Satellite Communication and Propagation Experiments Through the Alphasat Q/V Band Aldo Paraboni Technology Demonstration Payload

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Introduction

Current high-throughput satellite (HTS) systems for broadband-distributed user access are designed following two main concepts:

- The use of Ka band radio frequency (RF) links both for the forward and for the return link; this choice is due to the congestion of lower frequency bands and to the relatively large bandwidth available in the Ka band. Moreover, the RF technology in the Ka band is mature [1], [2].
- The use of multispot coverage: this technique is largely applied to increase the system throughput through frequency

HTS systems are dimensioned to support an aggregated total capacity (considering both forward and return links) of a tenth of a gigabit per second over a coverage area as large as Europe, with a single spot capacity of hundreds of megabits per second [3].

As a matter of fact, HTSs still offer much less bandwidth per user with respect to the terrestrial broadband networks. To achieve very high throughput towards "terabit connectivity," bandwidth efficient modulation schemes have to be used [4], [5]. However, because there is a trade-off between bandwidth efficiency and power in modulation schemes, high bandwidth requires more transmission power that is a limited resource in satellite systems.

Therefore, an important breakthrough is needed in terms of bandwidth availability. The Q/V band (40–50 GHz) seems to offer very promising perspectives, being unused for commercial systems and offering a large part of the spectrum allocated for satellite services [1]. In this frame, the medium-term HTS system architecture is based on the use of a Ka-band user link to maintain the user terminal compatibility with the current system and a Q/V band feeder link [4]–[7].

This solution is particularly attractive for the following reasons:

- The Q/V band spectrum allocated for satellite service is very large, about 5 GHz of near-continuous bandwidth both for uplink and downlink.

- The whole Ka-band spectrum (that is currently allocated both for feeder and user links of the HTS systems) will be available for user link, increasing the bandwidth allocated to the user segment. This will require a rethinking of International Telecommunication Union frequency allocation and a strong frequency coordination activity.

It is well-known that the atmospheric propagation impairments at extremely high frequency (EHF) bands (30–300 GHz) are severe, not only when rain events occur but also in the presence of clouds. The EHF electromagnetic radiation that propagates through the atmosphere is subject to absorption, scattering, depolarization, and fast fluctuations of amplitude and phase (scintillation) that have to be carefully investigated. Moreover, some mitigation techniques have to be analyzed and properly tuned to realize an efficient transmission. To counteract rain fading effects, high static link margins can be considered to ensure a minimum service outage duration. However, setting large link margins is in contrast with technology limitations of space and ground segments and with system efficiency. In fact, due to the large attenuation variation, mainly due to the presence of rain, setting static link

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margins manifests a tremendous waste of system resources in clear sky conditions and can increase the interference between different spots. The use of adaptive techniques, i.e., propagation impairment mitigation techniques (PIMTs), is effective in contrasting rain fading events without requiring static link margins; these techniques compensate for the fade, while at the same time minimizing the disruption to other services and the misuse of system resources.

In the frame of the previously introduced scenario, the -cient exploitation of EHF bands for broadband transmission over satellite links is a popular research topic [6]. The Italian Space Agency (ASI) has a proven expertise in these research topics, having funded both operative systems for Ka and Q/V bands propagation analysis, as Italsat F1 [8], [9] and advanced studies for the development of W-band (75–110 GHz) satellite communication systems [10], [11], [12].

In 2004, ASI started to fund a program for the assessment of Q/V band satellite communications [13], [14] and in 2006 proposed to the European Space Agency (ESA), under the Alphasat program, to host an experimental payload in Q/V band aboard the new Alphasat geosynchronous Earth orbit (GEO) satellite (Figure 1). Following several technology studies and preliminary accommodation activities, the ASI Q/V band payload has been selected as one of the four hosted payloads, namely, technology demonstration payloads (TDPs), for on Alphasat. The payload development has been supported by ASI as a contribution to the Alphasat project, which is executed by ESA in the framework of the Advanced Research in Telecommunications Systems (ARTES) 8 Telecom program. Thales Alenia Space, Italy, and Space Engineering were the prime contractors for the development of the payload, named TDP 5 [15], [16].

The objective of the Q/V band TDP mission is to perform satellite communication experiment and propagation experiments (also referred to as the experiment). The mission has been conceived by ASI with the support of Marina Ruggieri from University of Roma Tor Vergata as the principal investigator (PI) for the communication experiment, Carlo Riva, and the late Aldo Paraboni from Politecnico di Milano as PI of the propagation experiment. PIs have been responsible for providing ASI the requirements for the development of Alphasat system and are responsible for the execution of the experiments. The ASI Q/V band payload was later renamed "Aldo Paraboni" payload in memory of the late Aldo Paraboni.

The aim of the communication experiment is to design, optimize, and test the effectiveness of adaptive transmission schemes, i.e., PIMTs, over the Q/V band satellite channel [17]–[20].

The aim of the propagation experiment is to characterize the behavior of the propagation impairments in Q/V bands satellite channels. These two experimental campaigns are obviously related and are jointly conducted.

Alphasat was successfully launched on July 25, 2013, 19:54 Greenwich Mean Time, from the European Spaceport in Kourou (French Guiana) via the Ariane 5 ECA rocket. The orbit is inclined GEO (maximum ± 3°) at the location 25° east. The in-orbit test campaign ended in December 2013, and the experimental campaigns started at the end of February 2014.

Regarding the ground segment, ASI assumed directly the commitment to realize and deploy the ground terminals in Italy. The prime contractor for the development of ground terminals

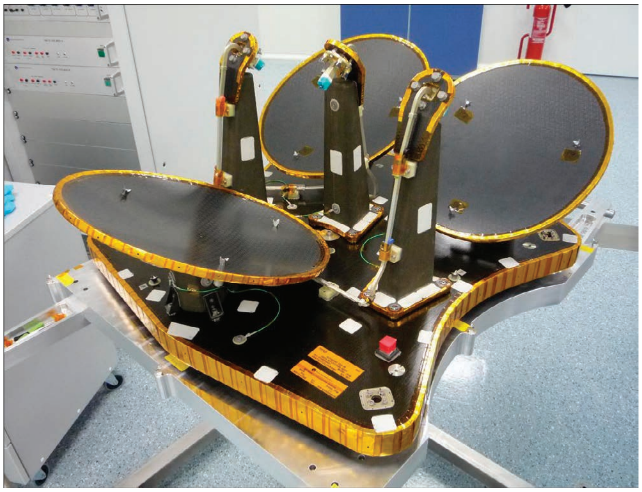

Figure 1.
View of the "Aldo Paraboni" payload.

is Space Engineering. A and propagation ground station is located in Tito Scalo (near Potenza, south of Italy) while a second ground station is located in Spino d'Adda (near Milan, north of Italy).

An additional communication and propagation terminal is installed in Graz, Austria; this station has been developed by Johanneum Research Institute (under an ESA contract), which has been invited by ASI to join the Q/V band experiments. Several other small propagation terminals will be located around Europe [21].

TDP 5 SYSTEM OVERVIEW

The Q/V band TDP payload is composed by two self-standing payloads [22], [23]:

- *A communication experiment payload* includes a two-channel transparent transponder operating in Q/V band with cross-strapping capabilities, with a useful bandwidth of 10 MHz. The Earth-to-space communication is operating in the V band: the central frequencies are 47.9 and 48.1 GHz. The space-to-Earth communication is performed in the Q-band region: the central frequencies of channel 1 and 2 are 37.9 and 38.1 GHz, respectively. The polarization is linear vertical. The payload is capable of managing three beams (up to two beams simultaneously active); in fact, the transmit and receive antennas foresee a beam pointed towards the ground station located in Tito Scalo and a second beam with selectable pointing between Spino d'Adda and Graz. The satellite onboard antennas have a receive gain of 38.3 dBi end of coverage (EOC) and a transmit gain of 37.5 dBi EOC. The nominal output power of the transponders is 10 W; no redundancy is foreseen for the communication experiment payload due to mass/power requirement constraints.
- *A propagation experiment payload* includes two beacons operating in Q and Ka bands, at 39.402 and 19.701 GHz, respectively. The Q-band polarization is linear 45° tilted, while the Ka band is linear vertical. The two unmodulated signals are coherent (generated starting from a common oscillator). The propagation experiment payload is fully redundant.

The communication experiment payload transponder can be

- *cross mode*, whereby the receive beam of one repeater serves the same geographical area of the other repeater transmit beam and vice versa (each channel is received and transmitted on different antenna coverage);
- *loop-back mode* in which each repeater is connected in transmission and reception to the same beam (each channel is received and transmitted on the same antenna coverage).

Therefore, the payload is capable to realize full-duplex communication between the station located in Tito Scalo and, alternatively, the station located in Spino D'Adda or Graz.

The two Italian ground stations are equipped with a large Q/V band antenna (4.2 m), with an antenna transmission gain of about 62 dBi; the high power element is an extended interaction klystron, with a nominal power of 50 W (and a peak of 200 W). The receiver section has a minimum gain-to-noise temperature of 33.3 dB/K. The ground stations, in addition to the beacon receivers, are equipped with radiometers, for nonrain atmospheric attenuation estimation, pluviometers, and meteorological ancillary instruments (surface temperature, relative humidity, and atmospheric pressure). The antenna element is equipped with a complete monopulse auto-tracking system that is able to automatically maintain accurate antenna pointing.

The system architecture is reported in Figure 2. Two control centers are responsible for the management of the communication and propagation experiments and are located at University of Rome Tor Vergata and at Politecnico di Milano, respectively. These two centers issue the experimental plans that are collected by a mission control centre; the ground request is forwarded to the terminals, while the satellite request is delivered to Inmarsat Satellite Control Centre through an ESA interface called TDPs ESA

The baseband communication section is based on the digital video broadcasting satellite second generation (DVB-S2) standard [20] for satellite broadband applications, developed by the DVB Project in 2003. The standard has been designed for different types of applications:

- broadcasting of standard-definition and high-definition TV;
- interactive services, including Internet access, for consumer applications (for integrated receiver-decoders and personal computers);
- professional applications, such as digital TV contribution and news gathering;
- data content distribution and Internet trunking.

COMMUNICATION EXPERIMENTS

The PIMTs that will be the objects of the communication experiment are adaptive coding and modulation (ACM), uplink power control (UL-PC), and space diversity.

The objective of the ACM experiment is to design and optimize ACM control algorithms for the 40–50 GHz communication channel. A trade-off exists between spectral and power for the selection of the best ACM mode; the ACM mode switching algorithm should optimize this trade-off, thus providing the best combination of spectral and bit error rate/frame error rate (BER/FER) [17], [18].

The objective of UL-PC experiment is the optimization of the adaptive change of the power transmitted by the ground terminal on the basis of link attenuation to maintain a constant power density at the satellite input.

The basic principle of the space diversity experiment is to identify optimal spatial rerouting of the radio path around the source of the fading [19].

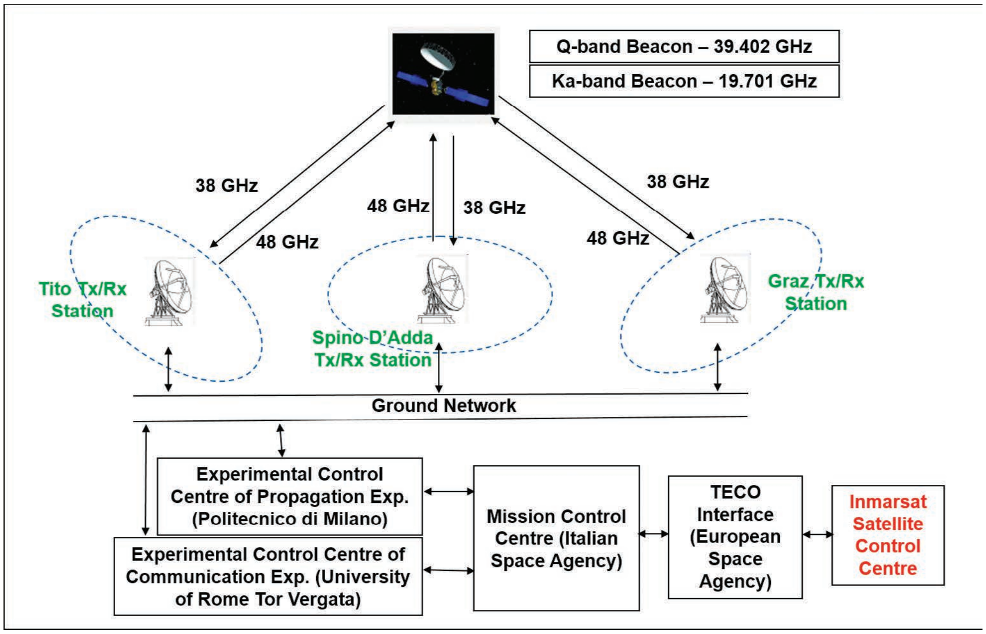

Figure 2.
Alphasat Aldo Paraboni payload Q/V band experiment system architecture.

Adaptive transmission techniques are based on a link quality estimator that drives the algorithm to follow the current channel conditions by using the most suited transmission parameters [24]. Therefore, the transmission parameters are selected on the basis of the channel estimation performed at the transmitter side (open-loop approach) or at the receiver side sending a command through a return link to drive the algorithm (closed-loop approach).

Channel variations are a consequence of a slow component (e.g., rain fading) and a faster component (e.g., scintillations) [25]. PIMTs cannot follow fast channel variations, but this type of variations must be taken into account during the design of PIMTs.

In the experimental campaign, the following channel estimation metrics at the receive terminal are considered for driving PIMT

carrier-to-noise ratio (CNR), signal-to-noise ratio (SNR), error vector magnitude (EVM), BER, and FER. Such link quality measurements are performed at various points of a receiver, depending on the complexity, reliability, and delay requirements. There are trade-offs in achieving these requirements at the same time. The closer the output of the channel decoder is to the link quality estimation, the higher the correlation with the perceived quality of service by the user (e.g., FER) is. However, the closer the antenna is to the link quality estimation, the higher the update rate of the estimation (e.g., CNR) is.

The data gathered from the ancillary equipment, such as radiometric data and the meteorological data, or that coming from the Q-band beacon receiver can be used to drive PIMTs in open-loop (or in conjunction with other measurements coming from a closed-loop control approach). However, in a typical future commercial system, these data will not be always available.

Channel estimation error and delay can result in low performance if the channel adaptive PIMT is not designed properly; the effects of channel estimation error and delay will be evaluated during the experiments.

The objective of PIMTs is to select the most suitable configuration of the transmission parameters (such as modulation format, coding rate, and transmission power) on the basis of the current state of the channel that is estimated through one of the previously described channel estimation methods.

An optimal adaptive transmission algorithm should account for a) the delay between the channel estimation and the packet reception (channel variations during the update process); b) channel estimation errors; and c) nonideal characteristics of the channel (nonlinearity).

For what concerns ACM, the modulation and coding (ModCod) used to transmit each physical layer frame (PLFRAME) is selected by the receiver on the basis of a link quality estimation metric and the current or predicted channel condition. A hysteresis loop could be included in the ACM mode switching algorithm to prevent undesired oscillations of the transmitting ACM mode in case of SNR jitter between adjacent SNR thresholds. Accounting for the long round-trip delay typical of a GEO satellite link may lead to an undesirable mode switching, and consequently, either reduction in data rates or an increase of BER.

Some results of the communication experiments are reported in this section; the complete results can be found in [24] and [25]. In particular, the main results on channel estimation technique and on ACM mode selection optimization will be discussed.

Because the DVB-S2 allows the insertion of pilot symbols within the frame structure, a data-aided (DA) SNR estimation algorithm has been used in the part of the experimental campaign, and its performance has been fully characterized. In a DA system, a pilot sequence (known to the receiver) is included periodically in each transmitted frame to ease signal-to-noise-plus-interference ratio (SNIR) estimation.

The SNIR estimation algorithm used in the part of the experimental campaign is based on the DA maximum-likelihood (ML) signal-to-noise-plus-interference ratio estimator (SNORE), as suggested by the DVB-S2 standard [20].

The SNR estimator has been characterized, using different average windowing to reduce standard deviation and comparing the Cramer-Rao lower bound (CRB) for the ML estimator on an additive white Gaussian noise (AWGN) channel [25]. The metric used for the comparison is the standard deviation of the estimator that is a statistical measure of the Some results are reported in Figure 3.

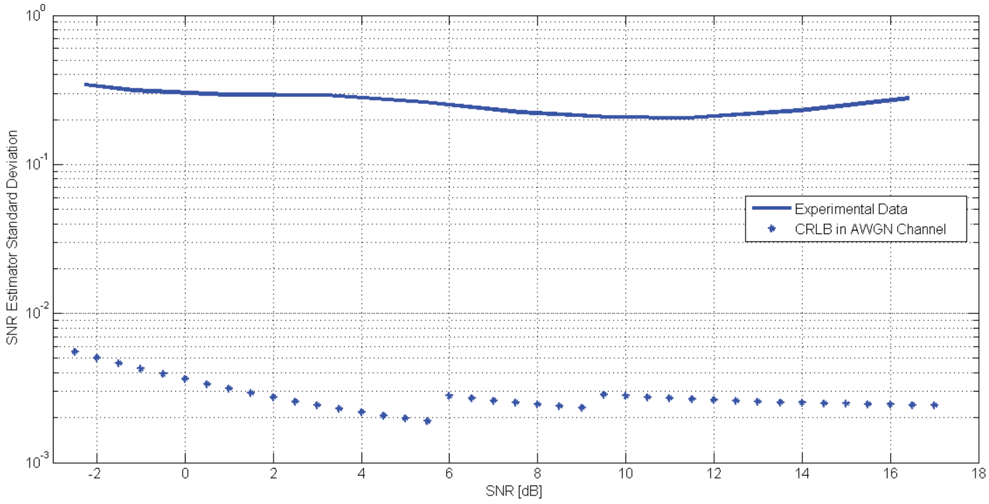

Figure 3.
Standard deviation of CRB and DA SNORE-based estimator (without average windowing) experimental data.

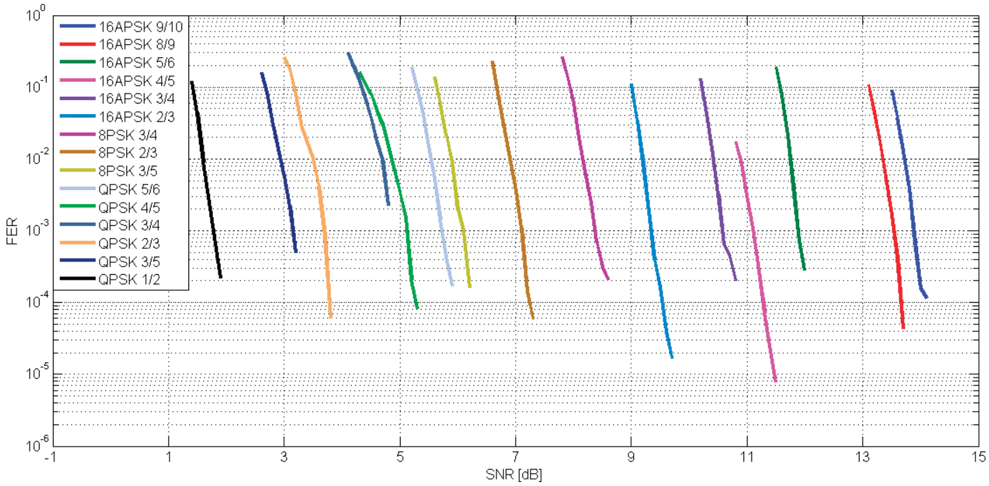

Figure 4.
Q/V-band satellite channel FER versus SNR for DVB-S2 ModCod.

Looking at the CRB, a slight increase of the standard deviation for high SNR levels can be noticed because the standard deviation is not only a function of the SNR value, but it is also a function of the total number of pilot symbols used for estimation [20]; however, the number of useful pilot symbols in the frame decreases as the modulation spectral increases (see TDP 5 System Overview section). Because high-order modulation schemes are used for high levels of SNR, the number of pilot symbols used for the estimation decreases as the SNR grows, thus reducing the estimator accuracy. The behavior of the experimental data matches the CRB, but it is clear that the performance of the estimator in a real channel is considerably worse than the theoretical performance in an AWGN channel.

As expected, experimental results show that the introduction of an average windowing reduces the SNR estimator variance for any average SNR and modulation (index) format. If no windowing is performed, the estimator variance is higher than 0.2 for the whole DVB-S2 SNR operational range; for SNR values lower than 1 dB, the variance is even larger than 0.3. For a windowing length of 5, the SNR estimation variance is lower than 0.2, when the SNR is higher than 6 dB. A windowing length higher than 25 guarantees a SNR estimation variance lower than 0.2 for the whole SNR operational range.

Once the SNR estimator has been characterized, the FER curves, as a function of SNR, have been for all the ModCod provided for the DVB-S2 standard; see [24]. Afterwards, the operative SNR thresholds for each useful ModCod have been to satisfy the FER service requirements; the main results are reported in Figure 4. Moreover, both ACM control logic based on thresholds and hysteresis control loops have been optimized during this part of the communication experiments.

In the following phase of the communication experiments, other PIMTs, such as the UL-PC and the spatial diversity will be analyzed, tested, and optimized through the Aldo Paraboni Q/V band payload.

The objective of the UL-PC is to adaptively change the power transmitted by a ground terminal on the basis of link attenuation to maintain a constant satellite input power density. UL-PC goals are to improve system capacity, compensate for fade, distribute power consumption, reduce interference (in particular, for mobile applications), and compensate for antenna gain roll off and mispointing. The UL-PC implementation strategy should be coupled with onboard to prevent transponders saturation; as a matter of fact, transmission of excessive power can cause harm to the space segment and to adjacent satellites.

Two main strategies of power control will be tested: open-loop UL-PC and closed-loop UL-PC. The one relies on the possibility to estimate the uplink attenuation at the transmitting ground station by using independent means, such as the downlink beacon measurement or radiometric measurements. An open-loop UL-PC experiment will use the downlink beacon signals in Q and Ka bands; uplink attenuation will be estimated on the basis of the frequency-scaling technique. The effectiveness of the

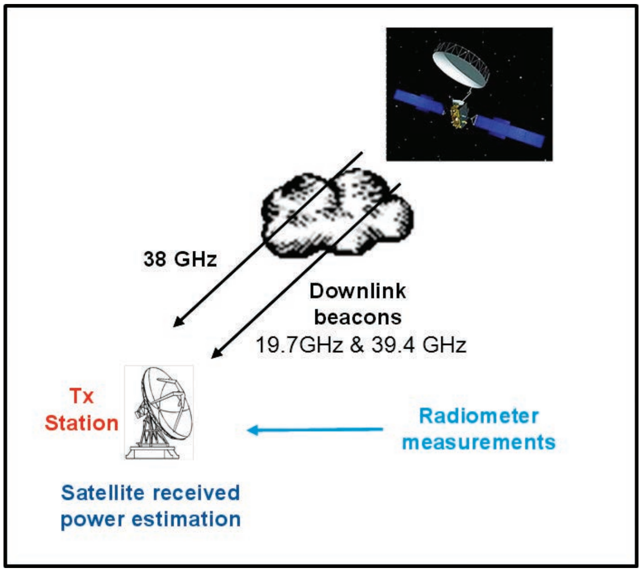

Figure 5.
Open-loop UL-PC.

open-loop power control is based both on the correct detection of downlink signal fade and on the frequency scaling of this value to the uplink frequency. The open-loop UL-PC system setup is depicted in Figure 5.

Closed-loop UL-PC relies on the possibility to evaluate the uplink attenuation on the basis of the self-transmitted downlink signal or the feedback coming from the received ground station (the latter technique is also referred to as "feedback-loop" power control).

The strategy can be applied if the transmitting and receiving stations are within the same satellite antenna coverage area; in the Q/V band TDP system, the transmitting station is located at the EOC of the transmitting satellite beam (pointed towards the receiver (Rx) station). In this context, for the transmitting station, it is very to measure the uplink signal attenuation, in particular, during medium and high fading events; hence, this control strategy will be tested, but a good uplink fading estimation result is not expected.

The second strategy relies on the fact that the Rx station can provide the transmitting station with some information on the total link attenuation through measurements on received signal SNR measurements. The Rx station will estimate, through its beacon receiver, the downlink attenuation so that it is possible to separate the effect of downlink propagation from the received signal level measurement. This information is then transmitted towards the transmitting station (through a ground link or through the satellite forward link).

Performance of the UL-PC will be evaluated using different metrics, such as power control accuracy and maximum level of fade that can be compensated.

Space diversity PIMTs, including site diversity and smart gateway diversity techniques, are based on the concept of spatial rerouting radio links to avoid the source of deep fading; this can be done because rain is a phenomenon spatially and temporally intermittent and inhomogeneous [24].

The site diversity technique is based on the concurrent reception of the same signal by (usually) two ground stations a few kilometers apart and connected via a terrestrial link; if the signal is heavily attenuated in one area, the signal received by the station with the best propagation conditions is used. The performance gains achieved using site diversity are dependent on the space and time correlation of rain events. The objective of site diversity is to maximize the service availability.

The smart gateway diversity technique that employs a number of gateway stations interconnected via terrestrial links is a very promising approach for broadband HTS systems. The objective is to realize a feeder link diversity scheme. The system architecture is based on the use of some gateways (GWs) connected with a terrestrial network so that it is possible to route feeder link data in a diversity manner to counteract deep fades on one (or more) gateway(s) [19], [26]. Two types of "diversity" approaches can be used in smart gateway techniques:

- Microscale diversity: this technique is based on the use of two (or more) GWs located in different positions within the same feeder downlink spot beam (typically, the distance of separation is between a few kilometers to a few tens of kilometers); the two GWs operates with a mutually exclusive logic on the basis of the atmospheric conditions. The one experiencing the best propagation condition is used to feed the spots on the user link, the other is placed on a hold condition.
- Macroscale diversity: this technique is based on the use of a set of GWs located within different feeder downlink spot beams. All the GWs can operate at the same time, feeding different user spots. When one of the GW experiences a deep atmospheric fade (even a full outage), its is distributed towards the other GWs in the network (that experience good channel propagation conditions).

Note that the technique requires a full redundancy for each GW; this increases the ground segment cost, and the use of fective).

The second technique does not require full redundancy for each GW, but an onboard connectivity with analogue transparent switching must be used to realize a full (or semifull) -rable channel connectivity between the GWs and the user spots. Note that some of the main critical issues in the smart gateway techniques are the synchronization in GWs network and the allocation of gateway feeder link capacity to users.

Considering the cumulative distribution function (CDF) of attenuation for a link, two parameters can be used to evaluate the effectiveness of such a technique: the diversity improvement factor, as the ratio of the single-site and joint outage time percentage, at the same attenuation level, and the diversity gain, as the difference (decibels) between the single-site and joint attenuation values for the same time percentage [19].

Space diversity techniques will be investigated during Q/V-band communication experiments. The TDP 5 smart gateway experimental setup foresees a cross-mode payload
for the whole experiment duration; one ground station will be

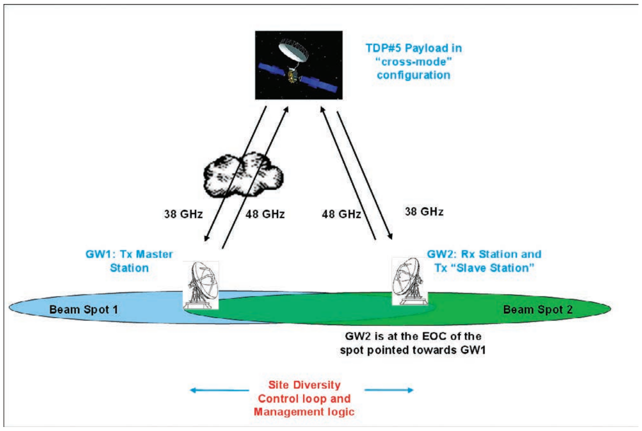

Figure 6.
Smart GW experimental setup.

considered the transmitting "master station" of smart gateway experiments, the other one will be the transmitting "slave station"; the latter will be also the receiving station of the experiment. Note that this station is located at the EOC of the beam pointing towards the transmitting master station.

In the initial conditions, the master station will transmit a signal to the receiver station; when a deep fade occurs in the master station uplink channel, the receiving station becomes also the transmitting station (even if it transmits at the EOC of the satellite beam); the setup is depicted in Figure 6. In this different site diversity control loops and management logics can be analyzed [26].

The site diversity experimental setup foresees a closed-loop payload on one ground station that will be considered both the transmitting station and "secondary receiving station" of site diversity experiments. Another ground station will be the "primary receiving station"; this station is located at the edge of the beam (pointed towards the transmitting station); hence, the link EIRP will be much lower than the one of the secondary receiving station. It is possible to compensate this scenario gain loss with the injection of noise in the secondary receiving station receiver chain so that the clear sky conditions of the two receiving stations can be considered similar.

The spatial diversity experiment main objective is to collect a large set of data to identify an tation switching control procedure and diversity management logic and analyze station synchronizations issues. The expected results will mainly concern spatial diversity management.

PROPAGATION EXPERIMENT

As previously outlined, the future broadband satellite communication systems with very high data rates rely on the use of higher frequency bands (i.e., Q/V and W bands). However, above Ku bands, atmospheric impairments are not only limited to rain effects but also clouds, and water vapor attenuation must be considered. Future systems must foresee the use of PIMTs, requiring accurate models for the spatial and temporal distribution of attenuation and measurements for their development and validation. Considerable efforts have been spent, since the 1970s to the end of the last century, to set up satellite propagation experiments: the Engineering Test Satellite Type II and the communication satellite for experimental purpose in Japan in the 1970s and 1980s, the Advanced Communications Technology Satellite in United States in the 1990s, the Olympus satellite from the ESA, and the Italsat satellite from ASI in the 1990s, to cite some examples. However, some propagation issues are still not completely addressed and need to be investigated further. For example, only the Italsat experiment allowed measurements above the Ka band in a limited number of site; the observation period of the measurements campaign was very often below 95–98% of the year, due to the receiver outages; a complete characterization of the signal spectrum was not possible due to the limited sampling rate (usually 1 sample/s) of the attenuation measurements; depolarization measurements were collected in few sites; simultaneous attenuation measurements in several European sites were available only for a very limited period.

The Aldo Paraboni propagation experiment addresses most of these issues by pursuing the following main objectives [27]:

- characterization of statistics of attenuation at two frequencies of 19.701 and 39.402 GHz (CDF conditioned to, for example, months of the year, hour of the day, etc.);
- characterization of the second-order statistics (fade duration and slope, scintillation conditioned to attenuation, and long-term and instantaneous frequency scaling);

Table 1.

Main Characteristics of the Propagation Experiment Beacons.

Ka-band beacon	Frequency	19.701 GHz
	Polarization	Linear V
	Antenna boresight	32.5° N, 20° E
	Equivalent isotropically radiated power	19.5 dBW
Q-band beacon	Frequency	39.402 GHz.
	Polarization	Linear tilted 45°
	Antenna boresight	45.4° N, 9.5° E
	EIRP	26.5 dBW

- characterization of space and time correlation of attenuation and of joint statistics with meteorological parameters;
- characterization of cross-polarization discrimination during rain and ice events;
- acquisition of sky-noise temperature;
- acquisition of the concurrent numerical weather products, such as meteorological radar, radiometers, European Center for Medium-Range Weather Forecasting, Meteosat, radio soundings, rain gauges, etc.;
- assessment, on the basis of the collected measurements, of the performance of various PIMTs, such as the partition of the onboard available power among various spot beams illuminating the served area, onboard common resources, etc.;
- study of the parameters measured during the concurrent communication experiment.

The Alphasat propagation experiment will be carried out by means of the Aldo Paraboni payload section constituted by two coherent beacons at the Ka and Q bands. The main characteristics of the propagation experiment beacons are listed in Table 1, and Figure 7 shows the coverage areas.

Two identical propagation ground stations have been achieved in Italy (the same used for the communication experiment): the one is located in Tito Scalo, while the second one is in Spino d’Adda.

Both stations will measure copolar signals at 19.701 and 39.402 GHz at a 16-Hz sampling rate with a 4.2-m-diameter antenna at an elevation angle of 42.1° (Tito Scalo) and 35.5° (Spino d’Adda). The cross-polar signal at 39.402 GHz is also measured. The ground antenna is equipped with a monopulse auto-tracking system with a tracking accuracy better than 0.01°. A humidity and temperature radiometer (RPG-HATPRO with seven channels between 22.234 and 31.4 GHz for tropospheric humidity and seven channels between 51.26 and 58.5 GHz for temperature up to 10,000 m), a tipping bucket rain gauge and an ancillary meteorological station complete the equipment of both stations. Figure 8 shows the ground stations installed at Spino d’Adda and at Tito Scalo. Figure 9 shows, as an example, the Ka- and Q-band copolar signal level (red and blue curves, respectively) and the Q-band cross-polar signal level (black curve), as measured at Spino d’Adda on October 7, 2014; note that the signal levels have not a common reference and cannot be compared directly.

To enlarge the of the propagation experiment, a propagation terminal was designed and realized in Graz by Joanneum Research and Graz University of Technology, under ESA ARTES-5 program for Telecom Technology. After Austria, many other European experimenters joined the propagation experiment realizing ground stations distributed all over Europe [21].

For an effective coordination among the experimenters, a work group has been established in the frame of the European Cooperation in Science and Technology Action IC0802 (“Propagation tools and data for integrated Telecommunications, Navigation and Earth Observation systems”), which ended in 2012 [28]. The group intended to participate in the measurement campaign with several experimenters with different receivers. Moreover, a General Assembly of the experimenters was set up by ASI and ESA during the Ka and Broadband Communications, Navigation and Earth Observation Conferences 2014 and 2015.

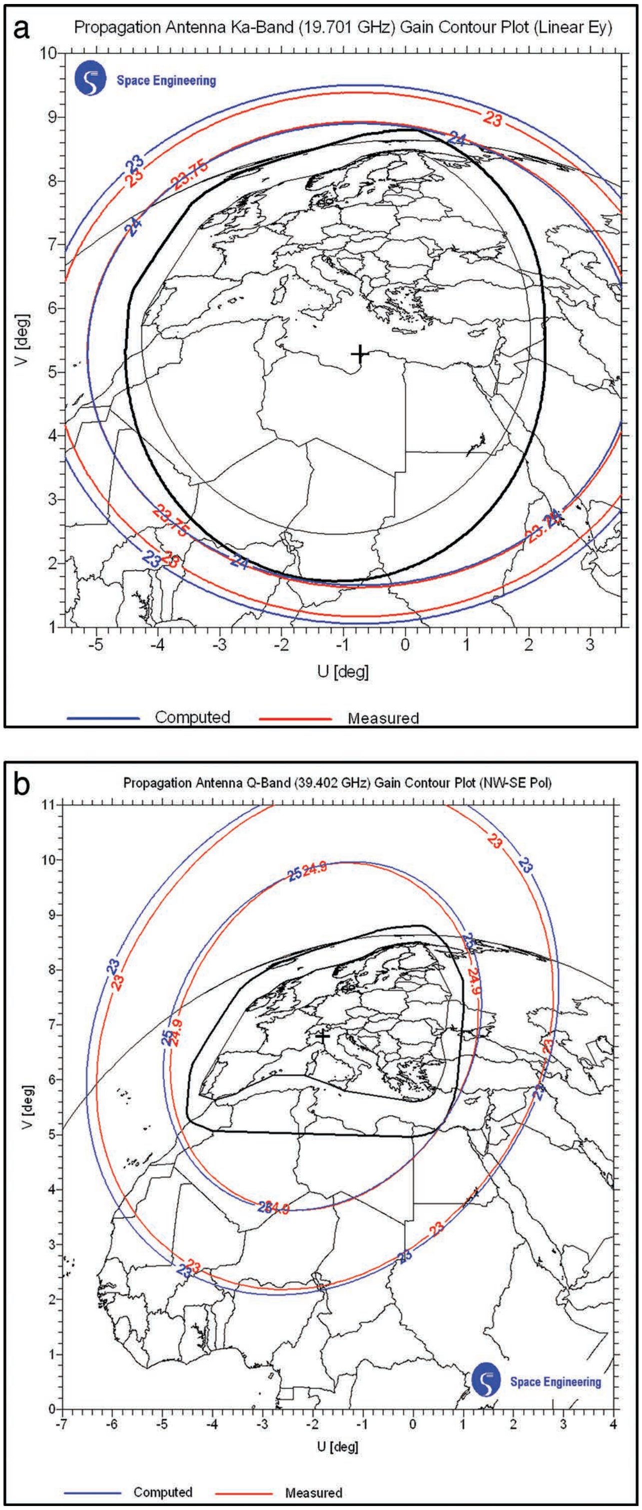

Figure 7.
Coverage areas of Ka-band (a) and Q-band (b) beacons.

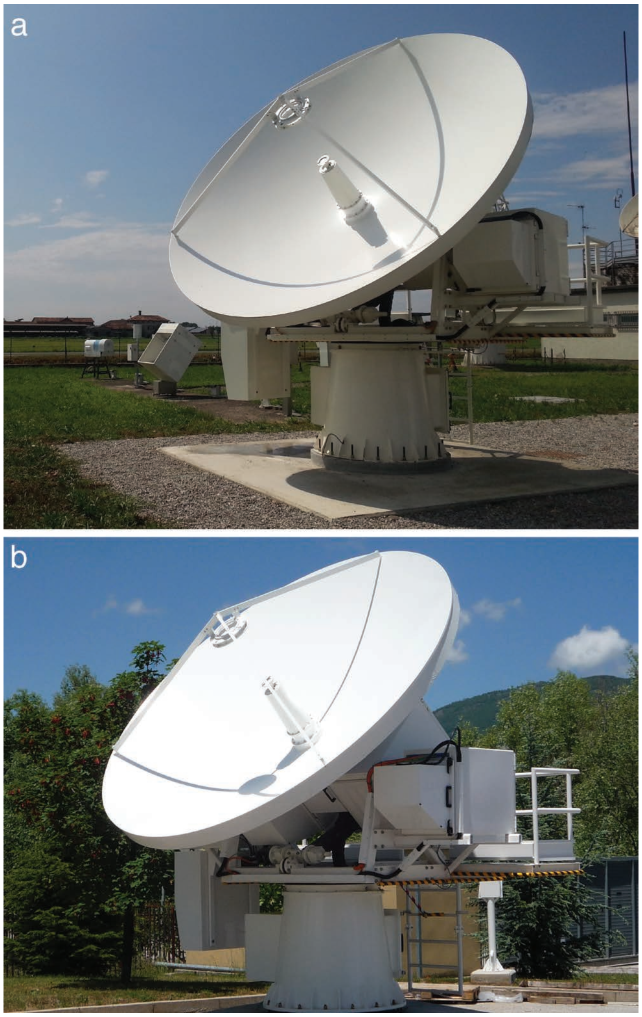

Figure 8.
Alphasat ground stations at Spino d'Adda (a) and Tito Scalo (b).

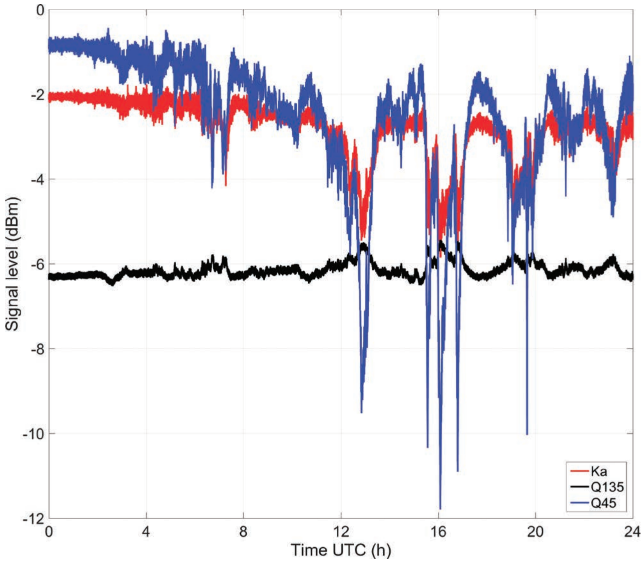

Figure 9.
Beacon level during a rain attenuation event at Spino d'Adda on October 7, 2014; Ka-band (red curve) and Q-band (blue curve) copolar beacon signal levels and Q-band cross-polar signal level (black curve).

CONCLUSION

Alphasat Aldo Paraboni Q/V band TDP is currently used to perform an important experimental campaign. The planning of the communication and propagation experiments campaign is outlined in the paper; moreover, some preliminary experimental results on the SNR estimation technique are reported.

The use of PIMTs at the Q/V band requires an optimization process and a long test campaign that is one of the main objectives of the mission. In particular, and second-order propagation statistics will be investigated, ACM techniques based on the DVB-S2 standard, together with UL-PC and space diversity techniques will be optimized and tested.

The results and the experience acquired from the experiments will allow a more effective use of the Q/V spectrum and will drive the development of future HTS systems. Furthermore, future deep space missions should consider the results of the Alphasat Q/V band experiments [29], [30], [31]. ◆

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