Validation of ground technologies for future Q/V band satellite systems: the QV – LIFT project

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Abstract— **With the aim of supporting the Terabit connectivity, High Troughput Systems – HTS rely on the exploitation of Q/V band. These frequency bands offer the possibility to have larger bandwidth availability with respect to the Ka band systems, and to realize feeder links and specific segments requiring high data rates such as aeronautical in-flight services.**

The design of a Ground Segment for Q/V band satellite communications implies several technological challenges. The design of antennas, power amplifiers with high efficiency and Low Noise receivers are critical, nevertheless they are fundamental to support high data rate transmissions. Furthermore, in order to counteract atmospheric impairments, a system able to implement and to manage a handover mechanism between gateways is also needed.

A Ground Segment for Q/V band high throughput system has been conceived in the project "Q/V band earth segment LInk for Future high Throughput space systems" (QV-LIFT), funded by the European Commission in the framework of the Horizon 2020 program. The consolidation of crucial technologies for new generation satellite communications is addressed, with the objective to ensure space accessibility to Europe and, in particular, to foster technology readiness of European industries in space related sectors.

This paper provides the description of key hardware and software developments for next generation HTS systems operating in the Q/V band, based on core technologies for both ground and user segments currently under development for the project QV-LIFT. The system test architecture which will be used to validate the developed technology and functionalities is also presented, together with the overview of the project status and validation plan.

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1. INTRODUCTION

In the field of satellite communications the last decade has been characterized by a positive trend of the associated market. In this timeframe the use of frequencies in the latest launched satellites has been constantly moved from the Ku band to Ka band, either for uplinks and downlinks (30 and 20 GHz, respectively).

At the same time the satellite communication services have been shifted from TV broadcast-only to multi-service communications such as, for instance, broadband Internet, with the result of the need of completely different systems.

The market, and consequently the providers, is now aiming at High Throughput Satellites (HTS) in order to support the so-called "Terabit connectivity" and the natural consequence is the requirement of different technologies capable to cope with it. One obvious way to solve this gap would be the use of frequency bands higher than the Ka one, such as the Q/V band (50 GHz for uplink and 40 GHz for downlink). This frequency could offer larger bandwidth availability for the feeder links and for specific segments requiring high data rates such as aeronautical in-flight services.

The use of Q/V band frequencies, with their larger bandwidth, would be also beneficial for future systems such as the 5G one. Furthermore in Europe, where many regions are still affected by the "digital gap", the availability of augmented bandwidth would be coherent with the Digital Single Market outlook defined by European Union.

The QV-LIFT project aims to develop some fundamental bricks of the Ground Segment technologies for the future Q/V band Terabit SatCom systems either at hardware level (key RF building blocks and subsystems that still represent a gap in the European technologies) and at network level (smart gateways management). The network improvements are needed to counteract the propagation impairments that are one of the main obstacles in the deployment of the Q/V band feeders system.

One goal of the project is to demonstrate that the related developments, either at hardware and network level, will reach the TRL6. In order to do this a unique and realistic test environment will be used. A mobile Q/V band terminal and three Earth stations will be linked to the Aldo Paraboni payload on board Alphasat [1], a unique test payload operating in Q/V band, creating the QV-LIFT smart gateway network. In this view, the QV-LIFT experiments will be the most comprehensive and advanced assessment operated in Q/V band.

The paper is divided in three parts. In the first part, the system scenario and the project objectives are given; the second chapter is related to the description of the reference system architecture and the subsystem requirements definition. Lastly, the validation plan is presented with the description of the test scenarios. The paper contains an updated description of the current status of the project and related achievements.

In order to reach the targeted TRL by the end of the project, the system architecture exploits existing assets. In particular, the Alphasat Aldo Paraboni payload [1] will implement the space segment link of the system. The QV-LIFT ground segment will comprise two ASI's Earth Stations, namely Earth station 1, located in Tito Scalo (Italy), where Gateway 1 will be based and Earth Station 3, located in Spino d'Adda (Italy), which will be used to emulate a user terminal or as a further Gateway. Gateway 2 will be based on a transportable Earth Station, which will be developed during the project combining off-the-shelf components and the RF building blocks developed in QV-LIFT. The system includes a mobile

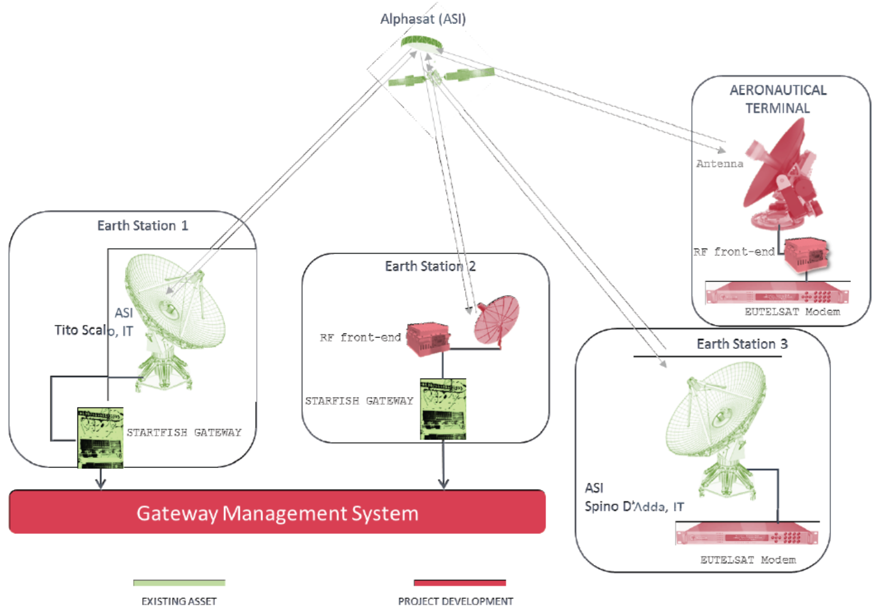

Figure 1. [] Overview of QV-LIFT. QV-LIFT smart gateway network relies upon existing assets (green colour): the satellite link from/to Alphasat and upon Earth Station 1 operating in Tito Scalo (Italy) and Earth Station 3 operating in Spino d'Adda (Italy) both made available by ASI. Also shown in green is the STARFISH gateway SW/HW made available by MBI. QVLIFT will develop and integrate the following subsystems (red colour): Earth Station 2, the mobile airborne terminal, the smart gateway management system.

2. SYSTEM SCENARIO AND OBJECTIVES

The QV-LIFT project aims to implement a system configuration where space, ground and user segments will be integrated to experimentally validate the project outcomes. The experimental assessment will be based on an advanced and flexible architecture which integrates a high performance satellite IP-based network and a system based on the concept of *smart gateways* [2] adopted to counteract the propagation impairments at Q/V band. The experimental validation will provide an important reference scenario for the exploitation of ground technologies for future satellite communication systems. Indeed, the targeted technology readiness level will provide a realistic workbench upon which the networks based on the future HTSs will be built.

An overview of the QV-LIFT smart gateway network is shown in Fig. 1.

Aeronautical Terminal, entirely developed during the project. The presence of three Earth station and one mobile terminal offers a unique test scenario which will be employed to validate the Smart Gateway Management System (SGMS), that will be developed during the project. SGMS will be built upon an existing gateway management system, STARFISH, developed by MBI in collaboration with Eutelsat and the European Space Agency, which is already operating but it does not contain any module to manage propagation impairments and gateways handover. Starfish is part of the Eutelsat Broadcast Interactive System (EBIS) which will be used to ensure bi- directional IP connectivity to the QV-LIFT network using DVB-S2 and F-SIM protocols. The integration of the QV-LIFT system with STARFISH, and then EBIS, will ensure a unique realistic scenario, with a real IP connectivity, on which the technologies developed in the project will be deployed and tested.

Therefore, key communication hardware at Q/V band will be developed responding to the needs of the ground segments. The building blocks required for the implementation of Q/V band communication terminals will be assembled in two different contexts: the Q/V band mobile aeronautical terminal and the transportable Earth station which will complete the ground segment assets made available by ASI.
In particular, the following building blocks will be developed:

- a high performance tracking pedestal for the mobile terminal;
- a GaN power amplifier MMIC at V band;
- a power combining High Power Amplifier based on GaN MMIC power amplifiers;
- a BUC (Block Up Converter) operating in the V band to be used in both the mobile terminal and the Earth station;
- a LNB (Low Noise Block down converter) operating in the Q band to be used in both the mobile terminal and the Earth station;
- a Tx/Rx, single aperture antenna for the mobile terminal ;
- a Tx/Rx single aperture antenna for the Earth station;
- the set of passive components (i.e. diplexer, power dividers, filters) to be used in the mobile terminal and the Earth station;

At modem level, QV-LIFT will re-engineer the IP satellite modem that is part of the Eutelsat solution operating in Ka-band. All the components will be developed and integrated to obtain a level of technological readiness adequate to a realistic operational scenario.
QV-LIFT will implement and experimentally evaluate the first Smart Gateway Management System (SGMS) designed for the new generation of Q/V band SatCom system. The Smart Gateway network will be developed assuming the presence of a (redundant) gateway where the outage traffic should be redirected to avoid the reduction of performance due to propagation impairments expected in Q/V band links. The system is of the utmost importance to achieve high data rate with high availability in the feeder links. The following outcomes are identified:

- network control functions that will support smart handover of communications between multiple gateway nodes (smart gateway);
- definition of new transmission modes which are better suited to cope with the Q/V channel specifications and peculiarity (i.e. highest dynamic range);
- integration in an already existing gateway management system operating in the S, C, Ku, Ka bands.

3. QV-LIFT SYSTEM DEFINITION

The first phase of the project is related to the definition of a reference HTS system architecture which will be outlined starting from the provision of requirements for the subsystems and following the approach shown in Fig. 1. High level requirements are related to:

- satellite coverage
- frequency bands and allocations
- satellite feeder link characteristics

Several different scenarios for future satellite coverage and communication payloads may be envisaged as significant fields for experimental campaigns; however, the frequency bands adopted are chosen within the constraints given by the ITU frequencies allocation to the Fixed Satellite Services (FSS): 37.5-47.2 GHz (Q band) and 47.2-50.2 GHz (V band). Within the QV-LIFT objectives it is foreseen to make available components and systems compatible with a bandwidth which is adequate for future applications, i.e. 3GHz, while targeting at the same time the requirements of a link based on the Aldo Paraboni payload.
The system definition activities are focused on the identification of a system architecture in the perspective of a real applicative scenario of bi-directional IP system over satellite, using a reliable Q/V-band feeder link, able to serve ground terminals and Q/V-band aeronautical terminals. User and system requirements are identified considering a reference HTS system architecture with Q/V-band feeder link.
The operational performance of the Alphasat Aldo Paraboni payload are taken into account, given that it will be the space segment employed during the test phase. Nevertheless, to broaden the analysis carried out within the project, specific evaluations will be done to estimate how requirements at system level and at sub-system level could be affected by using an advanced space segment with better performance with respect to the Aldo Paraboni payload.
State of the art statistical propagation models will be used for link budget calculations, as well as for the design and optimization of the SGMS and of the Propagation Impairments Mitigation Techniques (PIMTs) (fade duration and fade slope prediction models) [3].
A Multisite Time-series Synthesizer (MTS), able to generate simultaneous realistic time series of rain attenuation at different gateway sites, will be employed.
The system and technical requirements for the SMGS are formulated considering the user-case scenarios with the aim to define realistic traffic conditions. With the Q/V-band adoption for the feeder link, the availability of a larger bandwidth offer the possibility to set up a higher number of user beams with a highly flexible ground segment. On the other hand, given the strong signal fading due to the

propagation channel impairments, classic fade mitigation techniques as dynamic power control and adaptive coding and modulations might not be sufficient. Therefore, in order to ensure the agreed service levels to the users, the so called smart gateway and soft diversity concepts are adopted.

The RF and mechanical requirements of the mobile terminal and of the Earth station at sub-system and at component level are defined during the first year of the project. These technical requirements are given as input for the design and development activities as well as for integration phase and test campaign [4].
Two types of propagation prediction models (both recommended by ITU-R) are considered to calculate the atmospheric contribution useful for the aeronautical terminal and for the Earth station. In the first case, two separate link budgets will be prepared according to the airplane conditions (parking or flying). This activity will guide the trade-offs iteration of the up-converter and of the down-converter architecture. Preliminary RF chain simulations will be iterated for any power level or frequency plan revisions. Simulations will be performed to obtain accurate characteristics in terms of phase noise, spurious products, power levels and losses. Detailed specifications for individual components will be obtained from this analysis. The requirements for the pointing systems in terms of HW, SW and mechanical specifications are also addressed. In the case of the fixed terminal, a maximum antenna pointing error will be defined. For what concerns the on-the-move system, the maximum operating antenna pointing error will be established considering the aircraft motion dynamics to which the antenna will be subjected. In both cases, the requirements shall be such as to ensure an adequate RF performance.

4. VALIDATION AND TEST PLAN

During the first year of the project, part of the activity was focused on the definition of a preliminary test plan to be employed to validate the experimental assessment.
This will be the starting point of a more consolidated test plan which will be produced once all the subsystems will be ready for the validation phase. In particular, the test plan will also take into account the effective weather conditions on the regions used for the test campaign different test scenarios will be considered. During the testing phase, communication result parameters can be correlated to the conditions of the atmospheric channel by taking advantage of the availability of Alphasat Propagation experiment measurements [5]. Two different test cases are foreseen.
With the first Test case 1 the Smart Gateway Network will be tested by means of validating the Smart Gateway handover functionality. The scenario of the test using the Alphasat Aldo Paraboni Communication payload foresees the location of two redundant gateways under the same spot beam, for example one in the ASI site of Tito Scalo (Gateway 1) and a second one (Gateway 2) based on the Earth station.

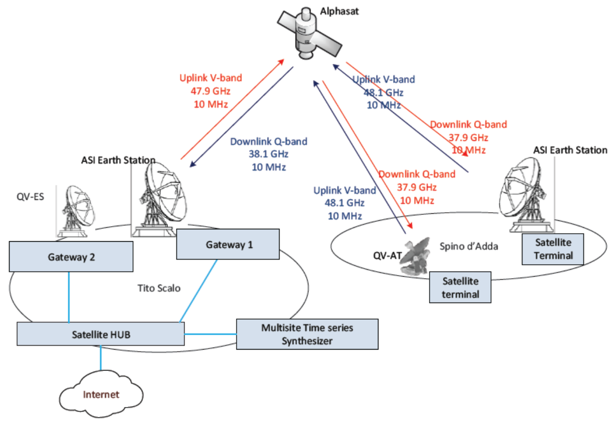

Fig. 2 shows the main components of the test scenario:

- The Aldo Paraboni Communication Payload on board of the Alphasat satellite;
- A Satellite Gateway (Gateway 1) located in the ASI ground station in Tito Scalo;
- A second Satellite Gateway (Gateway 2) based on QV-ES and located in the Tito Scalo spot beam;
- A Satellite HUB interconnected with the 2 satellite gateways and to the Internet;
- A Multisite Time series Synthesizer interacting with the satellite network, by providing realistic time series of the link attenuation (for all considered gateways) that can be used for the HUB decisions;
- A satellite user terminal with Q/V RF frontend in the Spino d'Adda spot beam; in this case, the major goal is to validate the Smart Gateway functionality on Tito Scalo spot beam, so the reference user terminal can make use of the existing ground station in Spino d'Adda.

The Aldo Paraboni Communication Payload will be configured in cross-link mode, meaning that what is transmitted from the Tito Scalo beam is received in the Spino d'Adda beam and viceversa. In this way, the Satellite Hub behind the gateways in Tito Scalo communicates with the terminal in Spino d'Adda that acts as user device.

According to the weather forecasts or to the real time estimation of the channel status (for example through BER or FER) or by simulating the channel status using the time series provided by the MTS, the Satellite Hub decides which of the two satellite gateways in the Tito Scalo beam is active. The location of the Gateway 2 will be chosen far enough from the Gateway 1 in order to provide the correct space diversity. It is worthwhile that, in this way, the classical site diversity technique will be also tested together with the smart gateway functionality.

In the case of heavy rain on the active gateway site, for example, it will be possible to activate the second one instead, without affecting the service provided to end users, here emulated through the satellite terminal in the Spino d'Adda beam. It will be also possible to emulate adverse weather conditions or outages in the main gateway site and verify that the whole system reacts accordingly by activating the backup unit. In a multi-gateway configuration, other handover strategies could be implemented:

A different scenario is targeted for the second case, Test case 2, that is the Q/V Communications in mobility. The main objective of this test case is the validation of the aeronautical satellite system developed in QV-LIFT and the assessment of the performance of the Q/V communication channel in mobility. In this scenario, the Satellite Hub will use the satellite gateway based for example in Tito Scalo, while the satellite airborne terminal will be installed on-board of a vehicle within the Spino d'Adda spot beam. The Aldo Paraboni Communication Payload will be configured in cross-link mode, similarly to the previous case.

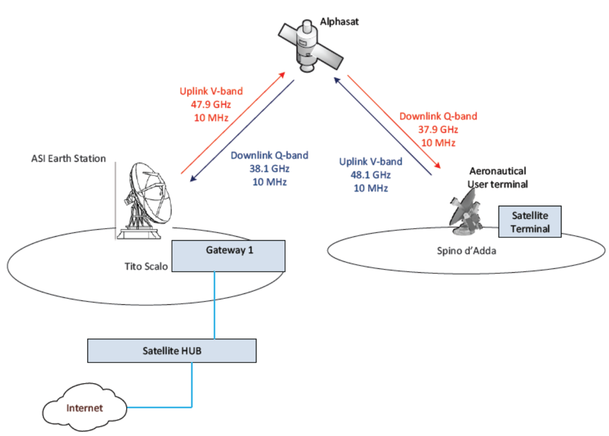

Fig. 3 shows the main components of the test scenario:

- The Aldo Paraboni Communication Payload on board of the Alphasat satellite;

- A Satellite Gateway (Gateway 1) located in the ASI ground station in Tito Scalo, Italy;

- A Satellite HUB interconnected with the satellite gateway and to the Internet;

- The aeronautical terminal with Q/V RF frontend (QV-AT) in the Spino d'Adda (Italy) spot beam. Notice that the terminal could be located in other positions. This will be evaluated during the course of the test program.

The capability to maintain the link will be assessed, within the limit of the spot area available, and the behavior of the terminal when the satellite signal is lost will be characterized. As per the previous case, the validation will be performed testing real IP communication services provided through the satellite network: this will implicitly assess the whole protocol stack and the availability of all components implementing the lower communication layers, including the physical (RF) one.

5. Conclusions

The paper aimed to introduce the reader to the QV-LIFT project objectives, status and developments, with particular emphasis on the high performance targeted and related challenges. The consolidation of crucial technologies will represent a fundamental step for new generation HTS systems.

Acknowledgements

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BIOGRAPHY

Giuseppe Codispoti*. received a degree in Electrical Engineering from the University of Calabria, Italy and a Master of Science's degree in Electrical Engineering from the California Institute of Technology in Pasadena, USA. During his graduate studies he was involved in class projects at the Caltech/ NASA Jet Propulsion Laboratory in Pasadena with the responsibility of the communication aspects. From 1993 to 2000 he was with Alenia Spazio, Rome (now Thales Alenia Space Italia) at the "On board Active Antennas Department" as designer, project and program manager in either Telecommunication and Remote Sensing programs.. In March 2000 he joined ASI, the Italian Space Agency, where he has been involved in projects regarding microgravity, remote sensing and telecommunications. At the moment he works in the Telecommunication and Navigation Division and he is the responsible of the Q/V Band Program of the Agency. He has been appointed as delegate and expert of the Italian Government in delegations of international bodies such as ESA, European Space Agency and UNO, United Nations Organization. He is member of Technical and Scientific Committees of public Foundations. He is tutor of Ph.D students of Italian universities.*

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