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# Large-Scale Site Diversity Experiment in Ljubljana and Budapest at Ka-band with Alphasat Satellite

Arsim Kelmendi<sup>1,3</sup>, László Csurgai-Horváth<sup>2</sup>, Mihael Mohorčič<sup>1</sup>, Aleš Švigelj<sup>1</sup>, Tomaž Javornik<sup>1</sup> and Andrej Hrovat<sup>1</sup>

<sup>1</sup>Jozef Stefan Institute, Ljubljana, Slovenia

<sup>2</sup>Budapest University of Technology and Economics, Budapest, Hungary

<sup>3</sup>ONERA/DEMUR, Université de Toulouse, F-31055 Toulouse, France

arsim.kelmendi@ijs.si, csurgai-horvath.laszlo@vik.bme.hu, mihael.mohorcic@ijs.si,  
ales.svigelj@ijs.si, tomaz.javornik@ijs.si, andrej.hrovat@ijs.si

**Abstract**— High throughput satellite communication systems, need to utilize less congested high frequency bands, such as Ka- and Q-bands and above with a large available radio channel bandwidth. However, the disadvantage of radio wave propagation at these frequencies is the increased attenuation and impairment caused from tropospheric phenomena, in particular by rainfall. Site diversity is an efficient technique to mitigate the attenuation due to rain. In this paper, we present the performance evaluation of the large-scale dual site diversity system based on the long-term beacon signal measurement of geosynchronous Alphasat satellite at 19.701 GHz between the Earth stations in Ljubljana and Budapest. The statistical analysis of one-year measurement of rain attenuation of the site diversity system is presented. The results show that the mitigation of the rain attenuation in site diversity is significant.

**Index Terms**—Alphasat, Ka-band, rain attenuation, satellite, site diversity, tropospheric propagation.

## I. INTRODUCTION

The deployment of high throughput satellite communication systems requires large bandwidths available in uncongested high frequency bands such as Ka- and Q-band and above. However, propagation of the electromagnetic waves at these high frequencies, is degraded and attenuated by various tropospheric phenomena. The most significant phenomenon that causes high attenuation is rain [1]. To mitigate the impairments of the signal by the troposphere, the techniques known as propagation impairment mitigation techniques (PIMTs) [2] are usually applied. An effective PIMT to mitigate rain attenuation is site diversity, which consists of two or more spatially separated Earth stations connected by terrestrial links. Due to the characteristics of the rainfall cells with limited dimension and rainfall intensity, the probability of rainfalls in all sites simultaneously is lower compared to a single site. Therefore, Earth-satellite communication can be successfully established, if rain attenuation can be effectively mitigated by selecting the Earth station with the lowest signal attenuation at a given time and connecting the selected Earth station to the desired Earth terminal through a terrestrial link.

Radio wave propagation measurement campaigns provide the experimental data for evaluating and developing predictive channel models that can be used to determine fade margins and geographic location requirements for Earth stations in a site diversity system. In the past, more site diversity satellite propagation measurement campaigns have been conducted at the Ka-band than at Q-band. Examples of site diversity at Ka-

band are reported in [3]-[8], and at the Q-band in [9]-[11]. In [11], we studied the large-scale dual site diversity at 39.402 GHz (Q-band) using measurements of the Alphasat satellite at two Earth stations located in Ljubljana and Budapest. In this paper, we investigate the large-scale site diversity performance at Ka-band between the same Earth stations as in [11] measuring the beacon signal from the Alphasat satellite at 19.701 GHz. The annual and seasonal joint CCDF of rain attenuation and diversity gains are calculated and presented in this paper from one-year measurements. The rest of the paper is organized as follows. Section II briefly introduces the site diversity experiment, while Section III explains data post-processing with the example of attenuation time series. Section IV, describes the statistical analysis of rain attenuation in two-site diversity. Final conclusions are provided in Section V.

## II. THE TWO-SITE DIVERSITY EXPERIMENT SETUP

The experimental setup of the large-scale, two-site diversity experiment was performed with two Earth stations located in Ljubljana and Budapest that measured beacon signals from the Alphasat satellite in Ka-band. The geosynchronous Alphasat satellite located at 25°East with the Aldo Paraboni payload on board, operated by ESA, transmits signals in Ka- and Q-band and enables scientific research measurements campaigns [12]. The Ka-band beacon operates at a frequency of 19.701 GHz in vertical linear polarization.

The locations of the Ka-band Earth stations are the same as the stations at Q-band, therefore the site diversity geometry is the identical for both bands. The Earth distance between the stations is 383 km as shown in Fig. 1.



Fig 1. Geometry of the site diversity experiment.

TABLE I. GEOMETRICAL PARAMETERS OF THE LINK

| Receiver Location | Latitude [°N] | Longitude [°E] | Elevation [°] | Azimuth [°] | Altitude [m] |
|-------------------|---------------|----------------|---------------|-------------|--------------|
| Ljubljana         | 46.04         | 14.48          | 36            | 165.5       | 292          |
| Budapest          | 47.48         | 19.06          | 35.14         | 172.13      | 120          |

The main link parameters of the experiment setup at Ka-band which are the same as at Q-band, are depicted in TABLE I. The Earth stations were developed and installed in 2015. A tracking mechanism is used to compensate for the elevation and azimuth variations of the satellite.

The Earth station in Ljubljana, developed by the Jozef Stefan Institute (JSI), was installed on the flat roof of the JSI. Only one parabolic antenna is used to measure the co-polar beacon signals in the Ka-band (19.7 GHz) and Q-band (39.4 GHz) as well as the cross-polar signals induced from depolarization [13]. The parabolic antenna with 1.2 m diameter, together with the LNB and the mechanical part of the tracking system is shown in Fig. 2.



Fig. 2. Antenna and tracking system at JSI flat roof.



Fig. 3. Antennas and tracking system at BME flat roof.

The Earth receiver in Budapest was developed by the Budapest University of Technology and Economics (BME) and is installed on the flat roof of the department's building [10],[14]. A Cassegrain type 0.3 m antenna is used for Q-band and 0.6 m antenna for Ka-band. Antennas and the tracking system are depicted in the Fig 3.

The one-year period of measurement data with high 97.53% concurrent data availability, from May 16, 2017, to May 15, 2018, are statistically analyzed and presented in this paper. Data from the same period were used for the site diversity analyses at the Q-band [11].

### III. POST-PROCESSING OF RAIN ATTENUATION TIME SERIES

Rain attenuation time series were extracted from the co-polar signal data from both Earth stations. The time series of rain attenuation at the Ljubljana station were originally obtained using the sampling rate of the received signal (6.1 samples/second) and then subsampled to obtain the same sampling rate of 1 sample/second as at Budapest station. Therefore, in the site diversity system, the joint attenuation time series, which are the minimum values of the attenuation time series between two sites at the same synchronized time, were calculated every second [15]. This is the case of the ideal selection scheme in site diversity, which provides maximum gain by switching instantaneously between stations and selecting the Earth-satellite link with the least rain attenuation at each synchronized time.

Fig. 4 shows an example of rain attenuation measurements for several hours at Ljubljana and Budapest on August 6, 2017, and the joint rain attenuation of the site diversity system. Three different intervals are marked in the figure to highlight the mitigation of rain attenuation by the site diversity system. In the first interval (1), the Earth station in Budapest had a huge signal attenuation of more than 25 dB due to heavy rainfall, while in Ljubljana the sky was almost clear. Therefore, the attenuation in the site diversity system is almost completely reduced by selecting the station in Ljubljana for enabling of the Earth-satellite link. In the second interval (2), both Earth stations experienced huge attenuation.

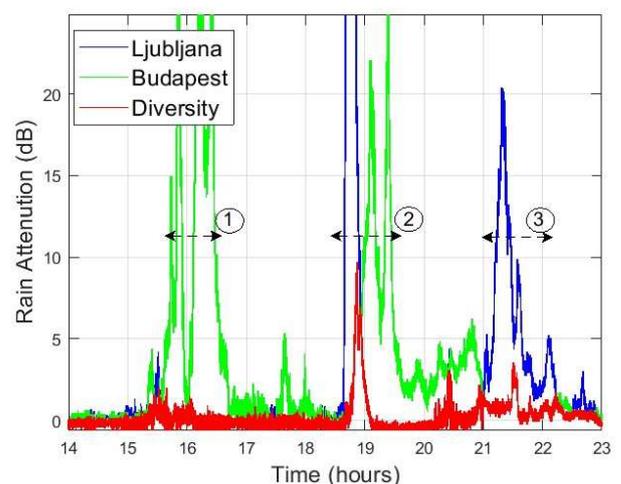


Fig. 4. Rain attenuation on single sites and site diversity during several hours on August 6, 2017.

At the beginning and end of the interval the attenuation was completely mitigated by selecting the station with near zero attenuation. However, since it rained simultaneously for several minutes at both sites, it was not possible to mitigate attenuation completely, and the joint rain attenuation reached a maximum of about 9 dB. In contrast to the time interval (1), the Budapest station is used in time interval (3), because the attenuation in Ljubljana was considerably higher, reaching 20 dB. The maximum attenuation in the Budapest stations, i.e., in the site diversity, is only 3 dB in this interval.

#### IV. CCDFs OF RAIN ATTENUATION AND DIVERSITY GAINS

The rain attenuation time series are statistically analyzed for the site diversity experiment and for both single sites. The results are presented for the one-year period as Complementary Cumulative Distribution Functions (CCDFs). The CCDFs curves of rain attenuation for each single site and the joint rain attenuation for the site diversity system are depicted in Fig. 5. As evident from the time series in the previous section, it is also clear from the CCDF curves that the observed site diversity system significantly mitigates the rain attenuation of the Earth-satellite system. For example, in Fig. 5 the attenuation exceeded for 0.01% of the time (about 52 minutes per year) of about 29 dB in Ljubljana and 17 dB in Budapest, respectively, is mitigated to ~3 dB by the site diversity system. In addition, the measurements reveal the attenuation of approximately 35 dB and 25 dB in 0.001% of the time (about 5 minutes per year) in the Ljubljana and Budapest stations, respectively, while the attenuation for the site diversity system is about ~6 dB. The mitigation of the attenuation is observed at all percentages, but is more effective at low probabilities where attenuation is caused by intense rainfall cells of short duration during the year. These intense rain cells are often limited in the dimensions, usually the higher the intensity, the smaller the horizontal dimensions. The theoretical uncorrelated joint CCDF curve that represents the minimum theoretical attenuation of site diversity when both single sites are uncorrelated, is also shown in the same figure.

The comparison of the measured joint rain attenuation CCDF of site diversity with the ITU-R Recommendation P.618-§2.2.4.1 model [16] and two copula-based prediction models, the Gaussian model [17] and the Clayton model [18], is performed and the CCDF curves are shown in Fig. 6.

The three models require rain attenuation at each site for prediction, and measured data are used in all three cases. The Clayton model performs slightly better. However, from the curves, it can be observed that the three models generally fit the measurements data quite well, as the measured data points scatter about 1 to 2 dB to the models at all percentages.

In Fig. 7 the CCDFs of joint rain attenuation for each season of the year are also shown. The season with the highest joint rain attenuation in the site diversity system is summer, while significantly lower rain attenuation was observed during the other three seasons - spring, autumn and winter. A similar observation has been provided at site diversity at Q-band [11].

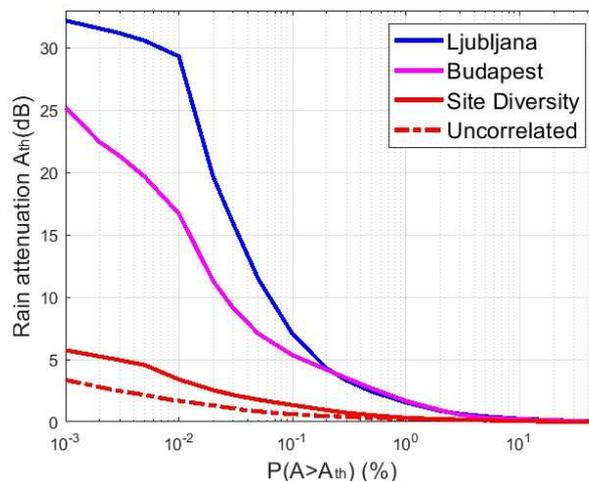


Fig. 5. One-year CCDFs of rain attenuation.

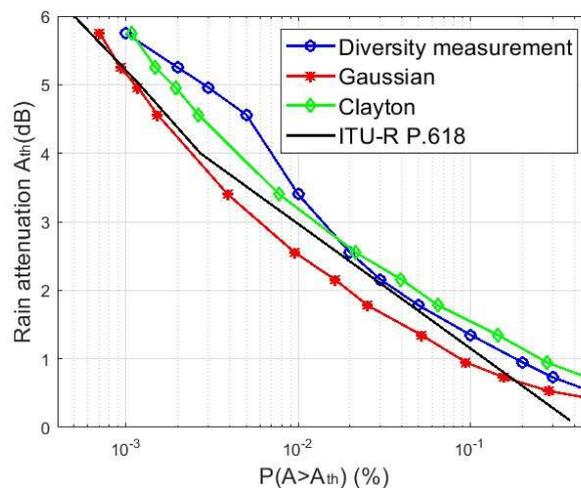


Fig. 6. ITU-R, Gaussian and Clayton prediction CCDFs compared to the measurements data in two-site diversity system.

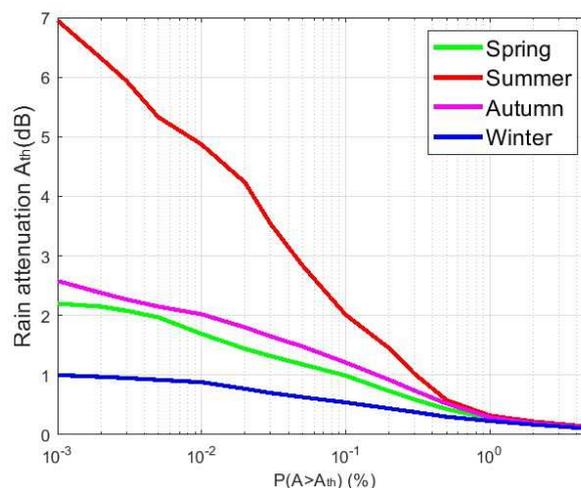


Fig. 7. Seasonal CCDFs of rain attenuation for site diversity system.

This is due to the fact the rain attenuation during the summer is more intense and characterized with possible high correlation due to occurrence of the rains simultaneously even if the stations are in large distance.

To better highlight the performance of the site diversity technique, the diversity gains at both Earth station of the site diversity system are calculated and depicted in Fig. 8 for one year and for each season separately. The diversity gains are calculated from CCDF data by subtracting the site diversity attenuation from the attenuation of the single site at the same probability.

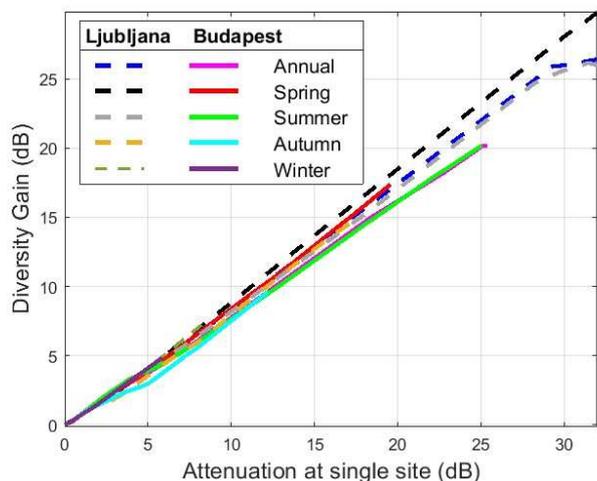


Fig. 8. Annual and seasonal diversity gain at individual site provided by deploying site diversity system.

The diversity gain curves clearly highlight the benefits of site diversity for rain attenuation mitigation. The diversity gain of the site diversity system increases almost linearly with increasing attenuation at a single site. Therefore, the highest gain is obtained at the highest attenuation. As can be seen from Fig. 8, the deviations between the curves are minimal, however, the diversity gains are slightly higher in Ljubljana compared to Budapest, i.e., mainly in spring, summer and during the year. This is due to higher attenuation at a single site in Ljubljana compared to Budapest.

## V. CONCLUSIONS

This paper presents a large-scale site diversity experiment setup with Earth stations in Ljubljana and Budapest, based on the measurements data from the Alphasat satellite in the Ka band.

The one-year measurement data are post-processed and the joint rain attenuation time series are obtained and statistically analyzed. The results are presented in form of CCDFs for single sites and the site diversity system.

From the time series example and also statistically from CCDFs, it is observed a significant mitigation of the attenuation in the site diversity system compared to the single sites. From the CCDF analysis, it was observed that for low percentages of the time during the summer season the attenuation was not completely mitigated compared to other three seasons where the attenuation is almost completely mitigated. This is due to the

fact that during the summer there are more large rainfall events that can be correlated, even if the stations are far apart.

Moreover, the performance of site diversity systems is observed through diversity gains for one year and each season separately. The diversity gain in the site diversity system increases almost linearly with increasing attenuation at a single site.

The measurement CCDF of joint attenuation is compared with three prediction models, the ITU-R model, the Clayton and Gaussian copula model. Although in this case the Clayton model performs slightly better, all models predict with less than 1-2 dB error in all observed percentages of time.

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## REFERENCES

- [1] A. Kelmendi, A. Švigelj, T. Javornik, A. Hrovat. Site Diversity in Satellite Communications: Modelling Using Copula Functions. Springer Nature. (2023).
- [2] A. D. Panagopoulos, P. -D. M. Arapoglou and P. G. Cottis, "Satellite communications at KU, KA, and V bands: Propagation impairments and mitigation techniques," in IEEE Communications Surveys & Tutorials, vol. 6, no. 3, pp. 2-14, Third Quarter 2004, doi: 10.1109/COMST.2004.5342290.
- [3] J. Goldhirsh, B. H. Musiani, A. W. Dissanayake and Kuan-Ting Lin, "Three-site space-diversity experiment at 20 GHz using ACTS in the Eastern United States," in Proceedings of the IEEE, vol. 85, no. 6, pp. 970-980, June 1997, doi: 10.1109/5.598419.
- [4] A. Kelmendi and A. Vilhar, "Preliminary statistical analysis of four site diversity experiment at Ka-band," 2017 11th European Conference on Antennas and Propagation (EUCAP), Paris, France, 2017, pp. 831-835, doi: 10.23919/EuCAP.2017.7928741.
- [5] M. Rytir, P. A. Grothting, T. Tjelta, L. E. Bråten, C. Riva, "Three-site diversity on low-elevation 20 GHz links in Norway," 21st Ka and BroadBand Communications, Navigation and Earth Observation Conference, pp. 1-8. 2015.
- [6] X. Boulanger, F. Lacoste, L. Castanet. Small and large scale site diversity experiment at Ka-band in the south of France. International Journal of Satellite Communications and Networking. 2018 Jan;36(1):14-28.
- [7] Garcia-del-Pino, P., Rocha, A., Riera, J.M., Garcia-Rubia, J.M. and Benarroch, A., 2010. Joint statistics of rain attenuation at 20 GHz in Madrid and Aveiro. IEEE Antennas and Wireless Propagation Letters, 9, pp.799-802.
- [8] Papafragkakis, A.Z., Kourogiorgas, C.I. and Panagopoulos, A.D., 2019. Site-Diversity Ka-Band Satellite Propagation Campaign in Attica, Greece, Using Alphasat: First 2 Years' Results. IEEE Antennas and Wireless Propagation Letters, 18(10), pp.2115-2119.
- [9] M. Buti, U.C. Fiebig. "Joint statistics of slant-path attenuation in distant sites measured with ITALSAT at 40 GHz," Electronics Letters, 42(18), pp.1014-1015.
- [10] F. Cuervo, M. Schoenhuber, M. Schmidt, L. Csurgai-Horvath, A. Martellucci, and J.R. Castro, "Alphasat site diversity experiment at Q-band in Austria and Hungary," 24th Ka Broadband Commun. Conf. (pp. 1-9). 2018.
- [11] A. Kelmendi, L. Csurgai-Horvath, A. Švigelj, M. Mohorčič, T. Javornik and A. Hrovat, "Site Diversity Experiment in Q-Band Satellite Communications in Slovenia and Hungary," in IEEE Antennas and Wireless Propagation Letters, vol. 22, no. 8, pp. 1967-1971, Aug. 2023, doi: 10.1109/LAWP.2023.3270839.
- [12] J.J. Rivera, A. Martellucci, P. Sivac, E. Benzi, A. Pandolfi, D. de Bernardo, S. Falzini, and G. Codispoti, "Alphasat Aldo Paraboni, an

- advanced Q/V band mission space segment," *International Journal of Satellite Communications and Networking* 37, no. 5 (2019): 397-409.
- [13] A. Kelmendi, A. Hrovat, M. Mohorčič and A. Švigelj, "Alphasat Propagation Measurements at Ka- and Q- Bands in Ljubljana: Three Years' Statistical Analysis," in *IEEE Antennas and Wireless Propagation Letters*, vol. 20, no. 2, pp. 174-178, Feb. 2021, doi: 10.1109/LAWP.2020.3043321.
- [14] Csurgai-Horváth, László, Bernard Adjei-Frimpong, Carlo Riva, and Lorenzo Luini. "Radio wave satellite propagation in Ka/Q band." *Periodica Polytechnica. Electrical Engineering and Computer Science* 62, no. 2 (2018): 38-46
- [15] Ventouras, S., et al. "Assessment of spatial and temporal properties of Ka/Q-band earth-space radio channel across Europe using Alphasat Aldo Paraboni payload," *International Journal of Satellite Communications and Networking* 37, no. 5 (2019): 477-501.
- [16] ITU-R Recommendation P.618-13,"Propagation data and prediction methods required for the design of Earth-space telecommunication systems", International Telecommunication Union, Geneva, Switzerland, 2017.
- [17] A. Kelmendi, C. Kourogiorgas, A. Hrovat, A. D. Panagopoulos, G. Kandus an A. Vilhar, "Prediction of Joint Rain Attenuation Statistics Induced on Earth-Satellite Multiple Site Diversity Systems Using Gaussian Copula," in *IEEE Antennas and Wireless Propagation Letters*, vol. 16, pp. 95-98, 2017, doi: 10.1109/LAWP.2016.2557960.
- [18] S. N. Livieratos, C. I. Kourogiorgas, A. D. Panagopoulos and G. E. Chatzarakis "On the Prediction of Joint Rain Attenuation Statistics in Earth-Space Diversity Systems Using Copulas," in *IEEE Transactions on Antennas and Propagation*, vol. 62, no. 4, pp. 2250-2257, April 2014, doi: 10.1109/TAP.2014.2302302.