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DYNASAT

Dynamic spectrum sharing and bandwidth-efficient techniques for high-throughput MIMO Satellite systems

D3.2: Bandwidth Efficient Techniques design - Version 1

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Abstract

This document presents a first version of the bandwidth efficient techniques design. The focus is on the techniques with features that have little impact specifications to contribute to 3GPP Release 18, *i.e.*, techniques that do not rely on channel state information knowledge at the transmitter. The considered techniques are MU-MIMO precoding techniques and Multi-Connectivity. The limitations of the considered techniques, some of them borrowed from the terrestrial literature, are identified, together with the needed adaptation to the identified scenarios where terrestrial cells are covered by several satellites.

Keywords: satellite communications, multi-user MIMO, non-terrestrial networks, beamforming, multi-connectivity, 3GPP.

Document Revision History

Version	Date	Description of change	List of contributors
V0.1	20/06/2021	ToC	UNIPR
V0.2	15/11/2021	First edit	MAG, UNIBO, TAS, UNIPR
V0.3	03/12/2021	Second edit	MAG, UNIBO, TAS, UNIPR
V0.4	30/11/2021	Submission to SAB	UNIBO
V1.0	15/01/2022	Submission to EU	UNIBO, UNIPR
V2.0	30/05/2022	Based on the Y1 review, the ToC and Annex have been removed and only a summary Executive Summary is provided	UNIBO, UNIPR
V3.0	15/11/2022	Based on the intermediate review, the revision history clarifies the main changes	UNIBO, UNIPR

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Nature of the deliverable:	R	
Dissemination Level		
PU	Public, fully open, e.g., web	√
CI	Classified, information as referred to in Commission Decision 2001/844/EC	
CO	Confidential to DYNASAT project and Commission Services	

* *R: Document, report (excluding the periodic and final reports)*
DEM: Demonstrator, pilot, prototype, plan designs
DEC: Websites, patents filing, press & media actions, videos, etc.
OTHER: Software, technical diagram, etc

EXECUTIVE SUMMARY

Satellite systems are expected to play a crucial role in future wireless networks. The inclusion of the Non-Terrestrial Network (NTN) component in the 5G ecosystem, foreseen in Release 17 of the 3GPP specifications, will improve the system flexibility, adaptability, and resilience, and will extend the 5G coverage to rural, underserved, and unserved areas. Satellite communication (SatCom) systems are fundamental components in support of Europe's ambition to deploy smart and sustainable networks and services for the success of its digital economy. From a pure broadcast and broadband delivery instrument, SatComs are therefore becoming an essential ingredient to efficiently support the concept of wireless connectivity anywhere, anytime, and at any device.

To completely enable this new role of SatCom, several challenges need to be fully addressed by research and innovation activities in the next decades. One of the main challenges is the maximization of the spectrum usage and the study of more efficient ways to exploit the available bandwidth is of paramount importance. The DYNASAT project aims at investigating, developing, and demonstrating bandwidth efficient transmission techniques for an advanced LEO-megaconstellation based satellite access infrastructure providing 5G and Beyond 5G (B5G) services to handset devices in areas beyond cellular coverage.

In the context of SatCom, the interference is generally avoided by transmitting signals separated in the time and frequency domains. However, resource sharing is probably the only option to meet the increasing demand of data rate. According to the interference management and exploitation paradigm, interference is not avoided by design anymore, but a certain amount of interference is intentionally introduced and mitigated or exploited, both at the transmitter and the receiver sides, using specifically designed transceiver architectures. Resource sharing can be implemented by adopting a multibeam satellite architecture and considering an aggressive frequency reuse that allows to reuse the same bandwidth in different beams. For this scenario, several bandwidth-efficient techniques to be applied at the transmitter and/or at the receiver can be adopted, some of them taken from the literature on terrestrial networks.

In the DYNASAT project, the bandwidth efficient techniques to be considered have been divided in three main categories, *i.e.*, short, medium, and long-term techniques.

The short-term techniques are the ones with features that have little impact specifications to contribute to 3GPP Release 18, *i.e.*, techniques that do not rely on channel state information (CSI) knowledge at the transmitter. The techniques of interest for medium and long term are precoding techniques that rely on the knowledge of the CSI at the transmitter, and that can exploit the presence of two or more satellites. Massive MIMO techniques from terrestrial networks will be also extended to the megaconstellation scenario. The main issue to be solved in this case is the problem of obtaining channel state information at the transmitter in satellite frequency division duplex schemes.

This document describes the adaptation of the identified short-term techniques to DYNASAT scenarios. The focus is in on **Multi-Connectivity** and **MU-MIMO** techniques.

Multi-Connectivity

NR-NR Multi-Connectivity (MC) and Carrier Aggregation (CA) [1] are promising techniques that can improve the spectrum usage efficiency in the considered scenario and that do not require the knowledge of CSI at the transmitter are the asynchronous The Multi-Connectivity defined by 3GPP is considered in this document and its applicability to the DYNASAT scenarios is assessed. Multi-connectivity is defined by 3GPP as a mode of operation whereby a multiple RX/TX UE in the connected mode is configured to utilize radio resources provided by multiple distinct schedulers located in two different NG-RAN nodes connected via a non-ideal backhaul. Multi-connectivity enhances performance in terms of data rate and reliability of the connection, providing additional robustness. Moreover, it provides seamless mobility by eliminating handover interruption delays, avoids the need to synchronize gNBs, and allows non-co-located deployments. In this document, two cases are analyzed, one where the user has access to both

TN and NTN resources at the same time, the other where the user has access to two subsets of NTN resources, either two NTN 3GPP systems or two satellites managed by two distinct gNB. It is also investigated whether asynchronous multi-connectivity would be beneficial for NTN and whether some enhancements are needed. Naturally, MC is only possible under the condition that the geographic locations of UE and Radio environments allow them to reach more than one of the network infrastructure access points. The numerical assessment of these techniques is reported in the companion deliverable D3.4.

MU-MIMO precoding

For the design of MU-MIMO techniques, the document provides: i) a detailed and exhaustive mathematical framework for the application of precoding in both the beam and feed spaces; ii) the design of a new short-term technique (SS-MMSE) and that of a long-term technique (LB-MMSE) for precoding; iii) the detailed description and design of proper normalisation solutions to take into account the maximum power per satellite; iv) the description of system-level procedures that allow the implementation of the short-term techniques; and v) a detailed vision of the foreseen signalling, synchronisation, and measurement aspects that are needed to implement the short-term techniques. The Multi-Beam algorithm proposed in [2], which does not rely on CSI at the transmitter but only requires the knowledge of the users' positions, is extended to the scenario with one or two LEO satellites in visibility and with typical 3GPP waveforms. The numerical assessment of these techniques is reported in the companion deliverable D3.4.

The document contains no body as it has been redacted according to the indications of the external Security Advisory Board of Dynasat.

ABBREVIATIONS

3GPP	3rd Generation Partnership Project
B5G	Beyond 5G
CA	Carrier Aggregation
CSI	Channel State Information
LB-MMSE	Location-Based Minimum Mean Square Error
LEO	Low Earth Orbit
MB	Multi-Beam
MC	Multi connectivity
MIMO	Multiple Input Multiple Output
MMSE	Minimun Mean Square Error
MU	Multi User
NR	New Radio
NTN	Non-Terrestrial Network
RAN	Radio Access Network
SatCom	Satellite Communication systems
SS-MMSE	Spatially Sampled Minimum Mean Square Error
UE	User Equipment
UL	Uplink
WP	Work Package

REFERENCES

[1] 3GPP RP-191600, “Multi-RAT dual-connectivity and carrier aggregation enhancements.”

[2] P. Angeletti, R. De Gaudenzi, "A Pragmatic Approach to Massive MIMO for Broadband Communication Satellites," IEEE Access, vol. 8, 2020.