Architectural Design of the Q/V Band Site Diversity Experiment Between Austria and Hungary

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Abstract. The architectural design of the Q/V band site diversity experiment between the transmit/receive ground station in Graz/Austria and the receive only ground station in Budapest is described in this paper. The ground station Budapest is connected via Internet to transfer information about the reception quality of the received signals and to request to adjust the modulation and coding. The uplink power is controlled by the station in Graz, based on the local received beacon signal from the satellite. The planed experiments and the expected results are described in the final paragraph of this paper.

Keywords: Q/V band · Site diversity · Availability
Satellite ground-station design

1 Introduction

Future High Throughput Satellites (HTS) can provide capacity in the hundreds of Gigabit/s to the user and need a broadband bidirectional access to the terrestrial network. Therefore feeder-links to and from the satellite are necessary. The Q/V band can fulfil this role perfectly because the bandwidth in this band is sufficient and no Ka band capacity between the satellite and the user terminal is needed for the feeder link. The challenge in the operation of the Q/V band is the higher fade dynamics which require fast fade mitigation techniques like Adaptive Coding and Modulation (ACM), uplink power control (UPC) and site diversity. All three will be investigated in the described system. The results shall help in the dimensioning of the future Q/V band ground stations and defining the fade mitigation parameters. This paper describes the architecture of the experiment performed via the Q/V-Band Aldo Paraboni Payload on Alphasat and the expected results.

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2 Architecture

The two ground stations are about 275 km apart and have therefore no correlated weather events (non correlated weather events require at least 40 km distance [8]), which make site diversity feasible (Fig. 1). The station in Graz described in Sect. 2.1. was built in the framework of an ESA, ARTES8 projects and is operational since 2013. The station has gathered already 3 years of operational data for fade mitigation techniques and channel modeling statistics.

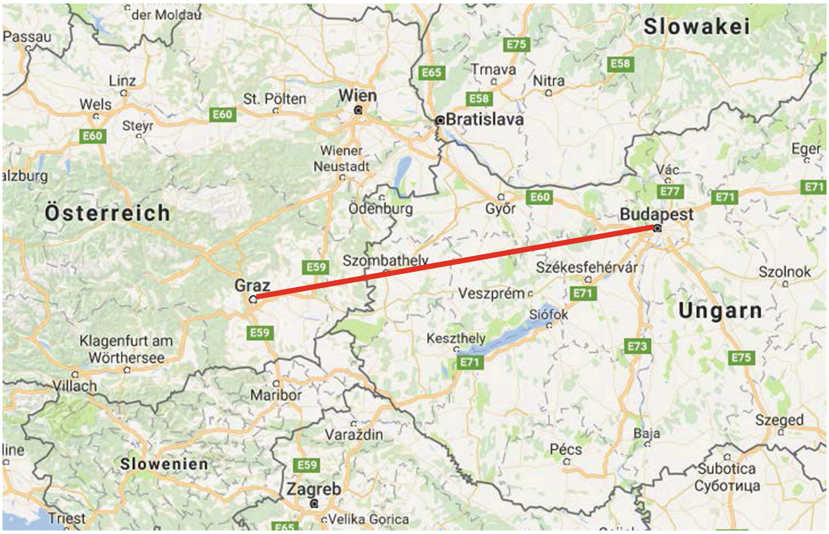

Fig. 1. Position of the two ground-stations with a distance of 275 km (Google maps)

In Fig. 2 is the overall architecture shown. The GS in Graz transmits a DVB-S2 signal [9] with a ModCod based on the reception quality, the SNR, of the signal at the GS in Budapest. The ModCod can be changed by every DVB-S2 frame if necessary, to adapt to the changing channel conditions. It is important to mention that the dead time between the measurement and the final reception of a new ModCod has to be taken into account of the control algorithm of the ACM system. This is described in detail in [5]. The feedback from the GS Budapest to the GS Graz is via terrestrial Internet and covers the following parameters (Table 1).

The timestamp is the local time of the GS Budapest synchronized to the station's GPS-based NTP server and helps to take the dead-time correctly into account. Based on the loopback reception of the secondary beacon signal (see Sect. 2.1) at the GS in Graz, it is possible to distinguish between the uplink and downlink fading, already described in [6]. With the information about the uplink fading be can compensate fading of about 13 dB with the Up-link power control.

Based on the feedback information from the GS Budapest we can set the required ModCod to compensate the downlink fading. All transmit and reception parameters are

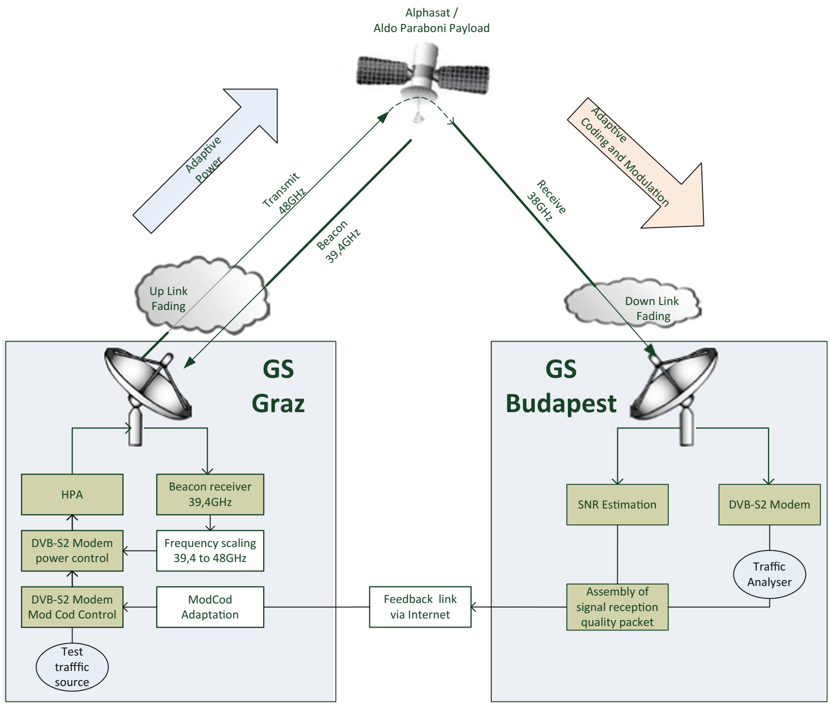

Fig. 2. Architecture of site diversity experiment between Graz and Budapest

Table 1. Exchange parameters between GS Budapest and Graz

Name	Type received	Bytes
Timestamp [s]	Unsigned int	4
Timestamp [µs]	Unsigned int	4
Received Beacon Power [dBm]	Float	4
Desired Modcod []	Unsigned int	4
Signal-to-Noise-Ratio [dB]	Float	4

recorded 24/7 and can be used for further post processing, like simulation of new improved fade mitigation techniques.

2.1 Ground Station in Graz

The communication ground-station in Graz is placed on top of a 35 m high historical tower, called Hilmwarte. The antenna is a Cassegrain system with shaped main and sub-reflector contours which meet the specified performance of a G/T of 33,8 dB/K and a gain of 61,2 dB @ 48 GHz.

In Fig. 3 you can see the block diagram of the GS in Graz [7]. Starting with the transmit path, the test data is generated in the self-designed packet generator and sent to the transmit port of the Newtec DVB-S2 modem EL470. The HPA supplied from CPI provides a nominal power of 50 W (400 W peak) with an EIK (Extended Interaction Klystron). The HPA is connected to the V-Band up-converter via a WR22 waveguide flange. An additional monitor output is provided by the HPA. This output is connected then to a test translator (48/38 GHz), which is required for operating the ground station for test purpose in loop-back mode. The amplified signal from the HPA can either be switched to a dummy load for measurement purpose or sent to the diplexer. This module provides an isolation of 100 dB between the TX and RX port. The final module before the feed is a motor controlled polarization adjustment.

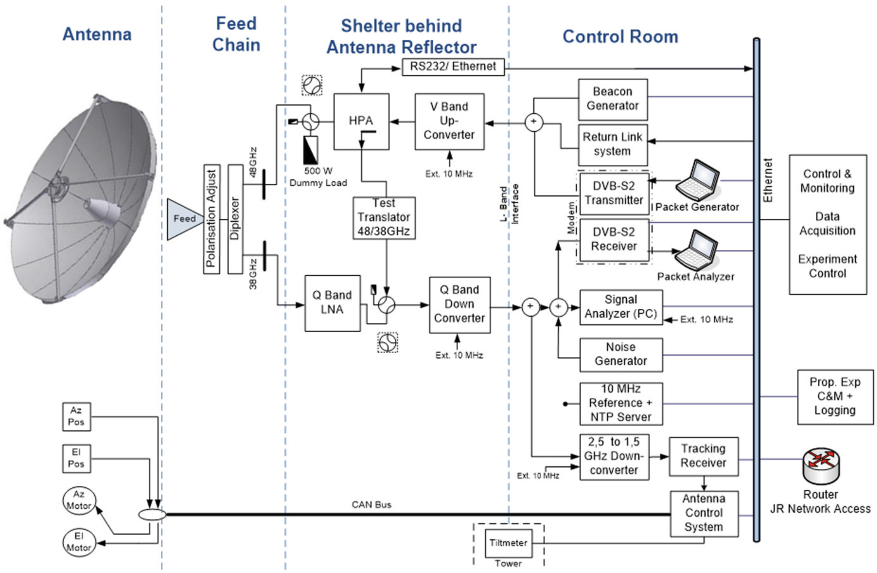

Fig. 3. Architecture of the ground station Graz

The receive part operates on the air-interface from 37,9 to 39,4 GHz. The signal passes the diplexer and arrives at the LNA (50 dB, 270 K). The down-converter can now select between the satellite signal from the LNA, and the signal from the HPA via the test translator. All waveguide switches are controlled by the control and monitoring program via a web-controlled I/O switch unit. The down-converter from Miteq allows adjustment of the drive output level in 0.1 dB steps.

Currently there are 3 experiments from the GS Graz operational on the 10 MHz transponder (Fig. 4): (1) The already mentioned DVB-S2 fade Mitigation experiment, which is also used for the site diversity experiment with Budapest. (2) We transmit a beacon from our GS and measure the reception signal power. This allows us then together with the reception of the satellite beacon to distinguish between uplink fading and downlink fading of our station in Graz. And finally (3) a low operational-point return link system which will be described in a separate paper in the future.

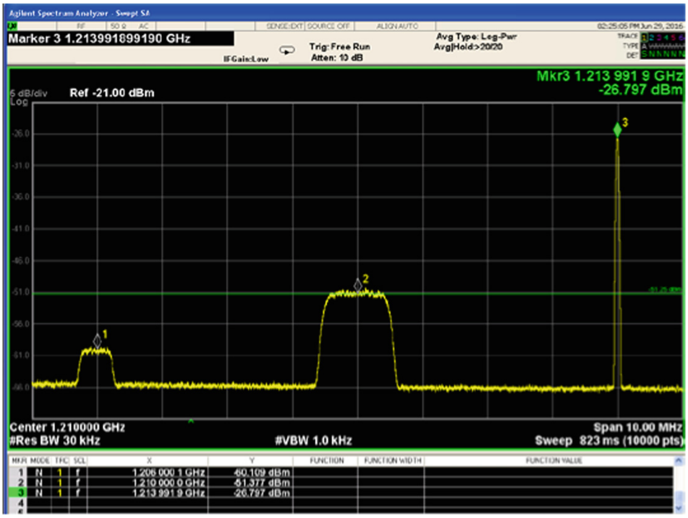

Fig. 4. Screen shot of the L-band IF spectrum transmitted from the GS Graz. The transmit frequency is 46,590 GHz higher from the values seen on the spectrum analyser markers. The 10 MHz transponder is used for 3 experiments. Left carrier (1): Low operational point, return-link system. Middle (2): DVB-S2 spectrum used for the site diversity experiment and other fade mitigation experiments. Right (3): Clean carrier transmitted from the GS which helps to distinguish between uplink and downlink fading

The 10 MHz Reference is a GPS-disciplined rubidium frequency standard source with an integrated NTP-Server. All devices will be synchronized to UTC with an average accuracy of 1 ms.

A self-designed packet generator and analyser software is executed on a PC. The packet generator loads the carrier with defined traffic pattern. The packet analyser finally measures the packet error rate (PER). The same packet analyser is used in the GS in Budapest.

The function of the signal analyser is to measure the SNR and to track the MODCOD of the Physical Layer Frames (PL-Frame) of the DVB-S2 generic stream. An accurate SNR measurement is essential for the analysis and development of Adaptive Coding and Modulation (ACM) algorithms, which can be selected as data-aided and non-data-aided approaches. To this end, we have developed a solution, which offers the possibility to test and optimize various SNR algorithms by means of software. The signal analyser is based on the GNU radio platform based on the Ettus Research HW. The HW provides an L-band interface with a down-converter and an AD converter with 100 MHz. All processing-critical operations which are based on sample information are processed in the FPGA and the symbol based signals on the attached PC platform.

2.2 Ground Station in Budapest

Figure 5 depicts the block diagram of the receive-only terminal in Budapest for the Alphasat Q/V Band Communications Experiment. The system was built to receive the satellite's EU1 beam and demodulate the DVB-S2 stream transmitted from Graz. The receiver is also capable of measuring the Q-band beacon signal transmitted at 39.402 GHz by the Alphasat Aldo Paraboni Payload and the unmodulated pilot carrier transmitted from the GS Graz along with the DVB-S2 signal.

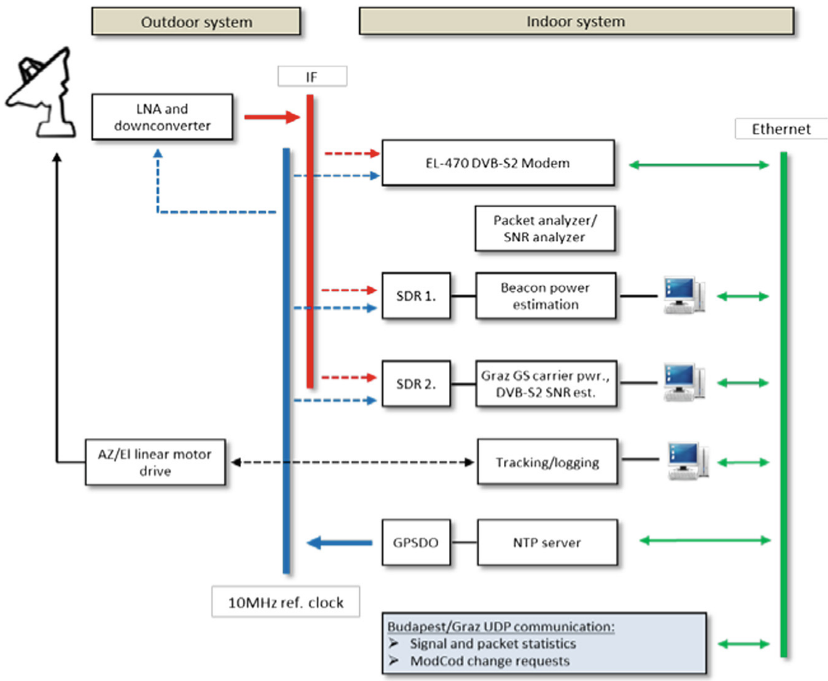

Fig. 5. System structure of the receiver terminal in Budapest

The preliminary link budget calculations that will be detailed in Sect. 2.3 have demonstrated that the system will be capable of receiving the DVB-S2 stream even under moderate/light rain conditions. This has already been proven experimentally during the initial system tests.

The main components of the receiver system are the following:

The antenna is an 1.8 m diameter, 52 dBi gain, Cassegrain type dish covered with radome [1]. The tracking system employs Az/El linear motors with program tracking, yielding ±5° range with 0.005° resolution.

A Low Noise Block with an estimated noise figure of 2.6–3.2 dB converts the 37.85–38.15 GHz transponder band to the IF band between 1420–1620 MHz, and the 39.4 GHz beacon to 2.9 GHz [2]. The GPSDO provides 10 MHz reference clock and also serves as a Stratum-1 NTP server for data timestamping. The DVB-S2 signal is demodulated and decoded using a Newtec EL470, DVB-S/S2 satellite modem [3]. Beacon signal power estimation, Graz GS carrier power estimation and the DVB-S2 SNR estimation are all performed using nuand bladeRF software defined radios [4]. The PC-based signal processing relies on the GNU Radio framework. One SDR receives the 10 MHz transponder passband, while a second receiver-is tuned to the down-converted beacon frequency. The packet analyzer software conveys information about the current reception conditions at the Budapest station to the experiment control PC in Graz, based on the number of correctly received DVB-S2 packets and the instantaneous SNR. The beacon power levels are also shared with the experiment control.

Figure 6 shows the spectrum of the received DVB signal in Budapest. At 2 MHz below center, the DVB-S2 spectrum can be seen, whereas the unmodulated pilot carrier is visible 2 MHz above center. The Alphasat Q-band beacon signal of the Aldo Paraboni experiment cannot be seen in this plot as it is down-converted to a frequency 1 GHz above the DVB spectrum of Fig. 6.

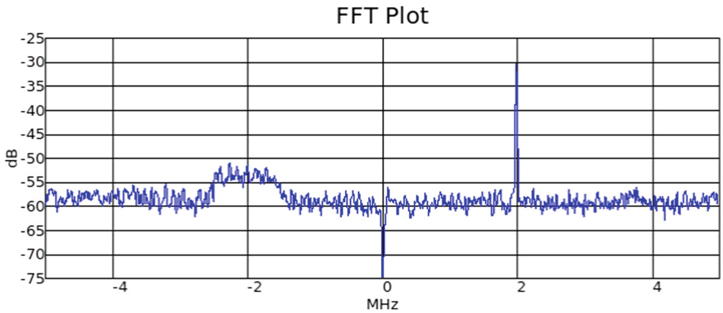

Fig. 6. The L-band IF spectrum of the received signal transmitted by the GS Graz in Budapest

2.3 Link Budget

In the receiver station in Budapest a Newtec EL470 DVB-S2 modem is applied to demodulate the signal transmitted by Alphasat. Table 2 is a link budget calculation for the Budapest GS, considering the satellite transponder parameters and the receiver factors. The contour loss is an estimation of the EU1 beam signal degradation at Budapest. Our measurements proved that the applied 2 dB is a realistic value.

The station is fully compatible with the DVB-S2 standard and because the Graz uplink station is using the same type of modem to modulate the signal, the stations are hardware compatible.

Nevertheless, the applicable ModCod combinations and baud rate depend on the station parameters and are also influenced by the propagation conditions, especially by the rain intensity at the uplink and downlink sites. In order to estimate the limitations of our system, we performed a link budget calculation, which is summarized in Table 2, assuming a symbol rate of 1 MSym/s. Clearly, in order to offset the smaller antenna gain in Budapest, one has to resort to the more robust ModCod combinations and use a smaller channel bandwidth.

Table 2. Link budget for the Budapest ground station

Parameter	Value	Unit
Frequency	38.1	GHz
Guaranteed EIRP	38	dBW
Earth–satellite distance	35756.0	km
Free-space attenuation	215.79	dB
Atmospheric loss	0.5	dB
Ionospheric loss	0.8	dB
Contour loss	2.0	dB
Receive antenna gain	52	dBi
Receiver bandwidth	1.25	MHz
Receiver noise figure	3.0	dB
Received signal power	−98.39	dBm
Received noise power	−109.03	dBm
Es/N0	10.64	dB
C/N0	71.61	dB

In the modem datasheet the manufacturer provides the required minimum E_S/N_0 values for the different ModCod combinations at 10^{-5} packet error rate. From Table 3 one can see that the station with the estimated parameters above can receive (at most) the lower 10 ModCod combinations, if the weather conditions are not too bad, at 1 Msym/s.

Table 3. Link margins for different ModCod

ModCod	Required Es/N0 [dB]	Receiver fade margin[dB]
QPSK 1/2	1.46	9,18
QPSK 3/5	2.86	7,78
QPSK 2/3	3.66	6,98
QPSK 3/4	4.36	6,28
QPSK 4/5	5.16	5,48
QPSK 5/6	5.56	5,08
QPSK 8/9	6.66	3,98
8PSK 2/3	7.16	3,48
8PSK 3/4	8.46	2,18
16APSK 2/3	9.66	0,98

3 Experiments

This project has various goals. First of all, we proved with calculations and later with test measurements that the EU1 beam can be received in Budapest with a relatively small, 1.8 m antenna. Reception test were successful, and we are currently evaluating the actual capabilities of the Budapest station compared to the predictions in Table 3.

The project is entering its operational phase in April 2017 and different experiments will be conducted to test the diversity operation and the Adaptive Coding and Modulation (ACM) mode.

One of the two SDRs in the receiver system is detecting the signal power of the TDP#5 Q-band beacon and the Graz GS unmodulated carrier in order to estimate the fading on the channel and, in addition, to distinguish the Graz uplink and Budapest downlink conditions.

The role of the packet analyzer in the Budapest receiver station is to support the ACM mode. The packet analyzer receives the IP packets from the DVB-S2 modem after the modem performed the DVB-S2 demodulation. The Graz GS transmits a well-defined packet structure, relayed by the satellite to Budapest. Analyzing the received packets permits to qualify the receiving conditions from a different aspect.

A third tool in the receiver station that supports the ACM operation is the SNR estimation, performed by the second SDR in the receiver system.

The beacon signal levels, the packet error statistics and the actual SNR value permit to implement an ACM algorithm and drive the Graz GS to switch between the available ModCod from the lowest QPSK1/2 up to the highest 16APSK2/3 allowed by the receiver system in Budapest. The ACM operation can take into account the diversity weather conditions and always ensures the optimal data transmission speed and quality between the uplink and downlink stations. The following figure is an example on the diversity conditions where the packet error rate in Budapest was influenced by the local and the remote weather conditions, respectively. The measurement was performed during the test phase of the station on 17/09/2016 (Fig. 7).

In order to ensure further data analysis the Budapest GS is logging in portable HDF5 files the following parameters (3 separated daily files are generated):

- Received packet statistics:
  - timestamp
  - number of corrected packets in the last time slot ($\sim$0.5 s)
  - last packet number
  - missing packet number in the last time slot
  - received packet number in the last time slot
- Signal:
  - timestamp
  - Q-band beacon power
  - Graz GS beacon power
  - Budapest GS DVB-S2 SNR
- ModCod:
  - timestamp
  - actual ModCod at Budapest GS

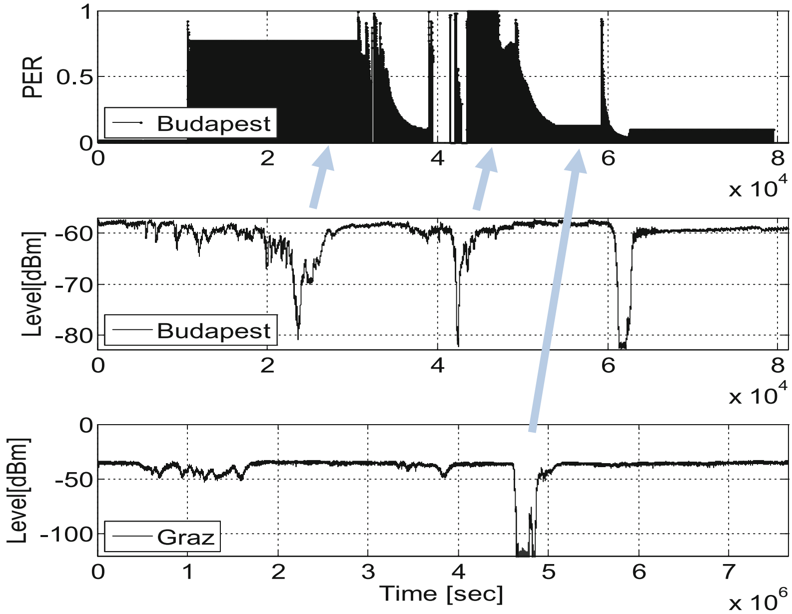

Fig. 7. PER and received power in Budapest and Graz

4 Conclusion

We described in this paper the architecture of the overall site diversity experiment between the Q/V band GS in Graz and Budapest and the in detail the architectures of the two GS. The results of the measurement campaign will help in the dimensioning of future Q/V band ground stations and will contribute in a better understanding of the channel. We will further publish our results after we have gathered statistically enough data for analysis.

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