COST CA 19111

European Network on Future Generation Optical Wireless Communication Technologies (NEWFOCUS)

Deliverable D4.1

Channel Modeling and Transceiver Design for UV and airborne IR Links

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1. Introduction

The working group4 (WG4) deals with Long-range links mainly focussing on airborne and satellite FSO links. Considering the channel modelling and transmission schemes for airborne IR links various publications and internal documents summarizing collaborative work within the working group members have been presented fulfilling the Milestone 4.1. However, not many activities have been reported in the UV region because of the topic is currently not much of interest in the community [6]

The activities for WG4 has been presented in terms of various input documents during working group meeting and discussed. Some of the topics that were covered are:

I. „Error control capability of NB-IoT MCS over satellite links with optical feeder links ", Alexis Dowhuszko, Department of Communications and Networking, Aalto University, Finland.
II. „Airborne and space laser communication ground terminal ", Andris Treijs, HEE Photonic Labs.
III. „Modelling near-Earth FSO channels and atmospheric seeing affected by turbulence and clouds ", Hristo Ivanov , University of Graz.
IV. "Resource allocation in a Quantum Key Distribution Network with LEO and GEO trusted-repeaters," in Proc. Int. Workshop Optical Wireless Comm., pp. 1-6, Sept. 2021, M. Grillo, A. Dowhuszko, M.-A. Khalighi and J. Hämäläinen.
V. "End-to-end error control coding capability of NB-IoT transmissions in a GEO satellite system with time-packed optical feeder link", Joan Bas and Alexis Dowhuszko.
VI. "Modelling near-Earth/deep-space FSO channels and atmospheric seeing affected by turbulence and clouds". Hristo Ivanov, Erich Leitgeb, Frank Marzano, Pasha Bekhrad.
VII. "Optical Wireless Channel Models for High Throughput Satellite Communication Systems" Dowhuszko Alexis
VIII. "Testbed Emulator of Satellite-to-Ground FSO Downlink Affected by Atmospheric Seeing Including Scintillations and Clouds", Hristov Ivanov.
IX. " On Hybrid Optical-Radio Communication Systems for 6G NonTerrestrial Networks ", Marc Amay, Joan Bas (CTTC).
X. "Influence of EDFA on the satellite QKD channel Research" – STSM, Ali Khalighi (ECM)
XI. "Background optical radiation measurement in Hungary". Gerhátné Udvary Eszter (TU Budapest).
XII. "Adaptive approaches to reduce long-range FSO channel distortions", Niek Doelman (TNO)

2. Characterization of atmospheric channel of airborne IR Links

TU-Graz contributed in characterization of atmospheric channel of airborne IR links in regards to Mie scattering attenuation (clouds) and atmospheric turbulence-induced fading. Both contributions [1] and [5] offer comprehensive channel modelling approach that considers the later effects. In particular, the adverse Mie scattering, impose significant risks for communication outage events. In order to foresee and evaluate those related issues within an optical wireless link, the [5] reports on experimental setup utilizing artificial Mie scattering sources based on mixture of different highly purified glycols and water. As means of determining the approach feasibility, both atmospheric microphysics by means of empirical modified Gamma Particle Size Distribution (PSD) functions and Mie theory are used to estimate the artificially simulated Mie scattering attenuation of glycol-water fluids characterized by their complex refractive indices. Moreover, all results are compared with analysed PSDs obtained based on laser diffraction system for two types of Mie-scattering machines that operate with the considered glycol-water fluids. On the other hand, a state-of-the-art laboratory testbed for verification of slant APD-based (Avalanche Photodiode) FSO links in laboratory conditions is proposed in [1]. In

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particular, a hardware channel emulator representing airborne IR communication links by means of fiber-coupled Variable Optical Attenuator (VOA) controlled by driver board and software is utilized. While atmospheric scintillation data are generated based on Radiosonde Observation (RAOB) databases combined with a statistical design approach, cloud attenuation is introduced using Mie theory together with empirical Log-Normal modelling. The estimation of atmospheric-turbulence-induced losses within the emulated optical downlink is done with an FSO IM/DD prototype (Intensity Modulation/Direct Detection) relying on two different data throughputs using a transmitter with external and internal modulation. Moreover, the receiver under-test is a high-speed 10 Gbps APD photodetector with integrated Transimpedance Amplifier (TIA) typically installed in OGSs (Optical Ground Stations) for LEO/GEO satellite communication. The overall testbed performance is addressed by a BER tester and a digital oscilloscope, providing BER graphs and eye diagrams that prove the applied approach for testing APD-TIA in the presence of weather-based disruptions. Furthermore, the testbed benefits from the used beam camera that measures the quality of the generated FSO beam.

In addition, DLR institute of Communication and Navigation has also contributed in the topic of channel model for FSO scenario in the form of guest presentations on topics like “QCalc: a tool to compute classical and quantum communication rates over free-space optical channels”, “Heritage in Free-Space Optical Air-To-Ground and Space-To-Ground Communication”. Additionally, in the upcoming white paper, two articles covering satellite QKD topic is addressed.

3. Development of hybrid optical-radio systems

CTTC contribution has been addressed to the development of hybrid optical-radio systems. However, it has been understood the hybrid optical-radio systems from two different ways. In the first one the communications have been evaluated from an end-to-end perspective. So, there are uplink and downlink channels but only one of them is optical and the other is radio. In this part no security scheme has been considered. The framework of the communications has been 5G. Two contributions on this area have been done [2] and [3]. In [2] was considered the forward link, i.e., from the Gateway to a NB-IoT Equipment through satellite. In the uplink, i.e., from the Gateway-Satellite the link was optical whereas in the downlink, i.e., from Satellite-to-IoT terminal, the link was radio. The satellite was GEO with a regenerative payload to support optical and radio links. Several communication technologies were considered in the uplink: DVB-S2, NB-IoT and encapsulating IoT in DVB-S2. The downlink was always used NB-IoT to support the compatibility with the NB-IoT terminals. Here it was used as a time-packing technique to improve the spectral efficiency of the uplink. In [3] was tested the opposite link, from UE to Gateway but through a UAV. The uplink in this case was radio (IoT-UAV) and the downlink was optical (UAV-Gateway). Here it was used as a frequency packing technique to improve the spectral efficiency of the downlink. The signal was fully NB-IoT in the uplink and downlink. As it is a multicarrier system, it developed the required signal processing to support multicarrier format and IM/DD detection for the optical links at the downlink. In [2] and [3] gains in spectral efficiency were achieved.

The other structure of the hybrid optical-radio system is to permit in the same link the optical and radio communications [7]. Toward this regard, three options emerge: i) capacity, ii) resilient and iii) security (QKD). In the capacity one, the optical and radio links are used simultaneously and with different data. In the resilient structure, the optical link is used as a primary link whereas the radio one is used as a backhauling solution. It is possible to use both links simultaneously if the SNR of the optical link is not very good but still good enough and the SNR of the radio link is large enough. Nevertheless, in this case, the information that transmits the optical and radio links is the same. Finally, the security

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scheme revolves around QKD strategy. The distribution of the quantum keys is done in the optical channel whereas the data one is done in a radio and/or optical link. In this case, it is necessary to dimension the generation of the QKD keys to its demand. In NGEO this demand depends on the visibility time of the satellite and so the beam size, latitude, and inclination of the satellite are key to have a higher or lower visibility time of the satellite. If the number of generated keys is lower than the demanded ones, QKD may have to reuse the keys. In this case, complementary techniques for increasing the secrecy rate of the QKD communications and the design of the satellite constellations have to be pursued.

4. Publications

[1] Ivanov, H.; Marzano, F.; Leitgeb, E.; Bekhrad, P. Testbed Emulator of Satellite-to-Ground FSO Downlink Affected by Atmospheric Seeing Including Scintillations and Clouds. Electronics 2022, 11, 1102. https://doi.org/10.3390/electronics11071102

[2] J. Bas and A. Dowhuszko, “On the use of NB-IoT over GEO satellite systems with time-packed optical feeder links for over-the-air firmware/software updates of machine-type terminals,” Sensors, vol. 21, no. 12, p. 3952, June 2021. DoI: 10.3390/s21123952

[3] J. Bas and A. Dowhuszko, “End-to-end performance of an uplink NB-IoT transmission relayed on a low-altitude UAV platform with non-orthogonal single-carrier FDMA in the optical wireless backhaul link,” Special Issue on Mobile Networks, Springer, pp. 1-22, June 2022

[4] M. Grillo, A. Dowhuszko, M.-Ali Khalighi and J. Hämäläinen, “Resource allocation in a quantum key distribution network with LEO and GEO trusted-repeaters,” in Proc. International Symposium on Wireless Communication Systems, Belin, Germany, pp. 1-6, September 2021. Doi: 10.1109/ISWCS49558.2021.9562139. (T4.2, T4.3)

[5] Hristo Ivanov, Erich Leitgeb, „Artificial Generation of Mie Scattering Conditions for FSO Fog Chambers, “ 13th International Symposium on Communication Systems, Networks and Digital Signal Processing (CSNDSP), Porto, Portugal, 2022

[6] A. Vavoulas, H. G. Sandalidis, N. D. Chatzidiamantis, Z. Xu and G. K. Karagiannidis, "A Survey on Ultraviolet C-Band (UV-C) Communications," in IEEE Communications Surveys & Tutorials, vol. 21, no. 3, pp. 2111-2133, thirdquarter 2019, doi: 10.1109/COMST.2019.2898946.

[7] M. Amay, J. Bas, “On Hybrid Free Space Optic Radio Systems as Enablers of 6G services”, In Proc. Of ICASSP Conference 2023

5. Other Activities

5.1. Training School

In addition, training school was organized in August 2022 in University of Prague covering the topics on WG3 and WG4. For WG4 following lectures/presentations were provided to educate but also to advertise what fields and topics are currently being investigated in research industries.

i. Free space Optical Communication activities in German Aerospace Center (DLR), Oberpffafenhofen, Amita Shrestha (DLR)
ii. Seminar on Optical Communication for Space, Dr. Dirk Giggenbach (DLR)
iii. Embedded Systems Development within the framework of new Space, Dr. Julio Ramirez (DLR)

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5.2. Short Term Scientific Mission

Moreover, several Short-term scientific missions were also done to maximize the collaborative work between different WG members.

XIII. „Modelling near-Earth FSO channels and atmospheric seeing affected by turbulence and clouds ", Hristov Ivanov (TU Graz) and Sapienza Universita di Roma. 2nd October -15th October 2021.

XIV. "Influence of EDFA on the satellite QKD channel Research, Ali Khalighi (ECM) and DLR. August 2022

XV. „ Development of High-Performance Adaptive Optics Control Algorithms for Free Space Optical Communication ", Joana Torres (DLR) and Instit d'Optique, April 2023 (planned)

XVI. "Influence of ASE noise from EDFAs on a free space QKD channel", Carlos Guerra Yanez (University of Prague), and DLR. June 2023 (planned)

XVII. „Emulation and Definition of Continuous Variable QKD systems ", Marc Amay CTU, April-May 2023.

5.3. White paper

Finally, second white paper is being prepared covering the topics for WG3 and WG4. Contributions from WG4 are:

iv. Giulio Cossu, Veronica Spirito, Michail P. Ninos, Ernesto Ciaramella, "Wavelength Division Multiplexing Free Space Optical Links".

v. Joan Bas, Marc Amay, "Review of Hybrid Optical-Radio Inter-Satellite Links in 6G NTN Including Quantum Security".

vi. Davide Orsucci, Florian Moll, Amita Shrestha, "Review of low-Earth orbit satellite quantum key distribution".

vii. Davide Orsucci, Florian Moll, Amita Shrestha, "Perspectives for global-scale quantum key distribution via uplink to geostationary satellites".

6. Future work and Conclusions

Several contributions to the milestone have been made in collaboration with different working group members in terms of training school, publications. Currently, we are also working on the white paper and some STSMs have been planned. Recently, a new Special Interest Group has been established with the motivation to knowledge exchange, networking and possible collaboration in the Quantum Communication domain.

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