Optical Feeder Links for Future Very High-Throughput Satellite Systems in B5G Networks

Ramon Mata Calvo(1), Tomaso de Cola(1), Juraj Poliak(1), Luca Macrì(1), Arled Papa(2), Serkut Ayvasik(2), Edwin Babaians(3), Wolfgang Kellerer (2)

(1) Institute of Communications and Navigation, German Aerospace Center (DLR), Muenchnerstr. 20, 82234 Wessling, Germany, ramon.matacalvo@dlr.de
(2) Chair of Communication Networks, Technical University of Munich (TUM), Arcisstr. 21, 80333 Munich, Germany, serkut.ayvasik@tum.de
(3) Chair of Media Technology, Technical University of Munich (TUM), Arcisstr. 21, 80333 Munich, Germany, edwin.babaians@tum.de

Abstract *Optimizing the optical feeder-links is essential in providing broadband connectivity between ground and space. The system architecture is being investigated and experiments are being performed to integrate B5G technologies. Atmospheric turbulence mitigation is being demonstrated to provide a stable feeder-link and maximize the data throughput.*

Introduction

Digitalization, internet-of-things, Industry 4.0 or 5G and its future evolutions require global broadband internet access. Ground fibre-based infrastructure provides internet access in the urban areas but its coverage decreases dramatically in the rural areas, even in the countries with the most developed infrastructure. Satellite communications can provide an extension to terrestrial network, reaching locations where no terrestrial infrastructure is available.

Current state-of-art satellite communications are based in radiofrequency (RF) on Ka-Band [1]. Developments are being performed in Q/V and W bands to increase the available bandwidth. However, this is limited to few GHz in the best cases. Thus, the increase of data throughput cannot be satisfied by the current RF systems, becoming the bottleneck. Optical frequencies offer a bandwidth in the order of 10 THz without any regulation. Due to the smaller divergence of the transmitted signals interference can be avoided and a higher security can be offered.

Most of current optical communication systems in space are used for demonstration purposes. The data highway is the first operational service provided by the European Data Relay System (EDRS) [2]. EDRS uses optical technologies in the inter-satellite links between LEO and GEO satellites, relaying Earth Observation data to ground via GEO. SpaceX is deploying the Starlink constellation based on LEO satellite with optical inter-satellites. Laserlight started developing and commercializing the transceiver technology that will be used in the future constellation. A demonstration on the last one is foreseen soon from the international space station [3]. The European Space Agency (ESA) also announced the deployment of high throughput satellite infrastructure within the Hydron program [4].

Optical links between ground and space are still under investigation. In 2017 the world-record on free-space optical communications was set to 13.16 Tbit/s demonstrating the high potential of optical feeder-links for extending the fibre connectivity in the space [5]. The system architecture needs to be defined and the main features need to be demonstrated in relevant conditions to guarantee a future system development.

The profitability of optical-based satellite communications is not just limited to the specific satellite context but can offer important benefits to the overall 5G and 6G networks. In particular, the support of eMBB (enhanced Mobile Broadband) services already see promising the integration of a satellite infrastructure because of the intrinsic geographical coverage. Moreover, the capability of enabling new use cases still belonging to the eMBB class such AR/VR applications would certainly benefit from much higher bandwidth, as currently available only with optical-based satellite systems.

The objective of this paper is to discuss the main challenges in integrating 5G and beyond technologies (B5G) in optical satellite communications. We also present the current experiments performed by DLR and TUM to demonstrate the potential of optical feeder-links in reaching global coverage of B5G technologies.

5G and beyond

As pointed out in the previous section, the role of satellite communications into the 5G overall ecosystem [6] is considered crucial to enable new services and support existing ones especially in the case of remote areas or scenarios where the overall offered capacity by the terrestrial infrastructure is temporarily not sufficient (i.e., in large events or in disaster management operations because of network disruptions). In this respect, the industry and the scientific community have dedicated quite some effort in the last years in order to define a suitable converged architecture aimed at integrating satellite and terrestrial segments [7], as witnessed by the many activities supported by the European Space Agency (ESA) and a few projects funded by the European Commission under the H2020 framework. The renewed interest towards satellite communication combined with terrestrial systems is however not limited to Europe, but has received an increasing interest at worldwide scale, hence confirming the added value that satellite systems may bring to future integrated systems. This potential has more importantly recognised the role of satellite communications also from a standardisation viewpoint in the roadmap of 5G specification work being carried out within 3GPP, where a dedicated work item referred to as non-terrestrial networks (NTN) [8] has been already introduced in the course of Release 16 especially for technical reports and then elected as one of the “technology champion” for the following Release 17, whose specification work has started in early year 2020.

The role of satellite communications is however not limited in the short-term as envisaged in the standardisation roadmap defined within 3GPP, but even on a longer time horizon as appearing from the emerging studies in the framework of B5G and more specifically of 6G [9],[10]. In that context, particular attention is being given to the case HTS systems building on mega constellations, in order to widen the possible business use cases towards low latency services which would be hardly achievable with traditional GEO satellite systems, apart from the cases where Multi-Access Edge Computing (MEC) concepts is exploited. Another key-technology considered in 6G for satellite systems is the exploitation of free-space optical communications in order to provide higher capacity than what typical RF-based systems are capable to offer. This possibility is considered particularly appealing for the application to satellite feeder link, i.e. close to the core network or content providers so that contents can be pushed to destination with unprecedented data rates. Obviously, the profitability of such high capacity is subject to a proper design of the gateways and the overall network infrastructure in order to cope with link outage and links instability, as further elaborated in the next section.

Particularly interesting is the possible adoption of the architecture options envisioned currently in 3GPP, though addressing exclusively RF-based systems, for the implementation of FSO-based future systems. As a matter of fact, there exist currently two main integration options between terrestrial and satellite systems, namely i) direct and ii) indirect access. In the first case, a user equipment (UE) can establish connectivity directly with the satellite, whereas in the second case, a relay node is placed in between. Moreover, satellite can be considered as operated in transparent or regenerative mode, with the latter particularly appealing for the case of LEO satellites (i.e., constellations). In the case of optical feeder link, two main satellite systems can be seen: 1) GEO HTS and 2) LEO HTS. In the first one, an indirect access can be considered so that a gNB is integrated in the satellite gateway or in any case implemented at the interface between the gateway and 5G core network. Under this configuration, therefore, the optical signal will be received by the satellite and then converted into an RF-based on for the downlink transmission to reach the final user through the relay node. In the second case, instead, it is reasonable to assume LEO constellations, with both feeder- and inter-satellite links building on FSO technology. Moreover, each satellite may implement a gNB in the case of a regenerative satellite payload. In such a way, the optical signal transmitted by a satellite gateway over the feeder link will be either switched by the receiving satellite to the neighbour satellites through ISLs or properly converted so that data can be dumped down from gNB to UEs by according to the 5G-NR technology. The second scenario is certainly particularly appealing because of the hype of LEO mega constellations, although implementing LEO optical feeder link introduces some complexity in order to make the link stable and reliable enough. In any case, independently of the specific reference architecture being taken as reference, emphasis has to be put on the integration of 5G and optical communication, as possible enabler of new services within 6G. As such, the next sections provide a high-level discussion of the main technical challenges and introduce a simple but meaningful setup to demonstrate the feasibility of such a concept.

Demonstration

Atmospheric turbulence is the main challenge for achieving a stable broadband space-to-ground connectivity with the required telecommunications availability. Scintillation

together with beam wander is responsible of the signal fading the uplink. Scintillation is signal fluctuations due to self-interference caused by phase distortions. Beam wander are pointing errors induced by the atmosphere. Beam-wander can be partially corrected by using the angle-of-arrival measurements of the downlink. The residual beam wander depends strongly on the separation between uplink and downlink introduced by the point-ahead angle (PAA). Whereas in GEO there is a certain correlation between up- and downlink, in LEO both atmospheric paths become uncorrelated.
An adaptive optics system can be used to correct the phase-distortions to achieve a stable fibre coupling in the downlink. Pre-distortion is being investigated to mitigate the uplink signal fluctuations.
In order to investigate the communication performance in turbulent relevant conditions, we developed a testbed between the DLR premises in Weilheim and the Weather forecast premises in Hohenpeißenberg [11]. This 10.5 km distance link is relevant to worst-case conditions in a ground-to-satellite scenario. The testbed includes two terminals, one emulating the satellite (see Figure 1) and one a ground station. The ground station terminal includes an adaptive optics system and both perform single-mode fibre coupling.

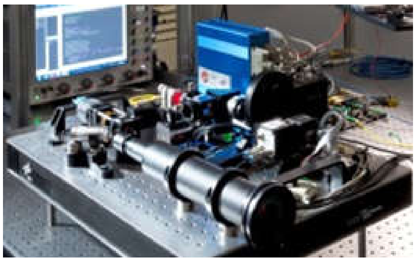

Figure 1. Optical terminal emulating the satellite

In Figure 2 there is a representation of the final setup. The 5G setup located at Arcisstrasse in the TUM premises will connect to the DLR OGS terminal via internet connection. The OGS and satellite terminals perform bidirectional optical communication. The command functions are sent via the emulated feeder-link, back to TUM.
Since the focus of the paper is to target the interaction of the satellite communications with the 5G terrestrial network, we test the optical communication with a 5G network based on OpenAirInterface [12] (Core and Radio Access Network) located at TUM. The 5G network of TUM is enhanced with a softwarized RAN controller [13][14] in order to provide flexibility and programmability as envisioned by 3GPP. In order to test a practical scenario, a mobile robot is connected to the 5G setup as an end user.

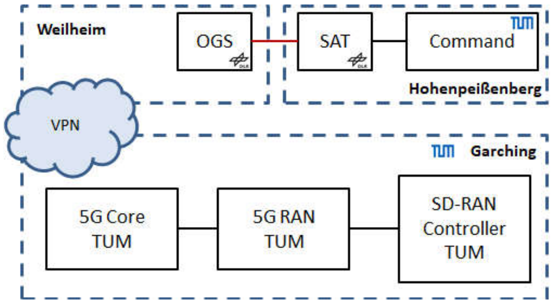

Figure 2. Measurement setup

The measurement campaign is planned at the end of October 2020. Current experiments are performed in the laboratory in preparation of the campaign. In the uplink direction, a computer is connected via Ethernet cable to a 10G Switch (NETGEAR XS508M). The switch features an SFP+ module port, from which a bidirectional optical connection is established towards the two testbeds. Each of the testbeds has one optical input and one optical output. The testbed then bridges to another SFP+ module, which is installed in another 10G switch. The switch is finally connected via Ethernet to the Internet. A block diagram of the setup is shown in below.

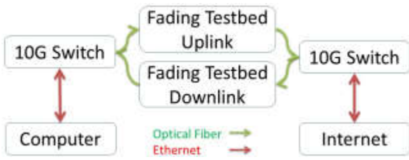

Figure 3. Laboratory setup block diagram

The purpose of the Fading Testbeds is to simulate the effects of the atmospheric turbulence on the optical communication. The testbeds therefore dynamically change the signal power. The testbeds are connected to the computer via USB and can be controlled using a dedicated software. This allows for activating or deactivating the fading effect of the Testbeds as well as to load various power vectors. For the test, power vectors measured using an uplink to terminal onboard the GEO satellite Artemis were used.
The setup showed a stable internet connection over a fading channel, even if with reduced performance, measuring aroung a 50% of packet loss when fading was activated.

Conclusions

Optical satellite communications are essential in acheiving global coverage of bradband internet access. We present the main challenges in the integration of B5G technologies in satellite systems based on optical communications. Preliminary experiments have been performed, preparing a demonstration where both technologies are integrated.

References

[1] Lutz, E., Towards the Terabit s satellite - interference issues in the user link *International Journal of Satellite Communications and Networking,* 2015

[2] Airbus,https://www.airbus.com/space/telecommunications-satellites/space-data-highway.html, 2020

[3] Airbus, ttps://www.airbus.com/newsroom/press-releases/en/2020/05/airbus-and-xenesis-sign-payload-contract-for-new-bartolomeo-platform-on-the-international-space-station.html, 2020

[4] Harald Hauschildt, Carlo Elia, Andrew Jones, Hermann Ludwig Moeller, Josep Maria Perdigues Armengol, "ESAs ScyLight Programme: activities and status of the high throughput optical network "HydRON"," Proc. SPIE 11180, International Conference on Space Optics — ICSO 2018, 111800G (12 July 2019); https://doi.org/10.1117/12.2535935

[5] Mata Calvo, R.; Poliak, J.; Surof, J.; Reeves, A.; Richerzhagen, M.; Kelemu, H. F.; Barrios, R.; Carrizo, C.; Wolf, R.; Rein, F.; Dochhan, A.; Saucke, K. & Luetke, W. Optical technologies for very high throughput satellite communications 2019, 10910

[6] T. de Cola, A. Perez-Neira, R. Channasandra and S. Covaci, "Guest Editorial, Integration of Satellite and 5G Networks," in IEEE Network, vol. 32, no. 5, pp. 6-8, September/October 2018.

[7] G. Giambene, S. Kota and P. Pillai, "Satellite-5G Integration: A Network Perspective," in IEEE Network, vol. 32, no. 5, pp. 25-31, September/October 2018.

[8] Guidotti et al., "Architectures and Key Technical Challenges for 5G Systems Incorporating Satellites," in IEEE Transactions on Vehicular Technology, vol. 68, no. 3, pp. 2624-2639, March 2019.

[9] O. Kodheli et al., "Satellite Communications in the New Space Era: A Survey and Future Challenges," in IEEE Communications Surveys & Tutorials.

[10] F. Rinaldi et al., "Non-Terrestrial Networks in 5G & Beyond: A Survey," in IEEE Access, vol. 8, pp. 165178-165200, 2020.

[11] Poliak, J.; Mata Calvo, R. & Rein, F. Demonstration of 1.72 Tbit-s optical data transmission under worst-case turbulence conditions for ground-to-geostationary satellite communications *IEEE Communications Letters,* 2018, 1-1

[12] Nikaein, Navid, et al. "OpenAirInterface: A flexible platform for 5G research." ACM SIGCOMM Computer Communication Review 44.5 (2014): 33-38.

[13] Foukas, Xenofon, et al. "FlexRAN: A flexible and programmable platform for software-defined radio access networks." Proceedings of the 12th International on Conference on emerging Networking EXperiments and Technologies. 2016.

[14] Papa, Arled, et al. "Controlling Next-Generation Software-Defined RANs." IEEE Communications Magazine 58.7 (2020): 58-64.