV broadcasting [4] to multimedia streaming in 5 G scenarios [5]. A lot of research work is currently done about the mitigation of atmospheric propagation effects that is a still an open issue in these frequency ranges.
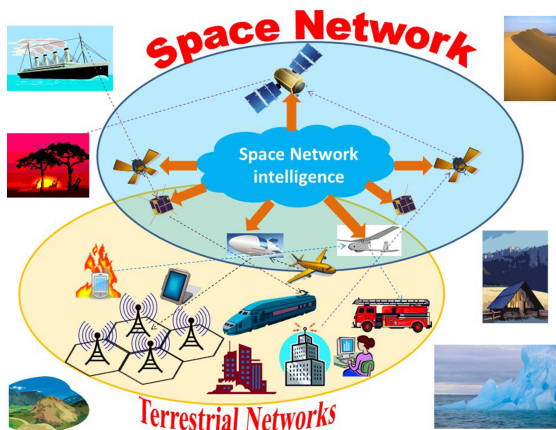

Figure 1.
Space 2.0 vision: Pictorial description.

SOFTWARIZATION OF SPACE NETWORKING

In order to bring intelligence to space, a substantial step ahead is required in terms of augmented flexibility and reprogrammability of the space network segment. In such a framework, software-defined radio (SDR) and software-defined networking (SDN) represent the key technologies. Most recent contributions, published in the literature, consider the SDN-based seamless integration of heterogeneous satellite links (free-space optical and radio) [6], reconfigurable CubeSat payloads based on SDR [7], and the integration of satellite networking in the 5 G ecosystem, obtained by means of SDN tools [8].

INTERNET OF REMOTE THINGS (IORT) AND IOST

A second revolution in Internet technology is growing around the concept of Internet of Things (IoT). Satellite communications may potentially play an important role in IoT. Indeed, smart objects are often remote or dispersed over wide geographical areas, or they are inaccessible. Such a situation is referred in [9] as IoRT. In such a framework, satellite communication would offer a broadband cost-effective solution for the interconnection of networks of smart objects with the rest of the world. Recent developments are considering IoRT in a wider vision encompassing smart environments in the deep space. In such a framework, we can speak about IoST. An interesting example has been shown in [10], where IoT and wireless power transmission are employed in deep-space exploration.

SEAMLESS INTEGRATION OF INTELLIGENT AERIAL NETWORKS AND WITH COGNITIVE AND SOFTWARIZED SKY NETWORKS

This is a very emerging topic in aerospace networking with a lot of potential for high added-value applications. The multitude of drones and UAVs flying over our heads configure a "smart cloud" capable of fulfilling advanced monitoring tasks in every kind of emergency, provided that coordination and seamless integration with long-range space networks is guaranteed. In [11], a valuable example has been presented, describing the use of satellite-based cloud radio access network in order to efficiently manage safety-critical information exchange from ground sensors, UAVs and remote control centers in border monitoring applications.

AUGMENTED THREE-DIMENSIONAL (3-D) REALITY FOR MANNED EXPLORATION MISSIONS

In the days of the 50th anniversary of the Moon walk of N. Armstrong and E. A. Aldrin, future space missions are being planned. The very ambitious target of these early millennium decades is to reach Mars with a manned crew. Techniques of augmented 3-D reality may provide a valuable support to the crew training, virtually reproducing the Mars surface environment. An example published in the literature is shown in [12], where a Virtual Astronaut is created as an interactive virtual 3-D environment to support the Mars Exploration Rover mission.

END-TO-END SYSTEM CONSIDERATIONS OF SPACE SYSTEMS

Much effort has been spent to promote the system engineering aspects of space system. However, this effort is mostly qualitative/process oriented, and are on the pragmatic side. In order to provide a more effective end-to-end system assessment of space systems, the panel intends to promote the investigation of more formal and analytical approaches, using, e.g., advanced statistical techniques, probabilistic inference, optimization methods, etc. Some examples are joint design for the Galileo's error correction and data compression system [13], statistical link analysis and margin policy for dynamic links [14], and joint data-layer and network-layer smart transmission protocols for reliable communications for fading channels [15].

INTEGRATED COMMUNICATION, NAVIGATION, AND SENSING

In the past few decades, communications and navigation have been developed in separate paths. But for space system, it is highly desirable to integrate the two systems together. For robotic and human space explorations beyond Earth, e.g., Moon and Mars, it is desirable to establish a low-complexity relay infrastructure (with a small number of orbiters) that provides integrated communications and navigation services to the visiting spacecraft [16], [17], [18]. The low-complexity integrated communications and navigation approach can also be useful for Earth's "GPS denied" applications, and for GPS augmentation in urban canyon environments [19]. Sensing and radars represent other actors in this integration process. Recent works are considering these aspects [20], [21], [22], [23], in the framework of safety-critical applications like maritime safety, autonomous vehicle guidance, and emergency rescue.

ADVANCED SIGNAL PROCESSING AND DATA FUSION TECHNIQUES FOR SPACE APPLICATIONS

Data fusion is the typical "glue" of advanced signal processing tasks, as it seamlessly integrates and processes information coming from heterogeneous sensors and signal sources. As far as space applications are concerned,

recent examples have been demonstrated about radiometric and inertial data fusion for deep space navigation, [24], SAR, optical and LIDAR data fusion for high-resolution mapping of protected areas [25] and multisensor satellite image fusion for the study of climatic changes [26].

PANEL VISION (FROM THE PANEL FOUNDER MEMBERS)

The vision and the perspectives of the panel, expressed by the founder members, are shown in Table 1.

Table 1.

Panel Vision from the Founder Members		
Founder member	**Please, explain the reason why did you decide to join the panel**	**Please, express your personal feeling about which outcomes do you expect in the near future from the panel activities**
Michael Rice, Brigham Young University, Provo, UT, Fellow IEEE, AESS member	I am a member of the AESS and this panel is my natural technical "home." I find interesting the problems, techniques, and challenges of satellite communication systems and want to be a part of the effort to apply different technologies to improving the capabilities and performance of satellite systems.	I hope the panel activities raise awareness of the interesting problems in satellite communication systems, especially with young professionals looking for interesting careers and young graduate students looking for challenging problems whose solution can make a difference.
Mario Marchese, University of Genoa, Italy, IEEE Senior member, ComSoc member	The idea to be part of an international panel to foster research and technical activities about satellite communication and networking is really stimulating. One of the key points is to fully understand the satellite role in the future 5G and to individuate a possible roadmap to get a full integration of satellites in the 5G environment. Thanks to their intrinsic ubiquity and broadcasting capabilities, satellite networks can play multiple roles in 5G, both as main communication segment for rural and risky areas, aircrafts, vessels, and trains, and as a mean to provide additional connectivity and bandwidth. Their integration in the 5G environment poses new challenges that this panel can help investigating through the promotion of courses, schools, meetings, conferences, journals where people both from industry and academy can openly discuss.	In the long-term the panel should be aimed at: disseminating knowledge, in particular to younger generations; technologists and scientists training; stimulating discussions and direct knowledge exchange. In this view, short-term outcomes should be the endorsement of courses, schools and meetings about dedicated selected topics, while medium-term outcomes should be the organization of conference sessions and panels where experts may communicate the state of the art and new ideas about hot advanced topics, and of special issues in journals and magazines to establish seminal knowledge.
Kar-Ming Cheung, Jet	Much research and development (R&D) in the fields of communications and networking of space systems has a tendency on	On the end-to-end system considerations of space systems, this panel should promote using vigorous and formal techniques in

Table 1.

(Continued)

Founder member	Please, explain the reason why did you decide to join the panel	Please, express your personal feeling about which outcomes do you expect in the near future from the panel activities
Propulsion Lab, Pasadena, CA, IEEE Senior Member	focusing on one specific capability, and do not consider its interactions with other functions in the signal processing and data flow chain, and with its environment. This parochial view sometimes impairs the efficiency and the utility of that capability in operations. System engineering and architecture are after-thoughts in many cases, and the efforts are mostly qualitative/process-oriented, and are empirical, hands-on, and pragmatic in nature. The "glue technologies" panel can help to advocate the importance of end-to-end system considerations in the early stage of the R&D efforts. In the past few decades, communications and navigation systems have developed along separate paths. Now there are very good communication radios and systems, and there are very good Earth-based navigation infrastructure and systems, but they are separated. For robotic and human explorations beyond Earth, e.g. Moon and Mars, it is desirable to establish a low-complexity relay infrastructure (with a small number of orbiters) that provides integrated communications and navigation services to the visiting spacecraft. The low-complexity integrated communications and navigation approach can also be useful for Earth's "GPS-denied" applications, and for GPS-augmentation in urban canyon environments. This panel can help to promote the system concept of integrated communications and navigation for Earth and beyond Earth's space applications.	statistical analysis, probability inference, and optimization methods in system analysis and trade, especially in the early stage of system design and architecture. This would facilitate infusion of advance technologies into space system operations. For integrated communications and navigation, this panel should promote new signal structures and signal processing methods that are useful for both communications and navigation. This would enable low-complexity planetary relay network infrastructure, and greatly reduce users' burden in terms of Size, Weight, and Power (SWaP) in communications and navigation.
Nicola Conci, University of Trento, Italy, IEEE Member	I am a member of the IEEE Signal Processing Society, being my background in the area of image and video processing. What I find particularly interesting in this panel	My hope for this panel is to foster the interdisciplinary dimension of scientific research, both at the foundation and application level, involving young and enthusiast

Table 1.

(Continued)

Founder member	Please, explain the reason why did you decide to join the panel	Please, express your personal feeling about which outcomes do you expect in the near future from the panel activities
	is the chance of applying my research to a new extremely challenging domain. I strongly believe that the computer vision and 3D image analysis applied in the context of virtual and augmented reality could find here novel and game-changing applications.	researchers from academia and research centers willing to tackle the challenges in satellite communication systems.
Maurizio Murroni, University of Cagliari, Italy, IEEE Senior Member	Satellite communication is crucial to support the broadcasting industry; currently, satellite broadcast digital services are available worldwide and represent an important market for the broadcasting stakeholders in near future. Furthermore, broadband access via satellite is gaining more and more space in the market while the upcoming 5G scenario is focusing on the converged satellite and terrestrial networks. In both scenarios the development of new services driven by the user quality of experience (QoE) is defining new generation satellite broadband network configuration and management. QoE assessment for broadband satellite communications is a challenge for new generation satellite broadband network performance improvement. Satellite stakeholders are investing R&D resources in this field looking at the academia as references partners to this goal. I believe the GLUE committee is the right place where this topic can be addressed.	The long term outcome of the panel should be leveraging the creation of a critical mass of researchers able to address the new challenges of satellite broadcast/broadband communications. The short term outcome should be the definition of the new challenges and trends to be pursued, the dissemination of them within the research communities, via the organization of dedicated workshops, summer schools, seminars, keynote speeches in the major events, such as international conferences and exhibitions.
Fabrizio Granelli, University of Trento, Italy, IEEE Senior Member	I have been a member of IEEE ComSoc for several years, and working on cellular and mobile networks I often found it interesting to think about integrating those effectively in the design of modern	In general, I expect the panel to identify a viable yet revolutionary roadmap for the design and deployment of novel approaches to satellite communications. Given the competences of the involved

Table 1.

(Continued)

Founder member	Please, explain the reason why did you decide to join the panel	Please, express your personal feeling about which outcomes do you expect in the near future from the panel activities
	wireless networks. This panel explores exactly this issue and clearly looks into the future, by defining a clear step forward into a more interdisciplinary approach to the design of future satellite communications and at the same time paving the way for integrating the best emerging technologies in networking.	experts, I hope this will represent a firm example of how the interdisciplinary nature and pervasiveness of communications should be successful addressed, and exploited to bring a revolution in the field.
Tommaso Rossi, University of Rome "Tor Vergata", Italy, IEEE Member	The panel is focused on stimulating thematic areas; as a matter of fact, "glue technologies" concept is one of the key topics in the current and future space-based systems for communication, sensing and navigation applications. 5G scenarios are leading us in the middle of a key turning point and space systems have to play an important role in such a complex and heterogeneous eco-system. The panel will provide the opportunity to gather experience from academy and industry to identify a roadmap for the full exploitation of new technologies as "softwarization" paradigms (both for the network and radio interface) and terabit/s connectivity supported by EHF.	The main outcomes could be the dissemination of panel activities through the organization of events, publications and courses. Moreover, it will be very important to create a strong liaison between academic and industrial actors to push the development of glue technologies, clearly identify the challenges and train experts.
Vlad Popescu, University of Transilvania, Brasov Romania, IEEE Member	Within the last years, the communication technologies have generated significant interest to the concepts of Internet of Things (IoT) and machine-2-machine (M2M) communications. Even though initially exclusively of terrestrial nature, these two concepts have shifted also in the satellite R&D domain, but are still conditioned by elevated hardware and access costs. The software-defined-radio (SDR) concept can contribute to the rapid development of IoT and M2M systems by providing a higher degree of flexibility in designing the wireless communication interfaces both for the last-mile terrestrial link as for the satellite links. Devices equipped with SDR modules could	This panel should promote the seamless integration among the vast range of technologies used for satellite communication and navigation, focusing on the hardware re-usability based in the software-defined-radio paradigm. This would lead on the long term to the considerable reduction of costs and time efforts and would also allow the rapid test and adoption of new communication standards, especially for the previously mentioned IoT and M2M applications.

Table 1.

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Founder member	Please, explain the reason why did you decide to join the panel	Please, express your personal feeling about which outcomes do you expect in the near future from the panel activities
	dynamically switch between protocols and could also embed spectrum sensing capabilities, useful both on terrestrial and satellite sides. These research fields can be further extended to all types of satellite communications and navigation systems and also for robotic and human explorations in outer space and on other planets. The key term here is re-configurability and it implies inherently a multidisciplinary approach: this panel can help to promote the aforementioned concepts and find new means and domains of application other than the ones initially presented, one example in this direction being the use in connected research fields such as satellite broadcasting technologies.	

UPDATED LIST OF THE ADJUNCT PANEL MEMBERS

(1) Mohammed-Slim Alouini (King Abdullah University of Science and Technology, Thuwal, Saudi Arabia Kingdom).

(2) Michael Devetsikiotis (University of New Mexico, Albuquerque, NM, USA).

(3) Giorgia Parca (Italian Space Agency, ASI, Rome, Italy).

(4) Giuseppe Codispoti (Italian Space Agency, ASI, Rome, Italy).

(5) Paolo Tortora (University of Bologna, Bologna, Italy).

(6) Barry Evans (University of Surrey, Surrey, U.K.).

(7) Eugene Grayver (Aerospace Corporation, El Segundo, CA, USA).

(8) Simone Morosi (University of Firenze, Florence, Italy).

(9) Sean Malek (University of Dayton, Dayton, OH, USA).

(10) Riccardo Bassoli (Technical University of Dresden, Dresden, Germany).

PANEL MEETINGS AND PARTICIPATION RULES

Two panel meetings per year have been planned. The first one is organized in the month of March during the IEEE Aerospace Conference in Big Sky (MT) (IEEE Aerospace Conference is the "home conference" of the panel). The

second meeting is organized in Rome (Italy) in September. The location of the September meeting is the Italian Space Agency (ASI) headquarter. The participation to the meetings is possible both in person and in remote.

The panel is open to all interested persons, coming from academia, industry, space agencies, etc. The IEEE membership is not required. Members of other technical societies are welcome. However, only active AESS members may serve as chair/vice-chair. If you want to join the panel, please send an e-mail to the panel organizers Claudio Sacchi (claudio.sacchi@unitn.it) and Marina Ruggieri (ruggieri@uniroma2.it).

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