ESA STUDY CONTRACT REPORT

No ESA Study Contract Report will be accepted unless this sheet is inserted at the beginning of each volume of the Report.

ESA Contract No:	SUBJECT:	CONTRACTOR:
400013171/22/NL/AF	5G-EMERGE Satellite-enhanced edge delivery (Executive Summary)	EBU – European Broadcasting Union

* ESA CR( )No:	No. of Volumes:1 This is Volume No:1	CONTRACTOR'S REFERENCE: 5GEMG-FR-9547-Iss03-Rev00

ABSTRACT:

This document presents the Final Report of ESA project "5G-EMERGE – 5G Satellite media delivery micro edge", one of the projects under the ARTES Strategic Programme Line 5G/6G.

The aim of 5G-EMERGE project is to develop an integrated satellite and terrestrial system optimized for efficient and cost-effective media distribution. The project uses 5G technologies to achieve technological convergence between satellite communication and online delivery mechanisms.

This report presents the key aspects of 5G-EMERGE ecosystem, the potential target markets, value proposition and market viability as well as validation of 5G-EMERGE service market requirements.

The work described in this report was done under ESA Contract. Responsibility for the contents resides in the author or organization that prepared it.

Names of authors: European Broadcasting Union (EBU)

** NAME OF ESA STUDY MANAGER:	** ESA BUDGET HEADING:
DIV: DIRECTORATE:	

* Sections to be completed by ESA

** Information to be provided by ESA Study Manager

5G-EMERGE

Satellite enhanced
edge delivery

WP 5: Dissemination & Planning Phase 2

WP 5.3: 5G-EMERGE Final Report

ESA Contract No. 4000138171/22/NL/AF

Ref.: 5GEMG-FR-9547

Title:

5G-EMERGE Final Report

Project:

5G-EMERGE

ESA Contract No. 4000138171/22/NL/AF

Issue_revision:	Iss03_Rev00
Date of issue:	28.11.2024
No. of pages:	63
Class:	Public
Internal ref.	5GEMG-FR-9547-Iss03-Rev00

Prepared by	5G-EMERGE Consortium
Revised by	5G-EMERGE Consortium
Approved by	5G-EMERGE Consortium
Authorized by	5G-EMERGE Consortium

Change Record

Issue and Revision number	Sections affected by the changes	Change reason
Issue_Revision: 01_00 Date: 10.06.2024 Pages: 36	All	First issue
Issue_Revision: 02_00 Date: 16.09.2024 Pages: 61	Sections 3.2, 3.3 and 4.3, new section 5, previous section 6	Update for Delta MS4
Issue_Revision: 03_00 Date: 28.11.2024 Pages: 63	Sections 2.2.2, 3.2, 3.3.1.3.1, 3.3.1.3.2, 3.3.1.3.3, 3.3.2.1.1, 3.3.2.2.1, 5 and 6.	Final version

EXECUTIVE SUMMARY

The 5G-EMERGE project aims to develop an integrated satellite and terrestrial system optimized for efficient and cost-effective media distribution. The key aspects are:

Hybrid Network Ecosystem
5G-EMERGE is a hybrid network ecosystem that seamlessly combines satellite networks with 5G and other terrestrial networks. It leverages the strengths of each technology:

- Satellites efficiently distribute popular content over a wide area
- 5G provides mobility and last-mile connectivity
- Terrestrial networks offer broadband access

Distributed Edge Delivery
The system is designed to deliver content as close as possible to end-users through distributed "edges" like:

- Home gateways
- 5G base stations
- Vehicle gateways

These smart satellite gateways at the edges can cache popular content and stream it locally to user devices like smartphones, tablets, and TVs.

Open Standards and Native IP
5G-EMERGE uses open standards and a native IP infrastructure to enable interoperability across different networks and providers. This allows seamless content delivery to users regardless of the underlying delivery channel.

Improved User Experience
By bringing content closer to users and avoiding network bottlenecks, 5G-EMERGE aims to provide a superior media playout experience. It enables high-quality streaming of live events, on-demand content, software updates, and more across various use cases like homes, vehicles, and mobile networks.

The 5G EMERGE consortium was able to successfully prove a solid problem-solution fit through prototyping, a series of demonstrators and testbeds that have been addressing the various media related use cases. The consortium has also undertaken substantial work to identify and study the potential target markets, defining a value proposition and market viability, and validate that a 5G-EMERGE service can meet the market requirements that the players represented in the consortium have identified.

Phase 2

Finally, in Phase 1 a vision and planning for Phase 2 was developed on basis of the first year's findings of the project. In this follow up new functionalities, covering Online Video Platform edge developments, business continuity work package, security improvements and multiple 5G-integration deployments. Multiple testbeds are set up for the DTH, DTV and DTE use case with specific development for these deployment areas and integration of the new functionalities. Aside of integration with existing satellite networks Phase 2 starts investigating ground services that can integrate with the near future NR-NTN satellite networks.

In summary, 5G-EMERGE represents a convergence of satellite and terrestrial networks using 5G technologies to create an efficient, scalable, and ubiquitous media distribution ecosystem. Yet, it is a strong solution-market fit that will determine the long-term success and viability of a 5G-EMERGE service.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

3GPP	3rd Generation Partnership Project
5GgNB	5G Next Generation Node B/Base station
5GNoD	5G Network on-Demand
5QI	5G QoS Identifier
ACU	Antenna Control Unit
AI	Artificial Intelligence
API	Application Programming Interface
APN	Access Point Name
ARP	Address Resolution Protocol
A/V	Audio/Visual
B2B	Business to Business
BUC	Block Up Converter
CAPEX	Capital Expenditures
CAGR	Compound Annual Growth Rate
CDN	Content Delivery Network
COE	Container Orchestration Engine
COTS	Commercial Off-The-Shelf
CP	Content Provider
CPU	Central Processing Unit
CTE	Critical Technical Element
DANE	DNS-based Authentication of Named Entities
DASH	Dynamic Adaptive Streaming over HTTP
DDoS	Distributed Denial of Service
DNS	Domain Name System
DRM	Digital Rights Management
DTE	Direct-To-Edge
DTH	Direct-To-Home
DTV	Direct-To-Vehicle
DVB-NIP	Digital Video Broadcasting – Native IP
DVB-S2X	Digital video Broadcasting – Second Generation Satellite Extension
DWH	Dataware House
EIRP	Equivalent Isotropic Radiated Power
EMI	Electromagnetic Interference

ETSI	European Telecommunication Standard Institute
F-SIM	Fixed Interactive Multimedia Service
FL	Forward Link
FLUTE	File Delivery over Unidirectional Transport
Gbps	Giga bits per second
GDPR	General Data Protection Regulation
GEO	Geostationary Earth Orbit
GPS	Global Positioning System
GSE	Generic Stream Encapsulation
GSE-HEM	Generic Stream Encapsulation-High Efficiency Mode
G/T	Gain/Temperature
GW	Gateway
HLS	HTTP Live Streaming
HTTP	Hypertext Transfer Protocol
H/V	Horizontal/Vertical
HW	Hardware
IDU	Indoor Unit
ICT	Information and Communication Technologies
IF	Intermediate Frequency
iOS	iPhone Operating System
IoT	Internet of Things
IP	Internet Protocol
ISP	Internet Service Provider
KPI	Key Performance Indicator
LADN	Local Area Data Network
LAN	Local Area Network
LEO	Low Earth Orbit
LNA	Low Noise Amplifier
LNB	Low Noise
mABR	multicast Adaptive Bit Rate
Mbps	Mega bits per second
MBS	Multicast Broadcast Services
MCC	Mobile Country Code
mDNS	multicast Domain Name System
MEC	Multi-access Edge Computing
MEO	Medium Earth Orbit

MiFi	Mobile WiFi
MPEG	Moving Picture Experts Group
MVP	Minimum Viable Product
NAS	Non-Access Stratum
NFVO	Network Function Virtualisation Orchestrator
NMS	Network Management System
NPN	Non-Public Network
NR	New Radio
NTN	Non-Terrestrial Network
ODU	Outdoor Unit
OPEX	Operating Expenses
OS	Operating system
OTT	Over-The-Top
PAAS	Platform as a Service
PC	Personal Computer
PLMN	Public Land Mobile Network
PoP	Point of Presence
PN	Public Network
QoE	Quality of Experience
QoS	Quality of Service
RAM	Random Access Memory
RAN	Radio Access Network
RLE	Return Link Encapsulation
RF	Radio Frequency
RH/LH	Right Horizontal/Left Horizontal
RL	Return Link
Rx	Receiver
SAAS	Software as a Service
SAND	Software Applications Networking and Development
SATCOM	Satellite Communication
SD	Slice Differentiator
SF	System Functionality
SIM	Subscriber Identity Module
SOTA	State Of The Art
ST	Satellite Terminal
SW	Software

TN	Technical Note
TRL	Technology Readiness Level
TS	Technical Specification
TVRO	Television receive-only
Tx	Transmitter
UE	User Equipment
UPF	User Plane Function
VLC	Video LAN Client
VM	Virtual Machine
VOD	Video on Demand
VNF	Virtual Network Functions
VPN	Virtual Private Network
VSAT	Very Small Aperture Terminal
WAN	Wide Area Network
WebDAV	Web-based Distributed Authoring and Versioning
WIFI	Wireless Fidelity
WLAN	Wireless Local Area Network
WP	Work Package

LIST OF DELIVERABLES

RD#	Applicable and Reference documents delivered by the 5G-EMERGE project in Phase 1 (Date/Reference)
RD1	**TN1.1 - System specification - Commercial requirements** (02.03.2023/5GEMG-TNO-4796-Iss02-Rev00) *This document provides an overview and definition of relevant requirements that enable or improve commercial viability of the 5G-EMERGE ecosystem, detailed with respect to the system as a whole and from the perspective of essential elements in the supply chain. The document is intended to cover the definition of the current and foreseen deployment scenarios, a collection of commercially relevant 5G use cases and their classification based on business relevance.*
RD2	**TN1.2 - System Spec – Service/Operational requirements and System architecture** (02.03.2023/5GEMG-TNO-4740-Iss02-Rev00) *This document defines the key requirements to be matched, in terms of services and operational aspects, to enable the deployment of the defined use-cases and applications and the design of a high-level integrated system architecture to fulfil those requirements.*
RD3	**TN 1.3 - System specification – Hardware/Software requirements & Technology scan** (02.03.2023/5GEMG-TNO-4818-Iss02-Rev00) *This document identifies the hardware/software (HW/SW) requirements/specifications necessary for the elements forming the different 5G-EMERGE use-cases defined in [RD1]. It also does a preliminary analysis of each component with a review of literature and technology scan relevant to the state of the art (SOTA) for the required components.*
RD4	**TN1.4 - KPIs to select Tech stack and Satcom methods** (02.03.2023/5GEMG-TNO-4880-Iss02-Rev00) *This document concludes and summarizes achievements of WP1 activities by drilling down on specific 5G-EMERGE system functionalities taking into account requirements defined in the previous TNs. In particular, TN1.4 aims to define the KPIs suitable for the selection of the technology stacks and Satcom methods, and then for the evaluation of the overall system and its sub-components deployed in the testbeds.*
RD5	**RTD – Requirements & Traceability Document** (02.03.2023/ 5GEMG-RTD-4724-Iss02-Rev00) *This document provides a collection of requirements and technical specifications for the 5G-EMERGE project, in accordance with ESA's requirements classification. Furthermore, the document provides an easy way to map the requirements to the three main Use-Cases/scenarios.*
RD6	**MVP – Minimum Viable Products** (02.03.2023/5GEMG-MVP-4801-Iss01-Rev00) *A Minimal Viable Product is a product (i.e., service, system, software, but also hardware) with enough features to satisfy targeted market scenarios. The scope of this document is to provide a description of the Minimum Viable Products (MVPs); which will effectively represent the tangible outcomes of the 5G-EMERGE project.*
RD7	**CTE – Critical Technical Elements** (09.10.2024/5GEMG-TNO-5271-Iss01-Rev05) *This document aims to capture and trace the project critical technologies. In ESA terms the new technology may be a Critical Technology Element (CTE), such as a system, subsystem, or component comprised of hardware and/or software.*

RD8	**SA and ICD - System Architecture and Interface Control Document** (12.02.2024/5GEMG-SA and ICD-5467-Iss01-Rev2) *This document presents the overall architecture (functional/physical), covering system, service and component levels, accompanied by a comprehensive description, and all interface control information.*
RD9	**DDD - Detailed Design Document** (09.10.2023/ 5GEMG-DDD-5667-Iss01-Rev1) *This document presents the detailed designs of the product, components and features which are already existing or will be developed in the 5G-EMERGE project, as well as defines all the development and integration activities which are necessary to support the identified Use Cases.*
R10	**DDVP - Design, Development and Validation Plan** (11.06.2024/5GEMG-DDVP-8473-Iss04-Rev00) *This document defines processes and procedures to design, develop and validate the three demonstrators, and to meet the objectives of the development that have been set in the 5G-EMERGE proposal.*
RD11	**TN2.1 - Technology Selection** (16.10.2023/5GEMG-TN2.1-5360-Iss01-Rev1) *This document selects the SW/HW products needed to implement and setup the baseline services, linked to the MVP, addressed by the 5G-EMERGE use-cases. The target is to draw the technological context for the realization of the demonstrators that will be used in the experimentation and development of testbeds.*
RD12	**TN2.2 – System Architecture Finalization** (12.10.2023/5GEMG-TN2.2-5470-Iss01-Rev1) *This document presents the overall architecture (functional/physical) of the 5G-EMERGE, covering system, service and component levels, accompanied by a comprehensive description. This deliverable provides the foundation for the System Architecture and Interface Control Document [RD8].*
RD13	**TN2.3 – Development Requirements** (23.02.2024/5GEMG-TN2.3-6352-Iss01-Rev00) *This document elaborates on the options and accounts for the definition of the development and validation processes which will then be defined in the Design, Development and Validation Plan (DDVP) and the Test Plan, Procedures and Report (TPPR).*
RD14	**TN3.1 - Industrialisation strategy - Value creation and value chain impact assessment** (11.10.2023/5GEMG-TN3.1-5866-Iss01-Rev2) *This document provides an assessment of demand for 5G-EMERGE services from the different vertical markets defined in TN1.1, based on desk research and interviews with potential customers and end users in the different vertical markets.*
RD15	**TN3.2 - Industrialisation strategy - Targeted industry segment assessment – Business case** (23.02.2024/ 5GEMG-TN 3.2-6597-Iss01-Rev00) *This document describes the architecture of the business case and how it can be used in the context of the 5G-Emerge business plan. It provides an example of a business case. The underlying assumptions and the methodology have been incorporated in an Excel tool (available in* [231115_TN3.2_Final ADL Business Case - v5.xlsx]*). The Excel tool can used for in-dept analysis and optimisation of the business case taking into account specific market conditions, input assumptions and business objectives.*
RD16	**TN3.3 - Industrialisation strategy - Launch strategy and suggested KPIs** (11.06.2024/5GEMG-TN3.3-8468-Iss01-Rev03)

	This document provides a launch strategy for a 5G-EMERGE service and offer KPIs that will ensure its commercial viability and help measuring its success. It draws on the findings documented in the deliverables [RD14] and [RD15] and can be used to prioritise follow up actions for Phase 2.
RD17	**SEP - Industrialization Strategy - Services Exploitation Plan (SEP)** (11.06.2024/5GEMG-SEP-8469-Iss01-Rev03) *This document presents an overview of the results of the work towards industrialisation of the 5G-EMERGE system in Phase 1. These results are used by the consortium partners in their own commercial approaches and market strategies.*
RD18	**TN 4.1 – Sprints to develop the Content provisioning layer** (21.02.2024/5GEMG-TNO-6593-Iss01-Rev00) *This document provides a report on the execution of the development work in WP4.1 Content Provisioning sub-work package.*
RD19	**TN 4.2 – Sprints to develop the Uplink edge layer** 21.02.2024/5GEMG-TNO-6558-Iss01-Rev00) *This document collects the meeting notes/agenda that were conducted in Q4 2023 related to the tests of all components in the Cloud Uplink Preparation Function (SF2) to ensure they work.*
RD20	**TN 4.3 – Sprints to develop the Satcom layer** (23.02.2024/ 5GEMG-TN 4.3-5645-Iss02-Rev00) *This document presents the architecture of the deployments tested during the project for the scenario of Direct to Home and for the scenario related to terrestrial and maritime Direct to Vehicle use cases, considering the use of forward and return links.*
RD21	**TN 4.4 - Sprints to develop SF4 Micro-Edge-Device layer** (23.09.2024/5GEMG-TN4.4-6588-Iss01-Rev00) *This document provides a report on the work done for the development and integration of the "Far Edge" System Function (SF4) of the 5G-EMERGE ecosystem.*
RD22	**TN 4.5 - Sprints to develop the Service Provisioning layer** (10.06.2024/5GEMG-TN4.5-8461-Iss02-Rev00) *This document provides a report on the work done for the development and integration of the "Service Provisioning" System Function (SF5) of the 5G-EMERGE ecosystem.* **TN 4.5 – Threats Assessment** (04.09.2024/5GEMG-TN4.5-8462-Iss01-Rev02) *This document provides an overview of cybersecurity threats and risks associated with the 5G-EMERGE project. The document includes a list of applicable and reference documents, acronyms, organizations providing threat identification, potential threat actors, 5G-EMERGE actors and assets, common industry standard threats, most common mitigations, and sub-function security requirements for SF1, SF4, and SF5.*
RD23	**TN 4.6 - Sprints to deploy & validate Direct-to-Vehicle use-case** (30.08.2024/5GEMG-TN4.6-6592-Iss03-Rev00) This document provides a report on the execution of the development work conducted in order to deploy and validate the 5G-EMERGE architecture in the direct-to-vehicle (DTV) scenario.
RD24	**TN 4.7 - Sprints to deploy & validate Direct to Home use case** (10.06.2024/5GEMG-TN4.7-8471-Iss02-Rev00) *This document provides a report on the execution of the development work conducted in order to deploy and validate the 5G-EMERGE architecture in the direct-to-home (DTH) scenario.*
RD25	**TN 4.8 - Sprints to deploy & validate Direct to Edge use case**

	(10.06.2024/5GEMG-TN4.8-8472-Iss02-Rev00) *This document provides a report on the execution of the development work conducted in order to deploy and validate the 5G-EMERGE architecture in the direct-to-edge (DTE) scenario.*
RD26	**TPPR - Test Plan, Procedures and Report** (04.10.2024/5GEMG-TPPR-9632-Iss03-Rev00) *This document is, alongside with the Design, Development and Verification Plan (DDVP) one of the main deliverables of the WP4: the development and validation of the demonstrators of the Phase 1 of the 5G-EMERGE project. It defines a test plan, and testing procedures to validate the three demonstrators. It also reports on the tests performed in Phase 1 and elaborates on the results.*
RD27	**TN 5.1 – White Paper '5G-EMERGE – Satellite enhanced edge delivery'** (10.06.2024/5GEMG-TN5.1-8358-Issue2_Rev00) *(also available in the web site:* https://www.5g-emerge.com/_files/ugd/9c7e17_4b231a35ceb34275a727f3459bf77873.pdf *This document has been prepared under the work of WP5.1 'Industrialisation segment deployment planning and strategy'. The goal is to be the first step in the dissemination process to the industry. It provides a high-level description of the 5G EMERGE solution for the delivery of media, the use cases addressed, the architecture and the values in terms of technical innovation, business developments and sustainability.*
RD28	**TN 5.2 - Outline proposal for Phase 2** (10.06.2024/5GEMG-P2OP-6647-Issue1_Rev00) *This document provides an overview of the proposal made to ESA for the Phase 2 of the 5G-EMERGE project.*
RD29	**TN 5.3 - 5G-EMERGE Whitepaper and Dissemination Report (WDR)** (28.11.2024/5GEMG-TN 5.3-9577-Iss03-Rev00) *This document summarises all the dissemination activities undertaken in Phase 1 to promote the goals and findings of the 5G-EMERGE project.*
RD30	**TN 5.3 - 5G-EMERGE Final Report (FREP) + Executive Summary (ES)** (28.11.2024/5GEMG-FR-9547-Iss03-Rev00) *This document provides an overview of the main findings and results of Phase 1 of the 5G-EMERGE project. They are aggregated in this report from the different document deliverables prepared during the project for ESA (see list of applicable and reference documents) which provide more detailed descriptions.*
RD31	**TN 6.1 - Detailed design of the Nomadic terminal** (20.02.2024/5GEMG-TNO-6.1-Iss01-Rev00) *This document provides a comprehensive overview of the detailed design process for a GEO-earth nomadic terminal, intended for satellite communication within the Ku-band frequency range. Utilizing innovative miniaturized metamaterial technologies, the terminal promises exceptional compactness and efficiency in RF front-end solutions.*
RD32	**WP6.2 - Implementation and modular test of the array feed System** **WP6.3 - Implementation and test of the integrated terminal** (20.06.2024/ 5GEMG-TNO-6.1-Iss01-Rev00) *This document provides a comprehensive overview of the modular evaluations and fabrication processes for MinWave's nomadic terminal, designed for satellite communication within the Ku-band frequency range. This document captures the progress and milestones achieved to date, providing a clear snapshot of the MinWave project's status within the 5G-Emerge initiative.*

LIST OF COMPANIES IN THE 5G-EMERGE CONSORTIUM

Companies in 5G-EMERGE CONSORTIUM, Phase 1		**Country**
1	Arctic Space Technologies AB	Sweden
2	Arthur D. Little	Norway
3	Brightcove	UK
4	Broadcast Critical	UK
5	Celestia Innovation	Netherlands
6	European Broadcasting Union (EBU)	Switzerland
7	European Space Agency (ESA)	France
8	Eutelsat Group	France
9	Hewlett Packard Enterprise (HPE)	Italy
10	Gcore	Luxembourg
11	Inverto (FTA)	Luxembourg
12	Fondazione LINKS	Italy
13	MBI s.r.l.	Italy
14	Nagravision AS	Norway
15	Nagravision Sàrl	Switzerland
16	Rai – Radiotelevisione Italiana S.p.A.	Italy
17	RomARS	Italy
18	SES Techcom	Luxembourg
19	SixSq	Switzerland
20	Telenor ASA	Norway
21	Telenor Maritime AS	Norway
22	Telenor Satellite	Norway
23	TNO	Netherlands
24	Varnish Software	Sweden
25	Viasat	Switzerland

1 Introduction

1.1 Scope of this Document

This final report of 5G-EMERGE provides an overview of the main findings and results of Phase 1 of the project. They are aggregated in this report from the different document deliverables prepared during the project for ESA (see table with the list of applicable and reference documents) which provide more detailed descriptions.

This report is intended for ESA internal promotion of the 5G-EMERGE Project.

1.2 Structure of this Document

Following the introductory Section 1 with the Scope of this document, Section 2 explains what the 5G-EMERGE project is, why it is important compared to existing systems and describes the use-cases addressed by the project.

Section 3 describes the technical developments and achievements of Phase 1 proposing the system architecture to satisfy the different use-cases. The test beds deployed by different stakeholders are also included explaining the major results of tests in each of them. Section 3 also discusses additional developments undertaken by some consortium members to address particular satellite receive antenna requirements to satisfy certain use-cases.

Section 4 summarises the 5G-EMERGE market offering and value proposition per segment with related market KPIs and on the other hand a proposed partnering strategy and commercial roadmap. It also provides a description of the dissemination activities undertaken to promote the goals and findings of the project.

Section 5 summarises the major outcomes of Phase 1 and recommendations for further work in Phase 2.

Section 6 provides an overview of the roadmap to deploy Phase 2 of the 5G-EMERGE Project.

Section 7 provides the conclusion.

2 The 5G-EMERGE's Project

5G-EMERGE is an ESA ARTES programme co-funded R&D effort involving 25 companies from 8 different ESA-member countries. It is designed to improve the efficiency of existing 5G and broadcast networks in delivering media services to consumers. This is achieved by combining both networks approaches and intelligent edge-caching.

Partnering companies have developed a set of commercial requirements, evolved from a set of use-cases. Once a core system was specified, they set about building a set of demonstrators and proofs-of-concept to validate the technical specification decisions made.

The 5G-EMERGE consortium has planned to develop the software and hardware components of the 5G-EMERGE ecosystem over two phases spanning four years.

In Phase 1 (Q1 2022 to Q4 2024):

- The project started with a system specification activity to gather commercial, service, and operational requirements from all stakeholders. This involved a technology scan to identify relevant solutions and specifications.
- In parallel, the project began agile development cycles to test and integrate existing solutions as modules in the ecosystem.

- A third parallel activity assessed the value creation and impact on the industry value chain, leading to a targeted industry segment assessment.
- The results of these three activities validated the system definition, including selecting the technologies to be used and the system architecture, as well as specifying the hardware (e.g. antennas) to be built in Phase 2.
- The system definition continued in parallel with the agile software development cycles, with requirements continuously updated to align with the development sprints.
- The agile development cycles have produced demonstrators for contribution mechanisms, satellite distribution/reception solutions, service provisioning layer, a testbed, and an end-user content service.
- In a second set of sprints, the developed modules have been integrated and validated end-to-end for the 'Direct to Vehicle', 'Direct to Home', and 'Direct to Edge' use cases, using hacked existing hardware.
- By the end of Phase 1, the software stack has reached TRL 6 for the baseline functionalities that demonstrate the operation of the ecosystem while there are still optimisations possible and new functionalities can be developed, while the hardware specifications are at TRL 3.

Phase 2 (Q4 2024 to Q4 2026) will focus on optimizing the ecosystem for specific industry verticals.

2.1 The Value proposition of 5G-EMERGE

Two distinct families of technologies have been developed for the distribution of media content and services: digital broadcasting over dedicated networks and streaming over the Internet. Broadcast networks, in particular satellite, are designed to deliver linear services over entire territories, irrespective of the size of audience (especially important for popular live events) but do not support on-demand services. Online streaming technologies enable both linear and on-demand services but may not scale well for large concurrent audiences. Currently there is no interoperability between them. Furthermore, terrestrial and satellite broadcast networks at present do not support IP transport and their penetration varies considerably between countries.

The current audience trends are characterised by a gradual decline of linear viewing and listening, and the rise of on-demand, personalised media consumption across a range of different devices and scenarios: TV sets, smartphones, tablets, PCs, and in cars. These trends are likely to continue in the coming years.

While smart TV sets and some custom-built set top boxes have the capability to receive both broadcast and streaming services, there is generally poor integration between the experiences. Personal devices such as smartphones, tablets and PCs can only receive streamed content over the Internet.

For broadcasters this means that no single distribution network can reach all user devices or meet all commercial and regulatory requirements. This has led most broadcasters to adopt a dual-platform distribution strategy: broadcast for linear services and streaming for on-demand and a smaller portion of linear services. Competitive pressure may force them to continue distributing their content and services over multiple networks. However, this approach results in ever increasing complexity and costs, and the need to keep up with technological developments. For many broadcasters this is a significant challenge. Furthermore, public service broadcasters have, as part of their remit, an obligation to provide services to the entire population, especially in times of crisis. To be able to fulfil this requirement they need resilient network infrastructure which will not be compromised by natural or man-made disasters.

Other stakeholders are confronted with their own set of challenges. Terrestrial network infrastructure is developing where this is commercially viable. Remote and rural areas are often dependent on public subsidies and remine underserved.

Satellite operators seek to leverage the advanced satellite technologies, but this requires a corresponding user equipment which is challenging in the direct-to-home use cases.

CDN operators continue to increase the capacity and capabilities of their networks. However, the challenge is often to ensure sufficient capacity at interconnection points with telecom networks. Furthermore, the growing media traffic requires the caching capabilities to be multiplied and placed closer to the users. If only terrestrial infrastructure is used, this leads to increased costs of delivering content to the caches and there is a risk that the efficiencies achieved by densifying the network of caches are impeded by prohibitive costs.

Smart edge functionalities enable innovative media services to be developed but these services can only be offered to the users if there is a cost-efficient way of delivering content to the edges at user premises or as close to the users as possible, e.g. at a network node. Using only terrestrial networks may not be adequate for that purpose.

Broadcast and broadband infrastructure are to a large degree complementary. Neither can entirely substitute the other. The same is true for satellite vs terrestrial infrastructure. To date, however, there has been no substantial effort to use them in a collaborative way. This is what 5G-EMERGE aims to achieve.

As noted in [RD16], the key elements of the 5G-EMERGE value proposition are:

- **Full IP Multilayer Approach**: The system introduces a novel concept of a full IP multilayer approach. This means that native IP satellite broadcasting is seamlessly interconnected across various edges, ranging from traditional DTH (Direct-to-Home) setups to network edges, vehicular applications, collective reception, and more. This approach allows for efficient content distribution across diverse environments and user scenarios using the same hybrid infrastructure.

- **Satellite Live IP multicasting to the edge**: The focus is on satellite edgecasting, which combines live IP broadcasting with multicast push delivery to intelligent edges. This enables the efficient distribution of high-capacity broadcast/multicast traffic directly to the edge, offering a wide coverage area ranging from small regions to entire continents. This can also **reduce terrestrial CDN costs** when delivering live events to large audiences.

- **Extended edge services**: The role of the edge server in the 5G-EMERGE network is not only to store content as close as possible to a requesting client device, thereby reducing latency and improving page load. The edge with sufficient processing power can host multiple applications that perform different tasks. For media applications this may include for example personalisation, dynamic ad insertion or even, in the more high-end devices, transcoding capabilities. But also outside the media application a network of edges functions as a virtualised cloud stack. This allows cloud deployment models as SAAS and PAAS.

- **Advanced Satellite Technology**: The value proposition leverages the capabilities of new-generation satellites that support gigabits-per-second (Gbps) broadcast/multicast traffic. These satellites are designed to enable direct delivery of IP streams to edges, contributing to improved efficiency and reduced latency in content distribution.

- **Integration with 5G technologies and NTNs**: Integration of satellite-enhanced edges in 5G-networks open multiple additional possibilities. Secure VPN services to distributed locations that share an IT back-end is one of the most promising business use cases in 5G. Satellite connection provides extra security, quality of service, resilience and reach. The satellite itself can be the 5G-RAN network moving the edge to the teleport. This allows further efficiencies in the direct-to-device communication.

- **Compact and Smart Terminals**: The development of compact and intelligent terminals is a central element of the value proposition. These terminals are designed to be compact in size, energy-efficient, and capable of self-pointing and receiving IP streams. This flexibility allows for a wide range of applications, from DTH with terminals as small as a laptop to slightly larger terminals at network edges and even terminals for mobile applications on vehicles or boats.

- **Improved resilience:** The advantage of a multi-layer IP infrastructure that combines native IP satellite broadcasting with online delivery for **business continuity management** lies in its exceptional resilience and redundancy. This hybrid approach ensures that, on a daily basis, resilience and quality of service are improved while costs of terrestrial CDNs are reduced. The same hybrid infrastructure ensures that during unforeseen crises, even when terrestrial networks are disrupted, content delivery remains robust and uninterrupted. Native IP satellite broadcasting offers wide-area coverage, delivering essential content to any edge (from DTH to buildings, vehicles, and network edges), while online delivery provides a base layer of distribution through existing internet infrastructure. This synergy guarantees continuous access to critical information and services, allowing media companies to fulfill their remit of providing essential content to citizens regardless of the challenges that may arise while having an economically sustainable solution.

The value proposition also takes advantage of the enhanced performance of future broadcasting satellites, including increased and flexible EIRP (Equivalent Isotropic Radiated Power) and G/T (Gain/Temperature) performance. This contributes to improved signal quality and wider coverage, enhancing the overall user QoE.

Overall, the 5G-EMERGE value proposition offers a holistic solution that addresses the challenges of efficient and widespread content distribution in the context of IP-based satellite broadcasting. By integrating advanced satellite technology, multicast capabilities, and intelligent edge terminals, the system aims to revolutionize how content is delivered, received, and consumed on a continental and global basis.

Technically, 5G-EMERGE enables several different use cases in the media sector outlined below and, potentially, in other sectors. This analysis focuses on the media distribution use cases, noting the possibility for the 5G-EMERGE solution to be applied in the broader context.

2.2 Use-Cases

5G-EMERGE identifies in [RD1] three different categories of use-cases, Direct-to-Home, Direct-to-Edge and Direct-to-Vehicle as shown in Figure 1. For each use-case category, test beds and demonstrators have been developed. In total there are five test beds in Norway, Sweden, Luxembourg, Italy and Switzerland. These test beds are used to validate the requirements from a functional and operational perspective.

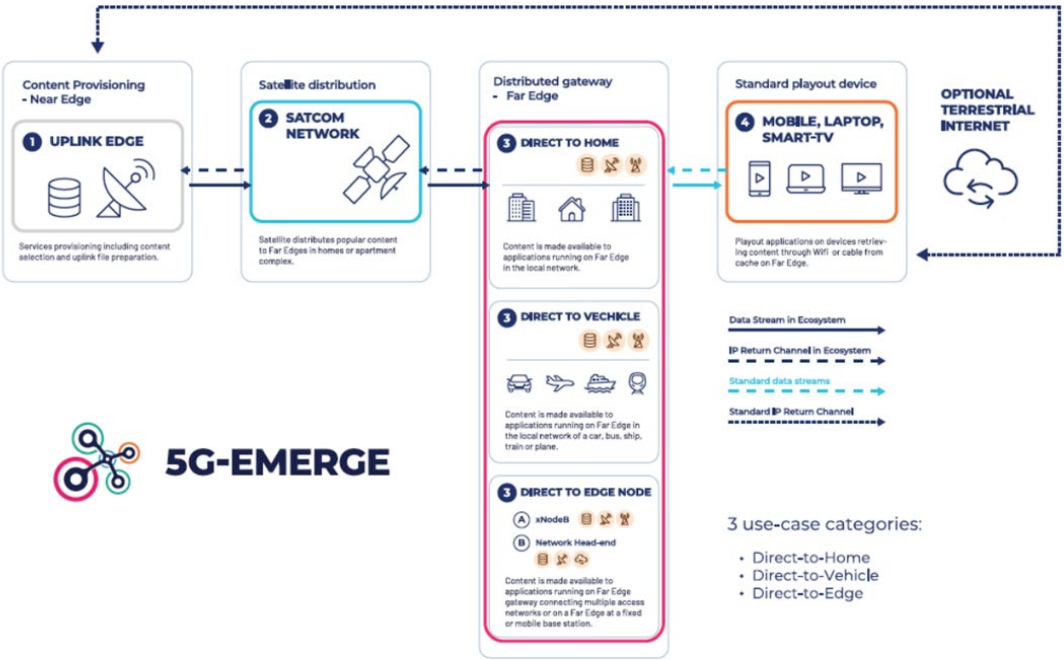

Figure 1: 5G-EMERGE use-cases.

2.2.1 Direct-to-Home (DTH)

The DTH use case class relates to the provisioning of media content services directly to end-users' houses. Both the edge-gateway and satellite antenna are installed at home. The edge gateway receives data from satellite and makes it available to in-home IP client devices using the service applications.

Technically, the Edge gateway sits on an end-user's Local Area Network at home, where it can be discovered by media clients using a standard device discovery protocol such as mDNS. The edge gateway contains a local cache, e.g.: a small RAM disk for live streaming and mass storage (possibly in-home NAS) for VOD media and may contain a built-in WIFI Access Point to allow the end-user devices to connect to it directly if no other local network is available.

The content provider aims to deliver media content to the end user in fixed locations - such as apartment buildings, apartment blocks, housing communities or individual homes – through a smart home gateway. The use-case explores the provision of media content to remote end users in the disadvantages areas that are currently inaccessible for media companies and presents a case for the de-congestion of ISP's and telecom core networks while providing premium content.

This use-case explores two key features for the service: 1) the provision of media content to remote end-users located in areas without adequate network infrastructure that are currently inaccessible for content providers due to the lack of coverage, and 2) the de-congestion of ISP's and telecom core networks while providing premium content, both improving availability, quality and latency of content delivery.

The geographical scope is Europe, with an emphasis on remote and sparsely populated areas, where terrestrial internet connections are limited. There is a potential to extend the scope to the rest of the world as well (in some less developed countries), as satellite networks provide global coverage and can be accessed from anywhere in the world.

This use case has been extended to consider the nomadic use-case where the content provider aims to deliver media content to end users that are alternating between their main residence and a secondary residence, i.e., a person living in the city in possession of a holiday cabin, without the end-user having two separate subscriptions & gateways.

The advantages of the nomadic use-case are:

- The user can access media services in their secondary dwellings using the same subscription and smart gateway as in their primary residence.
- Media companies can maintain access to their customers and keep gathering user data as the user alternates between different locations.
- No additional recurring costs for the users when compared to having two (or more) solutions, as there is no need to pay for additional subscriptions.

The DTH use-case also involves residential collective buildings, where the content provider aims to deliver media content to end users that live in collective buildings or small communities through a Smart Home Gateway. The 5G-EMERGE solution derives value from two key features:

1. The possibility of traffic offloading from the collective building's internet connection.
2. The provision of media content to end users located in disadvantaged areas that are currently inaccessible for media companies, due to lack of adequate network coverage.

Two target segments emerge for the use-case of residential collective buildings, separating on regional characteristics and demographic characteristics:

1. European collective residential buildings, e.g., apartment buildings, housing co-operatives
2. Remote, clustered communities in areas without adequate terrestrial network infrastructure

As an additional case, the Smart Home Gateway for collective building – non-residential – aims to deliver media content to end users at hospitals, schools, hotels, office buildings and other public locations. The solution explores two key features for the service:

1. Offloading the traffic from the collective building's internet connection
2. The provision of media content to end users located in areas without adequate network infrastructure that are currently inaccessible for content providers due to the lack of coverage.

These end users are affected by similar key drivers and trends as the individual home and collective building – residential cases, with a demand for consumption of media "anywhere anytime" being a key determinant.
The DTH use case class entails delivery of OTT video services over broadcast satellites with a large-scale deployment potential and a total addressable market of millions of households. This makes the DTH use case class particularly attractive for the entire media industry.
5G-EMERGE brings DTH satellite broadcasting to the next level, where satellite becomes an integral part of terrestrial Content Delivery Networks. Satellite can deliver OTT live video via multicast streams up to the end-user's homes and this multicast-delivered content will blend seamlessly with all other, unicast delivered, content at the level of the end-user's client device and application.

2.2.2 Direct-to-Edge (DTE)

The DTE use case class captures the scenario where the media content is provisioned at a location closer to the users (usually referred to as "edge") than the point of content origin. Two types of such locations are considered: a 5G base station and a Direct to Micro Data Center. The first refers, for example, to a base station location operated by a mobile network provider. The second type refers, for example, to a CDN point of presence or a location that can serve multiple 5G base stations, interconnected via microwave or a remote fiber ring.

This use-case considers the value of providing a smart gateway at network nodes for two differing applications. The first one is a 5G base station essentially functioning as an autonomous 5G Local Area Network (LAN). The second is a Metropolitan Network Node where a CDN point of presence (POP) would use a satellite connection instead of, or in addition to, a terrestrial connection.
The 5G Base Station use-case can be considered as a remote 5G base station or an autonomous 5G LAN with capabilities such as:

- Autonomous and private network features.

- Core network functionality enabling alternative backhaul and transport networks, including usage of satellite solutions.
- Local routing of traffic between devices connected to the actual 5G network.

The data and content to be communicated over the 5G base station may include, but is not necessarily limited to, media content with respect to various formats, categories and contexts.

The goals are:

- High quality and flexible networks for various applications in any location, remote areas and/or densely populated areas.

  This scenario includes delivery of live and other entertainment content for mobility applications (e.g. cruise ships) as well as rural communities connected to a small cell over satellite.
  The 5G-EMERGE platform is used for delivering the content to a micro-edge server installed at the far edge next to a 5G Base Station through which users can access it.
- Enable LANs for advanced media productions as well as operational purposes for industry and public sector.

  5G LAN is a technology for providing a wireless LAN using 5G technology instead of WiFi. It combines the high throughput, low latency characteristics of 5G with the characteristics of traditional LANs for offering advanced networking for typically enterprise and industrial environments.
  The 5G-EMERGE platform is used for delivering data and content to a micro-edge server installed at the far edge and connected to a 5G private network that offers a 5G-LAN service.
- Enable agile deployment of 5G Network on-Demand (5GNoD) – anywhere.

  This scenario may address a sports organization aiming to deliver high-quality live streaming of its events to viewers across different devices, while also ensuring low latency and high reliability for an optimal viewing experience. The content will be delivered over satellite to 5G base stations and distributed to end users thereof.

  During a live sports event, the organization can dynamically allocate additional bandwidth to support a high volume of concurrent viewers. After the live event, highlights and replays can be made available as Video on Demand (VOD). During peak times, such as right after the event when many viewers want to watch highlights, the organization can scale resources up to handle the increased traffic. Conversely, during off-peak times, resources can be scaled down to save costs.

  This service model leverages the flexibility and capabilities of 5G technology (5GNoD) to provide tailored connectivity solutions based on real-time demand offering important benefits such as Cost Management, High-Quality Viewing Experience, Scalability and Enhanced Engagement.

  The 5G-EMERGE platform is used for delivering the content over satellite to a micro-edge server installed at or next to 5G Base Stations through which users can access it and enjoy low latency and high quality viewing experience.

The first goal above was demonstrated by the DTE test beds in Phase 1 (see section 3.3) and will be further demonstrated in Phase 2. The agile deployment of 5GNoD is very similar to deployment of 5G networks in maritime environments, and the demonstrations of the 5G-EMERGE solution on-board a ship that will be done in Phase 2 will also largely verify that the 5G-EMERGE solution achieves the 5GNoD goal. Delivery of data and content to 5G-LANs will not be demonstrated in the 5G-EMERGE project. The Metropolitan Network Node use-case covers the scenario where a CDN point of presence (POP) would use a satellite connection instead of, or in addition to, a terrestrial one. As CDN seeks to expand their coverage, the satellite connectivity and the possibility to feed the caches directly from satellite broadcasts enables the POPs to be located in areas where terrestrial connections aren't available or not commercially viable.

The goals of this use-case are:

- Allow users in a densely populated developing area to access the video streaming service with the same speed and quality as users in highly developed urban areas.
- Increased CDN coverage and reliability (as a selling point of a CDN provider).
- The broadcast nature of satellite transmission can be exploited to populate multiple caches at once, resulting in a lower traffic load and costs than if this is done by unicast connections.

The DTE use case class represents a natural evolution of the current OTT delivery to users that are on-the-go and wish to watch TV content on their mobile devices. Public and non-public networks (NPN) are covered in this use case class. Most of the required (hardware) infrastructure is expected to be already present. In many cases, the addition of extra storage to support content caching and deployment of the 5G-EMERGE Far Edge applications and functionalities might still be required.

2.2.3 Direct-to-Vehicle (DTV)

Travelers in vehicles like cars, buses, ships, and planes tend to consume media during their trip. The Far Edge is in many of these cases connected to the on-board entertainment systems that control the user interaction with the content via in-built terminals. Other connection models allow wireless connections to handhelds of the end-users in the vehicle. Currently connectivity on the move is limited due to incomplete coverage and/or congestion of wireless terrestrial networks.

This use-case is focused on the delivery of high-quality media content to three different users:

- car owners and passengers to provide a local hotspot in the vehicle, supporting media services as well as other applications such as software updates and maintenance monitoring,
- collective transportation crew & passenger, with particular emphasis on buses, trams, trains and taxis as means of transport and
- crew members and passengers of cruise ships, fishing & merchant vessels and oil & gas platforms.

In the DTV use case, special antennas are needed to optimise the communication between the receiver located in the moving vehicle and the satellite. Most often phased array antennas are used that are designed to be installed on, or seamlessly integrated in the roof of the vehicle. Size and power limitations are essential in these deployments of software-controlled arrays of antennas that can track satellites and for a return channel need to create a beam of radio waves.

Smart Gateway on a Car is focused on the delivery of high-quality media content to car owners and passengers. The use-case aims to explore the potential of a 5G-EMERGE activated satcom reception for cars, with the delivery of media content being the main objective. The main objective of the smart gateway on a vehicle is to provide ubiquitous connectivity by relying on satellite where and when terrestrial links are either not available or are not the most appropriate solution.

The goals are:

- To offer wide range and high-quality media services to passengers
- To limit the impact of the user terminal integration (i.e., cost, form factor)
- To have 100% territorial coverage

These objectives can be achieved by combining 5G technology to enable the delivery of high QoS media content with the capability of satellites in multicasting or broadcasting over a large area, and potentially directly to user equipment. Moreover, a satellite network can also contribute to offloading traffic from terrestrial networks, e.g. by multicasting or broadcasting non-time-sensitive data in non-busy hours to be cached at the far edge and used when required. This alleviates the strain on terrestrial networks during busy hours.

Smart Gateway on Moving 5G Base Station aims to explore the provision of connectivity for the collective transportation crew & passenger needs, with particular emphasis on buses, trams, trains, and taxis as means of transport. Currently, connectivity in collective transportation is limited due to incomplete coverage and congestion of wireless terrestrial networks.

The goal is to provide connectivity to 5G networks for the collective transportation (buses, trains, vessels) crew & passenger's needs, i.e. news & entertainment.

Integrated terrestrial and satellite connectivity will be used to provide the most cost effective and reliable means of providing continuous service to the vehicles across 100% of the territory. The smart gateway will also provide a local hotspot for passengers in the vehicle and will support not only media services but also other applications such as software updates and maintenance monitoring functions.

Maritime use-case aims to deliver content to various maritime installations, including cruise ships, ferries, and offshore platforms. These installations are typically remote and rely on satellites to connect to onshore networks. Moreover, the number of individuals onboard a vessel can significantly vary, ranging from small offshore installations with a dozen workers to large cruise ships accommodating thousands of passengers and crew members.

In this context, the maritime use case falls under both DTV and DTE use case classes. While primarily targeting vessels, it naturally aligns with the DTV use case. However, offshore installations are more strongly associated with DTE use cases, particularly the 5G base station classification, as the edge connects to the locally deployed network infrastructure, rather than directly to end-user devices. Regardless, the overarching goal remains consistent: enabling end-users to access content at maritime installations, leveraging satellite for ship-shore connection and an onboard 5G NPN to distribute far-edge content to end-users.

Currently VSAT's are reliant on Geo-stationary satellites and RF are the go-to solution for providing connectivity to the maritime segment. This use-case will explore opportunities for 5G-EMERGE to realize the value of enabling new technology which will provide faster bandwidth with lower latency and reduced costs for the maritime industry.

Installation of network infrastructure onboard vessels and platforms poses significant technical and economic challenges. The virtualized far-edge components developed in the 5G-EMERGE ecosystem aim to streamline installation processes and adapt systems to specific installations. Additionally, virtualized 5G core and orchestrator technologies facilitate scalability and cost-efficiency as commercial off-the-shelf (COTS) hardware can be re-used for a broad range of applications.

To achieve full coverage for all end-users, the base stations must be deployed throughout the ship to ensure good radio conditions for all users, enabling them to connect to the 5G network. While radio access component (RAN) components can be partially virtualized, but still require a radio unit hardware component.

The goals are:

- To deliver media content to previously inaccessible customers onboard a vessel or stationed on an oil and gas offshore platforms.
- Improve the availability and latency of content delivery.
- High quality and flexible networks for various applications at sea, servicing stationary (rigs and platforms) and moving vessels.

Integration of satellite-enhanced edges in 5G-networks open multiple additional possibilities. For example, some LEO satellite constellations are starting to offer Direct-to-Device connectivity. 5G EMERGE will investigate how these new satellite systems could be integrated in 5G-EMERGE alongside other networks, with a particularly focus on 5G NR NTN in Phase 2.

3 Technical developments and achievements

This section presents the overall architecture (functional/physical) of 5G-EMERGE, covering system, service and component levels, accompanied by a comprehensive description, as well as it defines the necessary interfaces to support the description of the architecture and technical design.

3.1 System architecture and solutions

The following System Functionalities (SFs) have been identified in the 5G-EMERGE project (see Figure 2):

SF1 – Content Provisioning: encodes the key content, pushes it to the origin server and at the other end of the chain, plays it on the device that runs the end-user playout application.

SF2 – Cloud Uplink Preparation: selects the popular content relative to the used Satellite Communication (SATCOM) network coverage on the basis of data from SF1. It also prepares the content for the Teleport and can receive feedback data from the SATCOM Return Link (RL).

SF3 – SATCOM: connects the Cloud Uplink Preparation with the Micro-Edge Devices via an Uplink location, satellite network and antenna.

SF4 – Far Edge: provides edge functionality and connects to the end user IP Network through use-case specific access technology.

SF5 – Service Provisioning: manages the ecosystem and exchanges control and performance data.

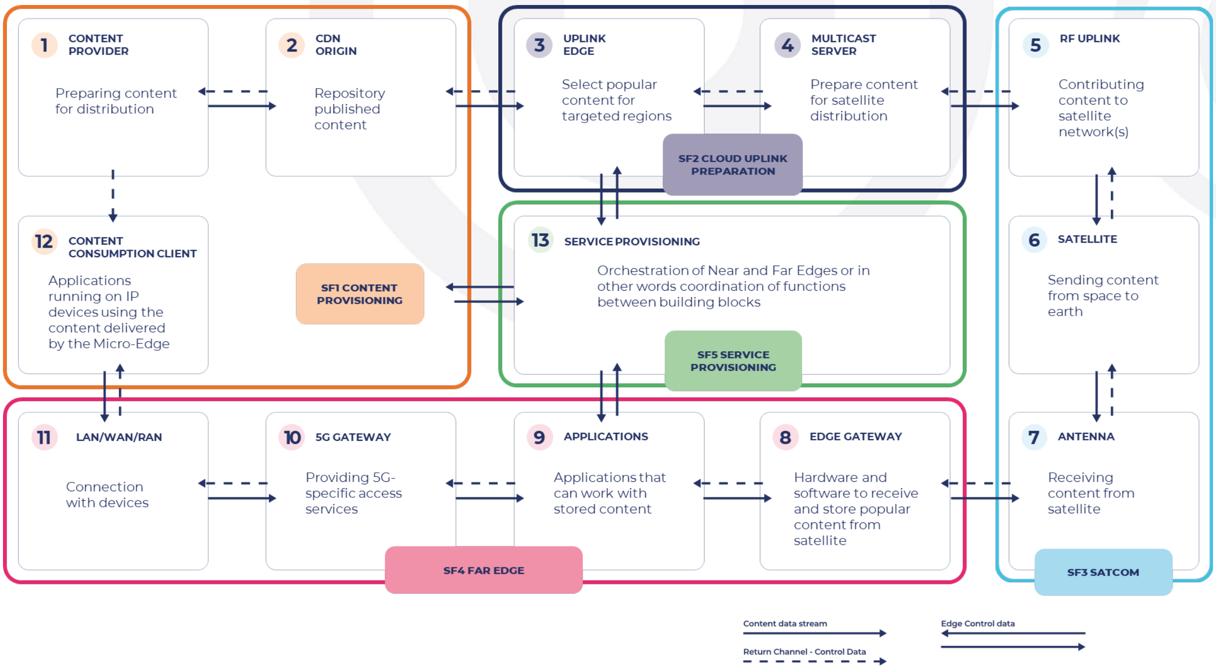

Figure 2: 5G-EMERGE main building blocks.

In turn, each SF consists of several actors/components, which are briefly described below:

1. **Content Provider**: Online delivery starts at the Content Provider (CP) that publishes content via an

Origin server.

2. **CDN Origin**: The Content Delivery Network (CDN) provider picks up the content from the CP Origin.

3. **Uplink Edge**: This is a 5G-EMERGE-specific server that is envisaged to run on a cloud stack in a well-connected Gateway and that manages both the reception from the CDP Origin and the transmission of selected content towards a Teleporter. This Edge server's main function is to cache content that is popular in the region covered by the reference satellite(s). It also can perform content manipulation services to support distributed 5G-EMERGE Micro-Edge device terminals. Together with the Uplink Edge, this is part of the 5G-EMERGE Cloud Uplink, which communicates with the 5G-EMERGE Cloud Service Management layer to receive data about popularity of content and coordinated tasks with the Micro-Edge devices.

4. **Multicast Server**: This server will prepare the content for satellite distribution. For the transfer of files via multicast, 5G-EMERGE relies on Multicast Adaptive Bitrate (mABR) technology. This technology supports both live and non-live file-based content. 5G-EMERGE selected, for its implementation in Phase 1, the European Specification ETSI TS 103 769 also known as DVB-MABR. In order to apply DVB-MABR to a satellite broadcast network, another specification, called DVB-NIP (Native IP), can provide the tools to signal and locate multicast streams across multiple satellite transponders and to allow to announce such Live, VOD or data streams to satellite reception devices.

5. **RF Uplink**: It sends the multicast IP stream in a modulated carrier to the satellite. At the same location, data from the RL can be received and demodulated. Existing physical layer protocols shall be used over the satellite link, such as Digital Video Broadcasting – Second Generation Satellite Extensions (DVB-S2X) and Fixed-Interactive Multimedia Services (FSIM).

6. **Satellite**: It broadcasts the signal over a region and provides the RL. It is mainly wide beam GEO satellites (and potentially MEO and LEO satellites).

7. **Antenna**: It is the first part of the 5G-EMERGE far edge terminal, which will be optimised for different use-cases including fixed and moving reception.

8. **Edge gateway on the 5G-EMERGE far edge**: It comprises the satellite or 5G networking layer performing the local breakout of user plane traffic towards the virtualized stack that runs the applications and integrates with the northbound Uplink Edge and the Service Provisioning layer.

9. **Applications on the 5G-EMERGE far edge (containerized)**: It describes all the applications running on the Far-Edge and inside the container environment. They effectively transform the received multicast to unicast before other content manipulations can be performed, such as content ingestion for advertisement localisation purposes, transcoding/repackaging optimisation for device playout, etc. In 5G-EMERGE, we concentrate on media processing, but the Edge-based platform also allows other applications to be used, or through the caching function, it can distribute nonmedia popular content such as maps or software updates.

10. **5G Gateway**: It connects the satellite Micro-Edge device enhanced network with the LAN, WAN or RAN and encompasses all the 5G functions implemented at the Far-Edge, tailored to the Direct to Home, Direct to Edge and Direct to Vehicle Use-Cases.

11. **LAN/WAN/RAN**: They are the network access interfaces for the playout devices of the 5G EMERGE Micro-Edge device.

12. **Content Consumption Client**: It comprises all the functions of a typical media client. These functions may be network device discovery protocols (to locate and communicate with the Far-Edge cache server), service discovery protocols (to inform end-users about the services made available to them), and, most importantly, the content decrypt and playback functions. Finally, the analytics subfunction oversees the provision of feedback to the backend about the playback of content, as already discussed.

More information can be found in [RD8] and [RD9].

3.2 Critical technical elements

One important aspect of the 5G-EMERGE project was to capture and trace the project critical technologies. In ESA terms the new technology may be a Critical Technology Element (CTE), such as a system, subsystem, or component comprised of hardware and/or software. A CTE is identified by the criticality of the technology element's importance in meeting functional and operational requirements and is either new or novel that poses cost, schedule, safety, or technical risks to the project or program (Salazar G. & Russi-Vigoya N, 2017).

During the System Definition activity of the project, 3 main CTE categories were identified in [RD7]. The first category/track covers 5G-related critical processes and technologies. The second track takes stock of all the orchestration processes/technologies that are critical to the 5G-EMERGE ecosystem. The third and last track covers caching and content discovery as critical process/technology domain.

For each category the state of the art and the status of the implementation of the market has been analysed. We summarise here the main challenges and the impact on the use cases and on satellite networks. Further details can be found in [RD7].

3.2.1 5G-related critical processes and technologies

Main challenges: Three main challenges have been identified related to 5G technologies. The first is the missing specification of interfaces between the micro-edge-device and different actors in the eco-system for the management of the end-to-end service. In Phase 2, we will address this gap following, among others, the guidelines for collaboration scenarios presented in the 3GPP specification TS26.501 which provide several examples of how the collaboration between an MNO and third-party content and services providers may be realized for the delivery of media services over 5G networks.

The second main challenge is related to discovery and security in communal sharing of the micro-edge. See section §3.4.

The third main challenge is collection of relevant data from the full delivery chain and exposition of these data as actionable dataset in the ecosystem (see section 3.2.4). This is addressed in Phase 2, where operational data (including energy usage from delivery chain: Origin, CDN, flute, satellite, caches, edges and nodes) and Quality of Experience (QoE) data from the front-end applications, is collected. In Phase 2 Dashboards for QoS, QoE, energy usage, and operational status of the system will be provided at the Services Provisioning level. This allows forecasts and decisions to be made that enable a smooth delivery of content to the end user, e.g. pre-fill caches in particular regions where content is popular. Or to improve operations, for example by steering content or optimisations for energy usage.

Impact on use case categories: In the DTH use cases there are challenges related to who should be considered as subscriber. For example, in the individual home it could be each individual person, or it could be the home as a collective. The challenge is even more complex in the collective building case where each individual person, each apartment, and the building itself can be considered as the subscriber. This also raises challenges related to collection and aggregation of consumption data. In addition, the collective building case has a challenge related to service modelling, a topic that require that both technical and business aspects are taken into account.

The DTE use case also has challenges related to collection and aggregation of consumption data, where data must be exchanged between the 5G and satellite systems.

One challenge that is common to the DTE use case and the Maritime Network Node use case is the missing interface between Non-Public Networks (NPNs) and Public Networks (PNs). The regulation in several European countries, including Norway, states that the NPN must be separated from PNs, i.e.

no roaming between them, to utilize the frequency bands allocated for NPNs. In other words, the interface is missing because the regulations require it to be so. Further, from a commercial and legal side, roaming agreements with other mobile operators doesn't allow local breakout of traffic as of now. NPN enable 5G end users to access the 5G-EMERGE ecosystem on the far edge, overcoming the commercial and legal challenges of local breakout in roaming scenarios. The end users can still access the public network with a dual SIM enabled phone, where one SIM is connected to the NPN and the other to the PN.

Impact on satellite networks: There will be no impact on the air interface of satellite networks. But it will have an impact on the satellite network management system (NMS), the set of tools that allows network administrators to manage, monitor, and coordinate network operations efficiently (see section 3.2.2). This will be part of the collaboration models that will be studied in Phase 2, see paragraph above.

3.2.2 Orchestration-related critical processes and technologies

Main challenges

The high-level system architecture of the various orchestration layers, first in the case where there is no 5G infrastructure, and then the case where there is a 5G infrastructure, have been analysed and two main challenges have been identified:

1. Integration of the various orchestration layers and real-time monitoring of various systems' parameters

All the orchestration layers and system components make the overall system complex to integrate. Furthermore, not all orchestrating components monitor the parameters that are relevant for the overall system and at the same / desired frequency in time. An example is the configurability of the satellite link that is needed to offer the required end-to-end QoS and the dynamic service orchestration and network management to guarantee the end-to-end QoS in runtime.

2. Extending the 5G orchestrator with additional interfaces

In Phase 1, the 5G orchestrator was used as it is without implementing any modification. Doing so, it was discovered that additional interfaces are needed to manage the service, e.g. the interface for management communication between 5G orchestrator and satellite platform and northbound interfaces for 5G core network management. This will be addressed in Phase 2.

3.2.3 Caching-related critical processes and technologies

Main challenges:

There are 2 categories of challenges:

1. Defining interfaces for the ecosystem which have not been addressed or know to be addressed in existing specifications. The following interfaces have been identified:

Reporting on the available Satellite network capacity (Mbps) and the reception region(s) (IP-ranges) of the used satellite network to optimize cache efficiencies.

Content popularity data from CDNs (for example recent request data or reverse proxy information/cache misses).

Content Providers' predictions on popularity of content which can be based on scheduling experience and information from content recommendation engines.

2. To decide what content needs to be part of the satellite multicast stream to optimise the delivery efficiency to the end-users via the intermediate cache on the 5G-EMERGE far edge. This is an optimalisation challenge. It can be addressed with an attempt to define a baseline functionality that might prove not to be optimal. A best guess approach as there are only a few proven market approaches.

The core of the second challenge is a predictive prefetching approach as opposite to the pure reactive traditional caching rules, based on requests to the origin. Normally content that is requested multiple times is cached upstream closer to the end users. With prefetching it has to be decided what content is 'interesting' from a caching perspective for a potential larger region depending on the used satellite network. The cache itself has to decide what will be stored from this multicast stream, assuming a coordinated exchange. The KPI to decide prefetching efficiency is a combination of cache hit ration, storage used on the far edge and bandwidth used in the satellite connection.

Impact on use case categories: The foremost difference is storage size and capability to serve concurrent users. The combination will determine what content is available and impacts the cache-hit ratio. The DTH use-case is complicated as it needs to support multiple content providers to be relevant for end-users. This could result in different applications competing for hardware recourses. This is also a limiting factor for DTV in cases where the hardware is limited in size/energy consumption. This and content discovery could be easier in the DTE use-case where it could be a single operator deciding what needs to be cached instead of multiple users / providers competing on resources.

Impact on satellite networks: Smaller regional coverage with higher gain will allow to deliver prefetching multicast streams with a higher efficiency and a better cache-hit ratio. For example, a 200 Mbps Ku Spot Beam will perform better than a 200 Mbps Ku band distribution covering a region of the size of Europe. Ku-band still more viable than Ka-band prefetching deployment if the price difference is large enough. A minimal return channel needed for those far edges that have no terrestrial IP connectivity is critical.

3.2.4 How to address the CTEs

In order the address the identified challenges and particularly their impact on the use cases classes, we have structured the Phase 2 project in work strands, with strand 1 focusing on project management and overarching system architecture, strand 2 focusing – horizontally – on the common edge functionalities and strands 3 to 6 focusing – vertically – on the use case classes (including a new use case class, "direct to device") (see section 6). The identified challenges will be tackled by the critical technologies that are brought into the project by the various Phase 2 work strands from 2 to 6, which are reported in the updated version of the CTE [RD7]". Specifically, the challenges related to 5G are addressed by new technologies in strand 2 and 3, the challenges regarding orchestration are addressed by new technologies in strand 2 and 5, the challenges regarding caching are addressed by new technologies in strand 3.

3.3 The development and testing phase

The objectives of the Phase 1 were to design, develop and validate the following:

- The 5G satellite multi-tenant system for the delivery of IP based live and on demand video services for three target market scenarios 'Direct-to-Home', 'Direct-to-Edge Node', 'Direct-to-Vehicle',
- The Network control and management, and services orchestration mechanisms and interfaces,
- The standardised northbound Application Programming Interfaces (APIs) to 5G native IP services platforms,

- The standardised southbound Application Programming Interfaces (APIs) to satellite gateways stations and satellite user terminals,
- The satellite reception and optimised content delivery enabled by micro-edges which include 5G core functions, 5G compliant satellite backhaul management, optimised caching, DRM and playout software for content consumption.

To deliver these objectives, innovative new products were developed:

- 'Direct-to-Home' micro edges optimised for stationary reception and content consumption in apartment/building/complex/hotels.
- 'Direct-to-Edge Node' micro edges optimised for installation and operations in access network nodes like 5G gNodeB (base stations) or network gateways operated by Content Delivery Network (CDNs) Providers/Internet Service Providers (ISPs).
- 'Direct-to-Vehicle' micro-edges optimised for reception on the move, for example in cars, planes, trains, buses or vessels installations to receive content that will become available to passengers inside the vehicle.

The development and testing phase of the 5G-EMERGE system was divided into 4 cycles:

- **Cycle 1 (KOM-MS1)** focused on the understanding of technologies and expertise provided by each project partner. First integrations and implementations took place. The goal was to have an end-to-end ecosystem ready at MS2.

- **Cycle 2 (MS1-MS2)** focused on building a first end-to-end demonstrator (DTH at EBU premises), to be presented at MS2 meeting. In the meantime, in parallel, Use-Case leaders worked on the definition of the demonstrators to be presented for each use case, during the MS3 meeting.

- **Cycle 3 (MS2-MS3)** focused on the building of the actual demonstrators for the DTE, DTV use cases. The integration of technologies to the different end-to-end demonstrators was done for two of the testbeds, and two new ones (DTV maritime use case, DTE use case) were presented during the MS3 meeting.

  In parallel, partners worked on the testing and validation of the 5G-EMERGE system. The objective for MS3 was to plan, document and perform the functional testing of the different existing demonstrators. The testing methodology and zoology can be found in the Technical Note 2.3 [RD13]. Related Test Designs and Test Cases were reported in the Test Plan, Procedures and Report (TPPR) document [RD26]. These Test Designs and Test Cases are templates for Test Campaigns which were run between MS3 and MS4. The corresponding Test Records are available in JIRA. The operational testing plan was prepared and presented during the MS3 meeting.

- **Cycle 4 (MS3-MS4)** focused on the testing and validation of the 5G-EMERGE systems in the different testbeds and Use Cases. First Operational A/B tests were defined. Functional and Operational A/B tests were conducted in the different testbeds. The results are available in the JIRA boards, and TPPR document [RD26].

3.3.1 The demonstrators/testbeds

The 5G-EMERGE system targets the 3 use-cases described in Section 2.2 of this document.

Each use-case required a specific system, which was put in place and tested in one testbed or more – creating use-case-specific demonstrators.

The list below summarizes the different demonstrators showcased, per use-case:

Direct-to-Home (DTH):

- Demonstrator at EBU premises,
- Demonstrator at SES premises,

Direct-to-Vehicle (DTV):

- Maritime demonstrator at Telenor Maritime premises,
- Car demonstrator (focusing on System Function 3, Satcom) at Viasat premises,

Direct-to-Edge (DTE):

- Demonstrator at SES premises,
- Demonstrator at Arctic Space premises,
- Demonstrator of SAND-DANE components by TNO, hosted by EBU.

The specificity of each use-case lies in the type of edge installation which will receive, unpack and distribute the content from the satellite. The Micro-Edge Device (SF4), and Service Provisioning (SF5) layers are use-case specific while having the same baseline concept.

The baseline ecosystem ensures the path of the content (live and on demand) from the encoder to the far edge devices. The detailed path of the content is available in SA & ICD [RD8], and DDD [RD9] documents.

These demonstrators were presented to ESA at the different milestone meetings. A detailed description and diagram of each of them is available in the Design, Development and Verification Plan DDVP document [RD10].

3.3.1.1 Direct to Home (DTH) demonstrators

3.3.1.1.1 DTH demonstrator at the EBU premises in Geneva

Figure 3 shows the diagram of the full configuration of the 5G-EMERGE satellite bidirectional platform used by the EBU (see [RD24]).

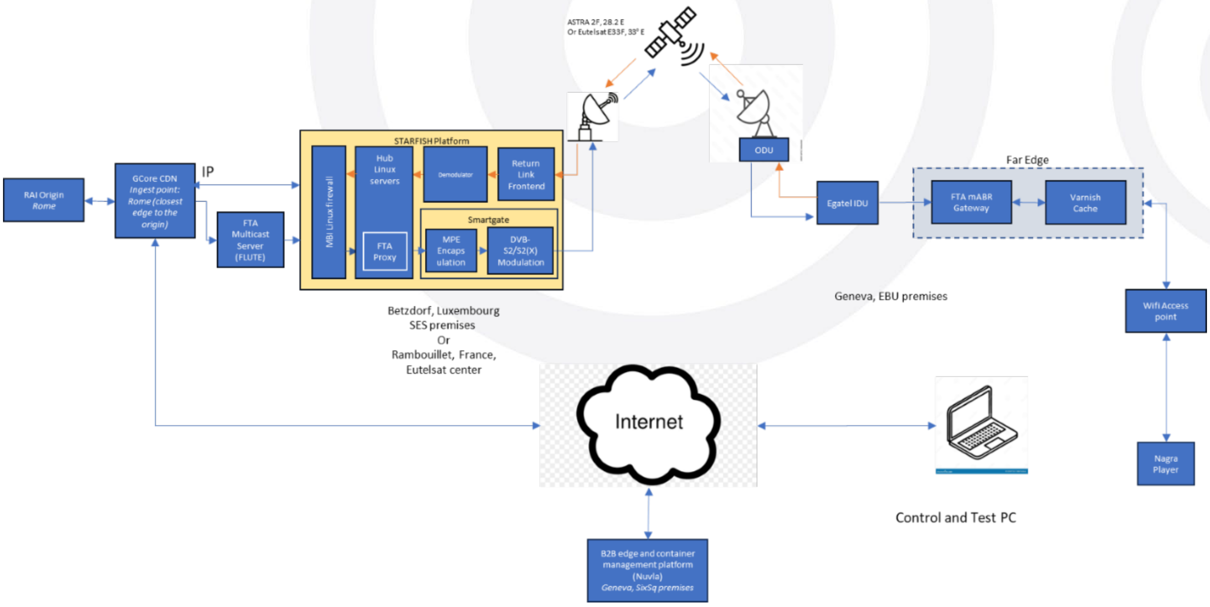

Figure 3: Diagram of the full configuration of the 5G-EMERGE satellite bidirectional platform used by the EBU DTH demonstrator for MS4.

At MS2, the main characteristic was the use of satellite forward link only to provide the content pushed by the mABR server at the near Edge, and a terrestrial broadband connection to provide other content requested by the user and not present on the Far Edge.

The path of the content is the following:

1. The content is brought to the encoder from live audio / video feeds.
2. After audio/video encoding, encryption by means of DRM and packaging (MPEG DASH and HLS versions), it is uploaded to the Origin server.
3. The content is sent to the Content Delivery Network (CDN) server, where it is ready to be retrieved by the mABR multicast server.
4. A request is emitted by the user equipment on a specific content, using internet connection. The request is sent to the local cache. If the content is not available on the local cache, the request is redirected to the gateway. If it is not available on the gateway, the request is transferred to the near edge equipment (mABR multicast server) and CDN.
5. The request triggers the retrieval of the content from the CDN by the mABR multicast server. It is transferred to the GSE encapsulator through a proxy.
6. The encapsulator, and DVB modulator, create data packets out of the file, ready to be exposed to the satellite from the ground station.
7. Packets go through the satellite, and downlink to the receiving antenna.
8. The content is emitted on the downlink segment of the satellite, and received by the Receiver antenna located in Geneva, at EBU premises.
9. The edge receiver decapsulates the data packets and replenishes the content file.
10. Far edge devices in Geneva run the gateway and the caching apps, orchestrated by the edge devices and apps orchestrator. The gateway enables the discovery of the content file by the caching system.
11. The content is exposed to the Nagra player, ready to be played by the user.

The demonstration of the EBU DTH use case at MS4 showed both live and on-demand content passing through the baseline ecosystem. In this use-case, the receiver has satellite internet connectivity through the satellite bidirectional link. In this case, two Egatel Dish antennas with outdoor unit (ODU) and Indoor unit (IDU) were pointed on ASTRA 2F (28.2° E) and on Eutelsat E33F (33° E) satellites.

The following features were demonstrated at MS4:

1- Playback of live content with the Nagra player, from the far edge, received via the Eutelsat satellite and the Egatel box. Both unencrypted and encrypted (DRM) contents were received. The Nagra application retrieves its metadata and encryption keys using a terrestrial connection.

2- Demonstration of Service Discovery techniques using the EBU player application developed for this purpose. The application can be adapted to its context on the local network, without any configuration or knowledge on the part of the user. Nagra's configuration parameters do not allow the return channel routing. However, 3 solutions have been considered to enable it to do so:

   a. use of a local DNS server (not included in the architecture plan)
   b. change the routing table in the router device
   c. change the network parameters of the devices (use of a proxy server).

   These solutions have been abandoned because they require the end user to have advanced knowledge of networks, or to deviate from the context of a local network.

   The EBU application uses the Service Discovery techniques proposed in the architecture blueprint.

3- Sending user usage data to the recommendation engine. The EBU player sends the user's content consumption data to the Peach data lake via the far edge proxy and satellite return channel. This data is then integrated into the analytical procedures. Presentation of Peach and demonstration of the first recommendation algorithms based on data from the EBU player

4- Reading VOD content with the EBU player, using bidirectional communication with the satellite. The user's choice of VOD content is transmitted via the satellite downstream channel to the Near Edge services. The content is then sent via the mABR server and Flute Gateway

The return channel by satellite has a limited bit rate, up to 140 kbits/s. With this limitation, it can be used for:

- DRM Control data, for example to do the Logon procedure of the Egatel box.
- Metadata from the Edge to the Recommendation system
- Requests for long tail content (other than the content pushed by the Recommendation system to the mABR Gateway).

Outside the 5G-EMERGE context, the Egatel satellite bidirectional link can be used to access the internet like any other means, but with limited uplink bitrate. The forward link speed depends on the bandwidth of the satellite channel allocated to the system. It can go up to several tens of Mbits/s.

5G components with access by non-3GPP devices

The DTH test bed at the EBU was extended so that the Far edge architecture included 5G components allowing access to the Far edge by non 3GPP equipment. In this case Wifi is also used as the non 3GPP equipment used in the home environment. The target architecture of the 5G components integration with the EBU testbed is shown in part of Figure 4.

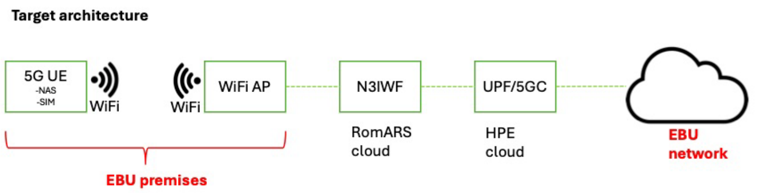

Figure 4: Target Architecture with 5G components.

The use-case here corresponds to the situation where the user access to the 5G-EMERGE architecture is managed by a 5G Mobile Network Operator that makes use of the satellite capacity to provide the media services to the user.

This setup uses the satellite forward link only (with the Inverto Airstream box). Internet access is made through the 5G network.

The demonstration consists in accessing a live channel received from the satellite segment of 5G-EMERGE on a user device that is connected to the 5G network through Wifi.

3.3.1.1.2 DTH demonstrator at the SES premises in Luxembourg

Figure 5 shows the diagram of the full configuration of the 5G-EMERGE satellite platform used by SES for the DTH use-case (see [RD24]).

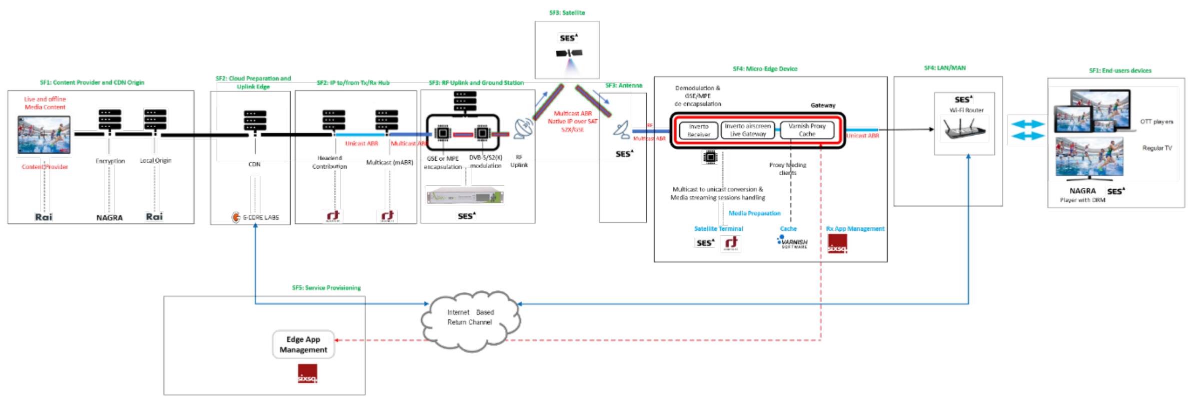

Figure 5: Conceptual diagram of the SES DTH demonstrator for MS4.

The path of the content is the following:

1. The content is ingested to the encoder from live audio / video feeds existing within RAI.
2. After audio/video encoding, encryption by means of the NAGRA DRM solution is applied at RAI. The content is packaged as MPEG DASH and HLS versions, and then uploaded to the Origin server.
3. The content is distributed via CDN servers, from where it is ready to be retrieved - or by clients connected via broadband - or by the mABR multicast server for distribution in multicast via satellite.
4. When a request for a particular content item is issued by the end-user via its user equipment, this request is sent via broadband to the request router. The request will generally be redirected to the nearest cache for fulfilment. If the content is not available on the local cache, the request is redirected further up the CDN. Depending on the number of requests the Far End Content Population Logic in SF2 which is the intelligence and logic behind the multicast distribution of content, may decide to broadcast particular content items a priori due to their popularity.
5. This then triggers the retrieval of content from the CDN by the mABR multicast server (more information on how this works has been provided in the MS1 description). The content which is then packaged in FLUTE multicast transport sessions is then transferred to the GSE-HEM encapsulator. In the particular implementation for the MS4 demonstrator the mABR server and the Encapsulator are not co-located. For the demo a VPN tunnel has been put in place between the mABR server running in the cloud and the Encapsulator which is located at the Uplink at SES.
6. The encapsulator, and DVB modulator, create modulated DVB-S2X signals which can then be uplinked from the ground station to the satellite.
7. DVB-S2X GSE-HEM is then carried via satellite to the receiving antenna.
8. The content is received by the Rx antenna located in Betzdorf, at SES premises.
9. The FTA edge receiver is used as a network bridge device that physically tunes to the DVB-S2X GSE-HEM signal and provides IP multicast data packets to the Far Edge Component (which is a micro form factor PC in this demo).
10. The Far Edge device in Betzdorf runs the DVB-NIP Gateway code and the caching apps, all orchestrated by the app orchestrator from SixSq.
11. The gateway exposes all the received content via its integrated web server.
12. The Nagra Player retrieves the content from the Web Server using the local Wifi Network.
13. When accessing the content and for encrypted content assets, the NAGRA player will retrieve the corresponding key material required for decrypting and displaying the content to the end-user.

3.3.1.2The Direct-to-Vehicle (DTV) demonstrators

3.3.1.2.1 DTV maritime demonstrator at Telenor Maritime premises

Figure 6 shows the diagram of the full configuration of the 5G-EMERGE satellite platform used by Telenor Maritime for the DTV use-case (see [RD23]). The TVRO receiving antenna used was on the land and not installed on a ship. Tests onboard a vessel are envisioned in Phase 2.

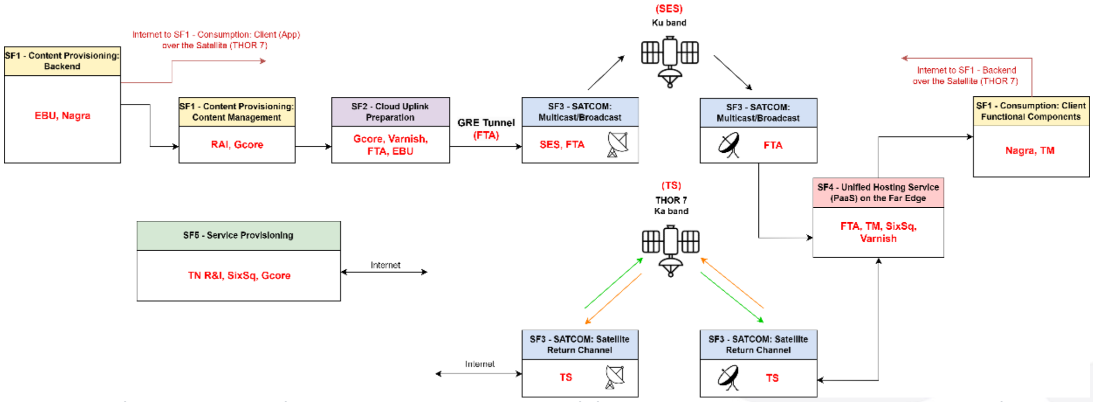

Figure 6: Architecture of the DTV Maritime demonstrator and partners involved.

The end-to-end demonstrator uses a UE that attaches to the 5G core on far edge. The UE has the Nagra app installed, used to show live video streams and video on demand. Media was streamed over SES Ka transponder and bidirectional return-link was provided by Telenor Satellite using VSAT. Furthermore, the demonstration showed content from the flute GW and from the Varnish cache, both deployed on the far edge.
Figure 6 reports the main blocks forming the architecture of the demonstrator, the interconnections among them, and the partners mainly involved. The different blocks correspond to the system functions (SFs) forming the ecosystem. A description of the different elements used inside each system can be found in [RD10].

3.3.1.2.2 *DTV car demonstrator at Viasat premises*

The architecture of the DTV terrestrial demonstrator is shown in Figure 7. As can be observed, this testbed is mainly focused on the demonstration of the SATCOM system function (SF3) and on the technical challenges related to the implementation of a bidirectional link with the satellite and the electronically steerable antenna provided by Viasat mounted on a moving vehicle, which works both in reception and in transmission.

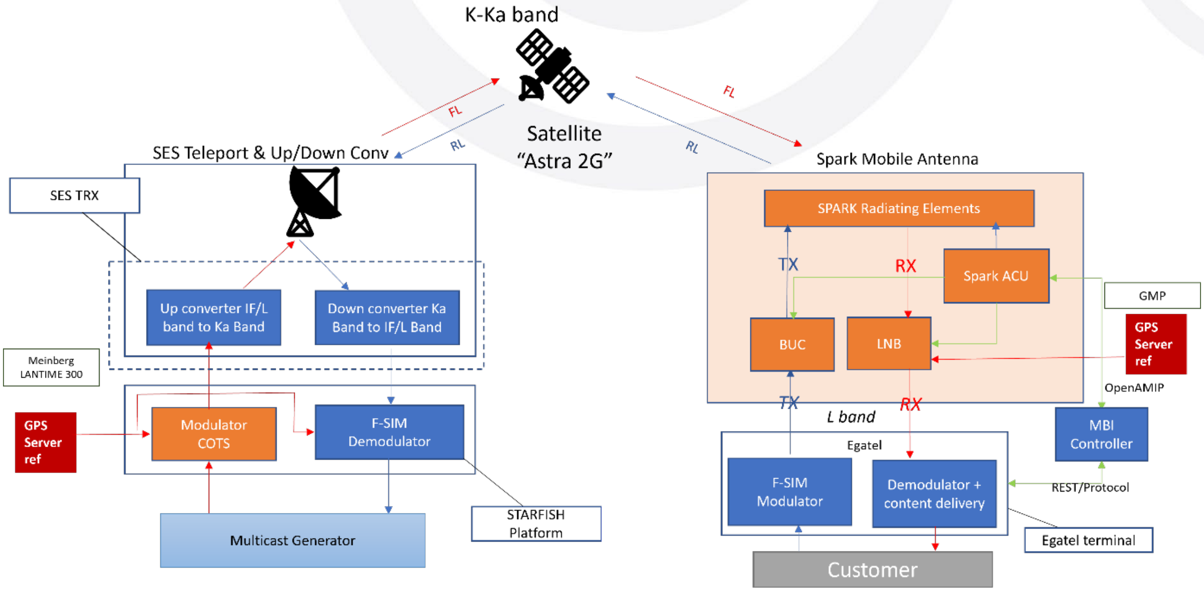

Figure 7: Architecture of the DTV Terrestrial demonstrator at Viasat premises.

A high-level description of the DTV terrestrial testbed reflecting the architecture shown in Figure 7 reported below.

SF2 - Cloud Uplink

- Tool to generate the multicast data stream, provided by MBI for demonstration purposes.

SF3 - SATCOM: Forward link (red arrows in Figure 7)

- Encapsulator / Modulator COTS provided by Viasat.
- Uplink antenna – SES Teleport in Betzdorf.
- Ka transponder Astra 2G provided by SES.
- Viasat Spark antenna used as the downlink (receiving) antenna.
- LNB provided by Viasat.
- Demodulator / Decapsulator provided by Viasat.

SF3 - SATCOM: Satellite Return-Channel (blue arrows in Figure 7)

- F-SIM Encapsulator / Modulator provided by Viasat.
- Viasat Spark antenna used as the uplink (transmitting) antenna.
- Ka transponder Astra 2G provided by SES.
- Downlink antenna – SES Teleport in Betzdorf.
- Down-converter / LNA provided by SES at the SES Teleport.
- F-SIM Demodulation / RLE Decapsulation implemented by the MBI STARFISH platform at the SES Teleport.

SF4 - Micro-Edge (Far-Edge host)

- LAN Access Network: WiFi and Ethernet cable connection provided by Viasat.

One of the main components of this demonstrator is the Viasat Spark antenna shown in Figure 8 (see also section 3.3.3).

Figure 8: Ka Band Spark antenna used in the DTV Terrestrial demonstrator at Viasat.

The Spark is an ESA antenna terminal manufactured by Viasat. It is composed of these main units:

- TX/RX tiles with their control boards.
- The ACU, of which the main tasks are programming the antenna beams through the phase array antenna, controlling the tracking loops, communicating with the Egatel modem.
- The BUC, which up-converts the signal stream at the output of the Egatel modem (frequency: 1960 MHz – 2070 MHz), to the TX frequency (27.5 – 31 GHz).
- The LNB, which down-converts the RX signal (17.7 – 21.2 GHz) to IF range (950 – 2150 MHz).
- GPS that provides a reference signal to the BUC and LNB.

The main specifications of the Spark antenna are:

- Satellite link: GEO
- Type: Electronically Phased Array Antenna
- TX frequency range: 27.5 – 31 GHz (Ka band)
- Rx frequency range: 17.7 – 21.2 GHz (Ka band)
- Electronical scanning range: Elevation: 90° – 30°, Azimuth: 0° – 360° continuous
- EIRP ≥ 52 dBW over the whole scan range
- G/T > 10.4 dB over the whole scan range
- Satellite acquisition: Automatic
- Dimensions: 140 cm x 74 cm x 11 cm
- Polarization: Dual circular

3.3.1.3 The Direct-to-Edge (DTE) demonstrators

3.3.1.3.1 DTE demonstrator at SES premises

The setup depicted in Figure 9 illustrates the baseline ecosystem of the SES DTE Testbed.

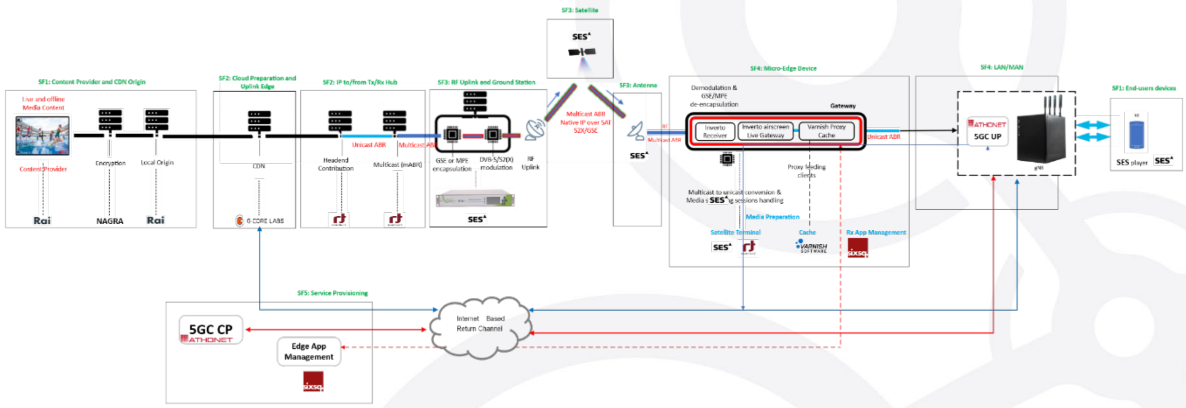

Figure 9: Conceptual diagram of the SES DTE Testbed for MS4.

The path of the content, which has many similarities with the DTH use case (see section 3.3.1.1.2 above, steps 1-10), is as follows:

1. The content is ingested to the encoder from live audio / video feeds existing within RAI.

2. After audio/video encoding, encryption by means of the NAGRA DRM solution is applied at RAI. The content is packaged as MPEG DASH and HLS versions, and then uploaded to the Origin server.

3. The content is distributed via CDN servers, from where it is ready to be retrieved - or by clients connected via broadband - or by the mABR multicast server for distribution in multicast via satellite.

4. When a request for a particular content item is issued by the end-user via its user equipment, this request is sent via broadband to the request router. The request will generally be redirected to the nearest cache for fulfilment. If the content is not available on the local cache, the request is redirected further up the CDN. Depending on the number of requests the Far End Content Population Logic in SF2 which is the intelligence and logic behind the multicast distribution of content, may decide to broadcast particular content items a priori due to their popularity.

5. This then triggers the retrieval of content from the CDN by the mABR multicast server (more information on how this works has been provided in the MS1 description of the SES DTH Testbed). The content which is then packaged in FLUTE multicast transport sessions is then transferred to the GSE-HEM encapsulator. In the particular implementation for the MS4 demonstrator the mABR server and the Encapsulator are not co-located. For the demo a VPN tunnel has been put in place between the mABR server running in the cloud and the Encapsulator which is located at the Uplink at SES.

6. The encapsulator, and DVB modulator, create modulated DVB-S2X signals which can then be uplinked from the ground station to the satellite.

7. DVB-S2X GSE-HEM is then carried via satellite to the receiving antenna.

8. The content is received by the Rx antenna located in Betzdorf, at SES premises.

9. The FTA edge receiver is used as a network bridge device that physically tunes to the S2X GSE-HEM signal and provides IP multicast data packets to the Far Edge Component (which is a micro form factor PC in this demo)

10. The Far Edge device in Betzdorf runs the DVB-NIP Gateway code and the caching apps, all orchestrated by the app orchestrator from SixSq: the Nuvla App.

11. The Nuvla App allows deployment of the FTA Airstream SW, which is then ready to serve any request for content.

12. The LAN, which hosts the FTA GW and the Nuvla App host is also connected to a Data Network of a 5G Network via a UPF.

13. The UPF is connected to a 5G Core running on a Virtual Machine (VM).

14. Both the Core and the UPF are provided by Athonet-HPE.

15. As part of the 5G Network deployed at SES a 5G Radio unit from Amarisoft was provided by SES: the Amarisoft Callbox Classic. The Amarisoft RAN component was connected to the 5G Core of Athonet-HPE. This integration required quite some effort as cloud connectivity issues and interoperability issues between sites and vendors had to be dealt with.

16. A UE connects to the 5G Network via the 5G Radio and has access to all the Satellite delivered content through the connected Data Network.

<u>Lessons Learned from the SES DTE Testbed</u>

One take-away lesson from this task was that 5G related setups with equipment from several vendors are not straight forward to deploy.

In 5G setups where:

a. Radio element is provided by one vendor,

b. the CP by another vendor,

c. the SIM is configured from a separate vendor,

d. and the UE may have special requirements (e.g., i-Phone specific configurations),

the result is that the system is very challenging to get to operate correctly internally, although all parts may be compliant to the same external standards.

Incompatibility between interfaces of the system give birth to issues which are hard to trace and even harder to attribute. Such issues are also commonplace with commercial vendor deployments where inside the overall system some key interfaces are not interoperable and may not provide the flexibility to easily change from one component to another.

In the test bed interoperability issues appeared between the HPE 5G Core, the Amarisoft Radio and the UE device with the test SIM Card. Three examples of interoperability issues that appeared are described also in text bellow:

1. Issue with lack of K value (Authentication Key (Ki) – This key is unique for each mobile number and is a 128-bit value code which shows that each SIM card number is authentic) and MCC code (Mobile Country Code): During tests with the Amarisoft 5G Core network – which was previously tested in the SES premises – test SIM cards without K value and with MCC value of 999 (internal use) was sufficient for the authentication and the registration of the SIM card of the UE to the Core network. From the other side, the HPE 5G Core network required a test SIM with a K value and did not register the SIM cards if the MCC was not set to the value 001 (Test network). This generated delays due to troubleshooting and the procurement of programmable SIM cards.

2. Issue with 5G slice SD value: Once more, the Amarisoft 5G Core network was able to register the Amarisoft 5G gNB without setting the 5G slice SD value. But the HPE 5G Core network required the configuration of the SD value to 00001 as to register the Amarisoft 5G gNB.

3. Issues with UE compliances: Tests of the HPE 5G Core network took place with Apple UEs in HPE premises. The latter UEs were not compliant with the Amarisoft 5G gNB.

The above (and other) examples indicate that an official 3GPP validation compliance tool could help find and potentially resolve interoperability issues. Based on our knowledge and test experience an official 5G compliance validation tool from 3GPP is missing. Such a tool, especially if opened sourced, could facilitate interoperability between different vendors across the industry.

However, we would like to highlight that all these issues have been resolved in the SES DTE testbed and there is no further work to be done in Phase 2.

3.3.1.3.2 DTE demonstrator at Arctic Space premises

The architecture of the DTE demonstrator at Arctic Space premises is shown in Figure 10.

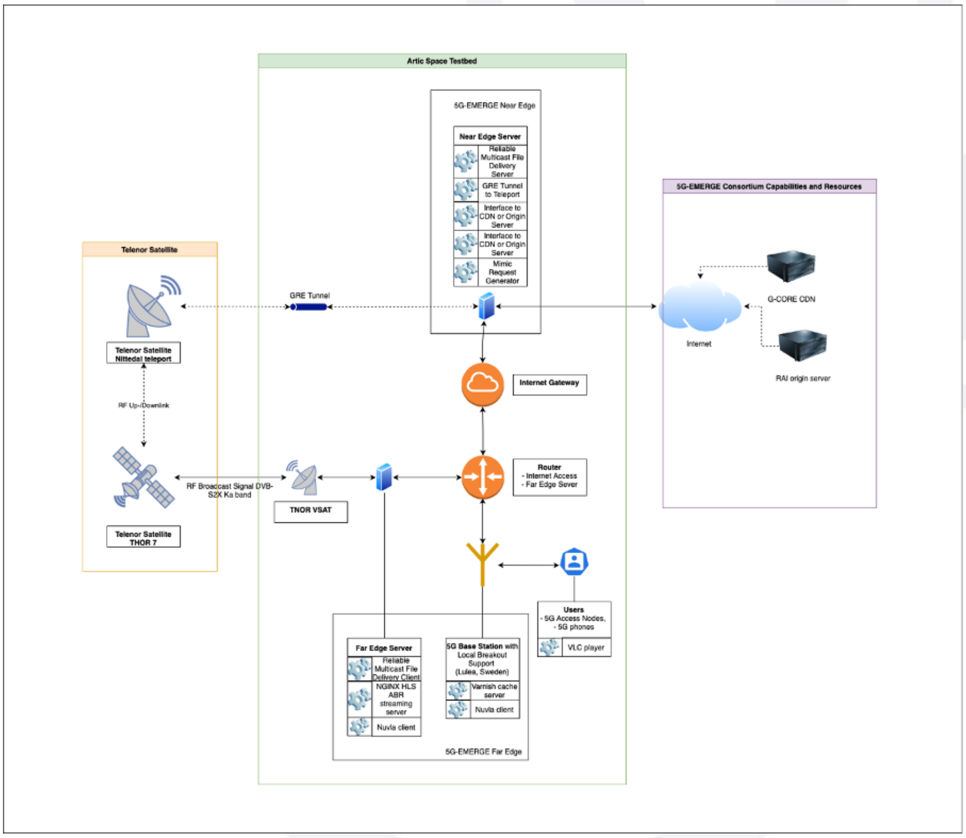

Figure 10: DTE demonstrator architecture and setup at Arctic Space premises.

The following partners and companies contributed to testbed implementation and setup:

- **RomARS** coordinated the demonstration in compliance with the DTE service definition, target KPIs and service requirements.
- **Telenor Satellite** contributed with a VSAT modem supplied with satellite capacity for both up- and downlink.
- **Varnish Software** contributed providing caching software to cache HLS streams requested by end-users on the 5G RAN Network.
- **Luleå Technical University (LTU)** [External Partner] Arctic Space has a collaboration agreement with LTU to access a 5G RAN Testbed with a local breakout interface. More information here: https://5ginnovationhubnorth.se/
- **SixSq** provides the Nuvla.io/NuvlaEdge solution for the dynamic deployment of the Virtual Functions at the Far Edge.

High-level description of the demonstrator:

- VoD content delivery for D2E - cache hit:

  1) Initial content pre-fetching on the far-edge caching is performed using satellite forward link. A popularity-based approach is considered. Although a single Satellite Terminal (ST) is activated in the demonstration, the satellite multicast transmission (IP-level) makes

demonstration valid in case of a pool of STs registered to the 5G-EMERGE system.
2) A user device sends a content request, which is redirected to the local cache (far edge).
3) The target content is locally cached and then can be directly streamed to the user coded with the most appropriate resolution. The video resolution is optimized, and delivery time minimized. At the same time terrestrial backhaul is not used.

- VoD content delivery for D2E - cache miss: In case of cache miss, the content request is forwarded to the CDN management system that triggers the sending of the content through the terrestrial connections (i.e. from the origin server or a CDN near edge cache) and evaluates (based on the total received requests for the same content) if multicast the target content through satellite multicast transmission updating the far edge caches.
- VoD content delivery for D2E - dynamic caching: The content requested by the UE is not available in the local cache and will trigger a "cache miss". The mABR Gateway will request the content remotely using a dedicated transport on the terrestrial link and the content is provided to the UE. In parallel, the CDN Management function will evaluate whether the content shall be pushed to the cache the UE is attached and near caches located in that region. This operation: i) will guarantee to the UE the content also in the near cache in case of mobility; ii) it will increase the probability that a content is present in the cache for other UE terminals.

The demonstrator was able to transmit static files as well as live streaming added to the Reliable Multicast File Delivery software.

A significant milestone was the standardization of how the Far Edge was going to be run. Previously, the Varnish caching service ran on a shared Kubernetes environment that was managed by the Research Institute of Sweden. The permissions on this multi-tenant system did not allow to deploy Nuvla. Nuvla is the edge orchestrator that is being used in the other test beds.
Therefore, in order to run Nuvla, a new virtual machine in the network of the Technical University of Luleå was deployed. This VM had Kubernetes installed with a Nuvla deployment, allowing it to deploy Varnish inside the same Kubernetes cluster. The newly deployed VM running Nuvla, was connected to the same 5G core network that the current Far Edge is connected to.

3.3.1.3.3 DTE Demonstrator at EBU premises by TNO

This section provides an overview of TNO's components envisaged for the 5G-EMERGE DTE use-case demonstration. These components are integrated into the DTH testbed developed and maintained by EBU within the ESA 5G-Emerge project (see section 3.3.1.1.1).

The components are as follows:

1. **SAND client and DANE**

The DANE (the DASH Aware Network Element) is an element of the architecture as depicted in SF4 of the SA diagram. It supports receiving connections from the SAND client plug-in and provides it with bandwidth usage suggestions based on the available media representations and network capacity. The SAND client plug-in is an element of the architecture as depicted in SF1 (Consumption part) of the SA diagram and it receives the aforementioned DANE suggestions and configures the player to follow the recommendations accordingly. The DANE and the SAND client plug-in exchange messages in standardized form in accordance with ISO/IEC 23009-5. As a result, the QoE (Quality of Experience) of the DASH player is enhanced, and network bandwidth utilization is improved.

2. **Private network 5G solution**

The 5G network is an element of the architecture as depicted in the architecture diagram in SF4. While the system architecture requires a public network, a private 5G network will be used for integration. From a functional point of view, it corresponds to the public Mobile Network Operator (MNO). The use of the 5G network will enable a terminal supporting this technology to connect to the Far Edge and take advantage of the Content Delivery provided by this system. It is to be noted that the demo describes a DTE use case. However, since TNO is not an MNO, TNO does not have rights to deploy a PLMN (public network). For this reason, and for the purpose of the demo, we had to deploy the network as an NPN (private network). From a functional point of view in the context of the demo, there is no difference between this private network and a public network, hence the reference to the SF4 diagram.

Figure 11 illustrates the TNO DTE demonstrator at EBU.

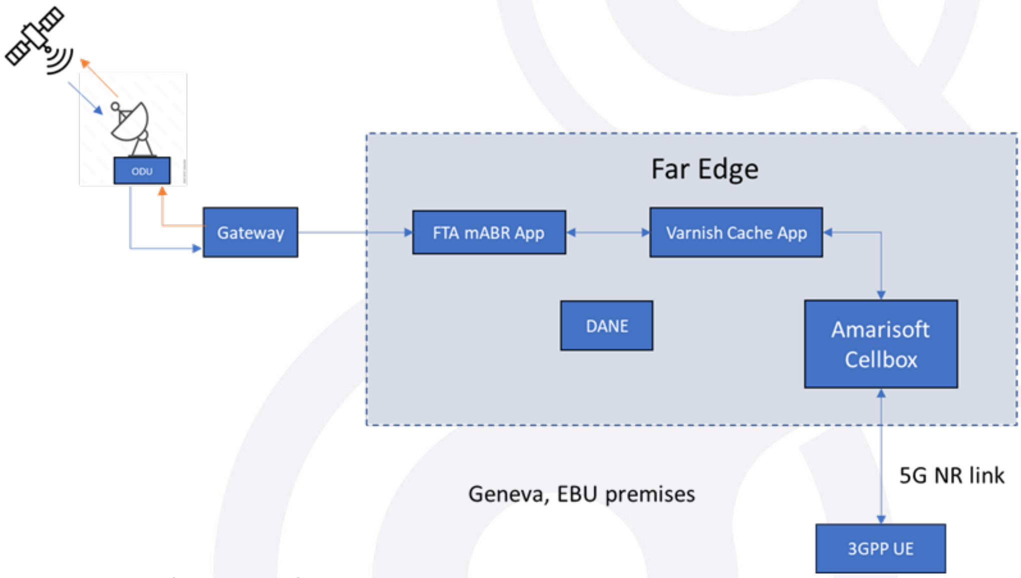

Figure 11: Diagram of the DTE demo at the EBU Far Edge.

This setup can use the satellite forward link only (with the Inverto Airstream box) or the Egatel bidirectional kit. Internet access is made through the 5G network.

The use case here corresponds to the situation where the user access to the 5G-EMERGE architecture is managed by a 5G Mobile Network Operator that makes use of the satellite capacity to provide the media services to the user.

The demonstration consists in accessing a live channel received from the satellite segment of 5G-EMERGE on a user device that is connected to the 5G network through a real 5G NR link, in the band 3.4 – 3.6 GHz.

3.3.2 The tests performed

The demonstrators were tested and validated both at functional and operational levels. A summary of the tests performed is provided in the sections below. A more detailed description is available in the Test Plan, Procedures and Report TPPR [RD26].

3.3.2.1 Functional tests

Functional tests were defined to validate the functionality of the 5G-EMERGE system and check its conformance to the requirements. Hence, the requirements defined by the System Architecture and Interface Control Document [RD8] (see also section 3.1), and TN1.4 [RD4] (via RTD - Requirements & Traceability Document, [RD5]) are covered with test cases.

3.3.2.1.1 General functional tests

The functional tests performed to validate each SF of the 5G-EMERGE system architecture are summarised below.

SF1 – Content Provisioning
On the content management side, the following tests were done:

- Validate the delivery and functionality of different type of services (VOD and Live services at high quality), different type of formats of streams (HLS, MPEG DASH) and of DRM encrypted content (Apple FairPlay, Google Widevine)
- Test the different areas of the encoder - security and functionality: validating the metadata, able to feed the Origin server using different protocols (HTTP, WebDAV)
- Validate the setup of the origin server and its connections
- Validate the CDN Load Balancing and Optimization to ensure the efficient functioning of the video streaming infrastructure, particularly in the context of CDN load balancing, geographical optimisation, and the integration of DNS-based and Anycast methodologies
- Verify the ingestion of metadata for both VOD and live assets and playout of A/V content on user device from the CDN

In the backend a verification was made of the account creation, content keys creation (by DRM) and licenses creation (by mDRM system).
Regarding the playout device, the following was done:

- Test ability to view content on different platforms, i.e. validating the apps/player on different platforms: Android platforms, iOS platforms, web browsers (Chrome, Safari, Firefox)
- Test the micro-edge and its connection to the end user device
- Test the content playback

SF2 – Cloud uplink preparation
Regarding the uplink edge, the following tests were done:

- Validate the Uplink Edge functionality, ensuring it generates, encapsulates, and delivers content over satellite networks reliably.
- Validate the remote management and capabilities of content to the service provisioning layer.
- Unicast Repair Mechanism – Automatic Request for Data Repair: Verify that the Far-Edge can automatically detect data loss during transmission and can automatically repair requested data

SF3 - SATCOM
The tests were done using Ku-band and Ka-band GEO satellites available which provide European coverage and satisfy the needed bandwidth requirements. The antennas used supported GEO satellite links and both linear polarizations (V/H). LEO and MEO were not tested in Phase 1.

On the RF uplink side, the tests ensured that the system supports the transmitted/received signals requirements on the Forward Link, e.g. polarisation, centre frequency, symbol rate and roll-off, transmit power, modulation and coding etc.

Some testbeds also validated the Return Link activation and configuration, to guarantee all the needed functionalities, i.e. to confirm that the far-edge terminal can correctly log-on to the bidirectional platform, and that the Return Link can be employed for content retransmission requests.

SF4 – Micro-edge device
One major test was the 5G-EMERGE Micro-Edge Orchestration and Management. This Test aimed to validate the modularity, remote management, orchestration, and deployment options of applications within the Micro-Edge containerized environment of the 5G-EMERGE project:

- Verify that different applications can run and interact within the Micro-Edge environment utilizing Nuvla/NuvlaEdge for orchestration, emphasizing modularity and micro-services architecture.
- Verify the remote deployment of applications on Micro-Edge devices using NuvlaEdge's management and orchestration capabilities.
- Validate that configuration changes can be made remotely on the Nuvla UI management interface and are correctly propagated to the applications running on Micro-Edge devices.

- Validate the compliance of the 5G-EMERGE Edge management and orchestration functionalities with the ETSI MEC standards within the Micro-Edge environment.
- Verify the deployment of the Gateway as edge hardware within the Micro-Edge environment, ensuring it meets the deployment options specified for the 5G-EMERGE project.
- Validate that a Gateway, once deployed as hardware, functions correctly with a configured and running Container Orchestration Engine (COE) within the Micro-Edge environment.
- Verify that the caching that takes place on the Micro-Edge devices shall ensure that upstream (unicast) content requests to the CDN are significantly reduced, by maximizing the so-called "cache-hit ratio".
- Verify that the cache has a Hypertext Transfer Protocol (HTTP) endpoint which can be remotely triggered to invalidate specific objects from the cache.

Regarding the applications, the major test was to validate that the SAND-enabled 5G-EMERGE player web application client successfully connects with a DANE deployed in the Micro-Edge, ensuring that as clients play DASH content, they receive bandwidth assignments from the DANE in a way that the combined assigned bandwidth to all clients does not exceed the maximum available bandwidth configured in the DANE.

The gateway tests ensured that the 5G system works as intended, either with all 5G Core components on the far edge, or with only the UPF on the far edge. The 5G system includes the 5G RAN:

- Verify that UE can attach to the 5G system, with all 5G components at the far edge.
- Verify that UE can attach to the 5G system, with UPF component at the far and the control plane functions on the public Cloud.
- On Telenor Maritime testbed, specific tests were performed to check if the user can access data over VSAT and TVRO. QoS tests were also performed in the Maritime test bed with up to 10 devices. All devices had the same QoS parameters (e.g. slice, APN, ARP, 5QI etc. according to 3GPP). Tests with an increased number of devices will be done in Phase 2 to get more statistics.

The LAN/WAN access options provided via wireless link were verified. The two main wireless access options were tested, based either on 3GPP (NR) and non-3GPP (WiFi) technologies.

SF5 – Service Provisioning

The objectives of the tests were to validate that the Service Provisioning layer of the 5G-EMERGE system adheres to 3GPP and ETSI standards, is capable of managing Near-Edge and Far-Edge hosts and can deliver MEC applications effectively. The following tests were performed:

- Verifiy the Service Provisioning layer's capability to establish and maintain a secure VPN connection with Near-Edge Hosts over terrestrial IP networks
- Assess the Service Provisioning layer's ability to establish and manage IP network connections with Far-Edge Hosts, utilizing terrestrial IP return channels where available
- Ensure that the cloud provisioning layer offers the required remote management and orchestration functionalities for the 5G-EMERGE system
- Assess the capability of both Near and Far-Edge hosts within the 5G-EMERGE system to dynamically deploy local applications, ensuring flexibility and responsiveness of the edge computing layer
- Verify that MEC applications are correctly packaged as Docker images and can be delivered and accessed through a Docker registry in line with the 5G-EMERGE project's requirements
- Evaluate the Network Function Virtualization Orchestrator's (NFVO) capabilities to dynamically instantiate resources at the Near and Far-Edges and to deploy Virtual Network Functions (VNFs) as required by the 5G-EMERGE system
- Verify that the Service Provisioning servers within the 5G-EMERGE system can run applications that collect and exchange data regarding consumption, quality of experience (QoE), quality of service (QoS), and end-user preferences

- Evaluate the processes and systems involved in collecting consumption and usage statistics performed by Nuvla B2B Cloud-Edge Management Platform to ensure they comply with the General Data Protection Regulation (GDPR)

Tests were also performed in the DTE demonstrator at the EBU-TNO to verify the presence of usage statistics and QoE/QoS in a DWH for use in the creation of dashboards and reports (see section 3.3.2.1.7).

The DTV maritime demonstrator performed specific tests to ensure proper orchestration of the 5G system (see section 3.3.2.1.4).

3.3.2.1.2 Specific functional tests at the DTH demonstrator at the EBU

The following tests were performed:

- Playing Video on User Equipment over the satellite Egatel bidirectional connections (Eutelsat and ASTRA satellites) through the Far Edge
- Connecting to internet by satellite through Far Edge to:
    - Update and deploy Far Edge App using Nuvla
    - Request a VOD without terrestrial internet connection
- Connection to the Far Edge through 5G components (Romars/HPE)
- Connection to Far Edge through a 5G node (NR) (TNO) (see section 3.3.2.1.7)

3.3.2.1.3 Specific functional tests at the DTH/DTE demonstrator at SES

The following tests were performed:

- Lock of FTA gateway on satellite signal
    - The purpose of this test was to check that content files are properly received by the Micro-Edge and are ready to be served to any video player connected to the network of the dedicated machine running the SES Far-Edge Nuvla App.
- Reception of live video streams in FTA webserver
    - The purpose of this test was to verify that the video files are received from the satellite by the FTA GW and the files are ready to be served to any video player connected to the network of the dedicated machine running the SES Far-Edge Nuvla App.
- Video playback through the FTA webserver
    - This test verified that the video files can be successfully served by the FTA Airstream component of the SES Far-Edge Nuvla App to any network video player.
- Video playback through Varnish webserver
    - This test verified that the video files can be successfully served by the Varnish container component of the SES Far-Edge Nuvla App to any network video player.

3.3.2.1.4 Specific functional tests at the maritime DTV demonstrator

The DTV maritime demonstrator (see section 3.3.1.2.1) performed tests to verify content access through 5G Core at the far edge. Three test cases were defined:

- Verify that the end-user devices connect to the Micro-Edge via 5G to retrieve the content. The test performed validated that a 5G connected user can access data over VSAT and TVRO from the far-edge.
- Verify that the end user connects to WiFi tethering device ("hotspot"). The test performed validated that the user can connect to a 5G "hotspot" to access data over VSAT and TVRO from far-edge.
- Verify that local content is available on the 5G device. The test performed validated that local content stored on the far-edge was available in the App on the 5G device (UE).

The main functional achievements were:

- Development and deployment of private 5G system
- Integration to far-edge hosting environment
- End-to-end integration with ecosystem

3.3.2.1.5 *Specific functional tests at the car DTV demonstrator*

Functional tests with the DTV car demonstrator (see section 3.3.1.2.2) were done to assess and validate the performance of the Egatel Modem IoT-First integrated with an auto-pointing Spark antenna from Viasat. Main Functional achievements:

- Both Multicast streams (FL and RL) were received from a moving vehicle with no packet lost.
- Capability of the Viasat Spark antenna of communicating with its on-purpose implemented antenna control unit (ACU). Then, using the information retrieved from the Egatel modem, enables GEO satellite auto-pointing and tracking the satellite.

3.3.2.1.6 *Specific functional tests at the DTE Arctic Space demonstrator*

The objectives of the tests were to:

- Validate that the UE terminal can access either public Data Network (DN) and Local Area Data Network (LADN) using 5G NR access.
- Verify that the services provided by the edge to the end user are in an optimized manner. An example is that the caching that takes place on the Micro-Edge devices shall ensure that upstream (unicast) content requests to the CDN are significantly reduced, by maximizing the so-called "cache-hit ratio". Another example is the offloading of the Near Edge by enabling satellite transmission of video content to the Far Edge server.

3.3.2.1.7 *Specific functional tests at the DTE EBU-TNO demonstrator*

The tests verified the presence of usage statistics and QoE/QoS in a DWH for use in the creation of dashboards and reports. The tests were performed as follows:

- The clients log player statistics to the metrics server (a configured influxDB server).
- The result is then displayed as graphs using a Grafana dashboard. Afterwards, the data is extracted from the metrics server for later analysis.
- The devices can register in the network and request resources accordingly.
- 5G network is there as an alternative access network that can be used to reach FarEdge.

The test result can be seen immediately with Grafana (see Figure 12 below), and the results are extracted from the metrics server (based on InfluxDB) afterwards to further analyse all the data after the test.

Figure 12: Display of the QoS data collected at the DTE demonstrator by TNO at EBU premises.

3.3.2.2 Operational tests

3.3.2.2.1 A/B testing

Non-functional tests were performed on the 5G-EMERGE chain to evaluate performance and advantages of the system compared to other content delivery solutions (A/B testing method). These operational tests targeted A/B testing in the different use cases, to compare QoE metrics between content retrieved from the CDN, and content retrieved from the 5G-EMERGE DTH (EBU testbed), DTV (Telenor Maritime testbed), DTE (SES testbed) systems.

A first campaign of A/B testing was conducted on June 4-5 but turned out not to be conclusive as metrics from the 5G-EMERGE chain were not available in the player.

The rerun of A/B testing took place over three days –28-30 August 2024. The metrics from all apps over the three days were collected and an analysis report was provided using the Tableau dashboard. However, the aggregated metrics did not fully reflect the user experience. Raw data was then extracted and analysed by testbeds to draw accurate conclusions. This required substantial work and needs to be improved in Phase 2 to automate the metrics analysis.

On the first day, in the DTH testbed at the EBU the performance of the 5G-EMERGE proposal was compared to an internet connection throttled to 2 Mbps. This choice was made to simulate real situations where an internet connection is congested due to large number of users or where internet speed itself is limited due to suboptimal infrastructure.

On the second day streams of assets were played from CDN only over broadband Internet by Nagra players. On the third day, streams were played from hybrid satellite only via the far edge devices present on the EBU and SES test beds.

On three days of testing, distinct devices were used (mixture of Android and iOS devices). Tests were performed with live content and with VoD content.

The tests showed that when comparing the QoE data from the more centrally located CDN-cache in the network with the playout session data from the local (far) edge cache, there were no substantial differences. The quality perspective of end users is the same when enough internet bandwidth is available. A more operational conclusion drawn from the testbeds is the need for Quality of Service monitoring at different interfaces of the service delivery chain and end-to-end service QoS orchestration and management. Especially when multiple components provided by different vendors/actors are active in the chain, a jointly defined open telemetry protocol to aggregate comparative operational data is essential.

The tests also showed that via the throttled internet connection of 2 Mbit/s the adaptive bitrate stream of the test content scaled down to 1 Mbps and could only be displayed on one device. The local (far) edge is not limited by the internet connection bandwidth. The cache on this edge could serve the highest available quality streams to multiple devices at the same time, proving one of the advantages of satellite enhanced edge delivery.

Latency measurements were performed on the Arctic Space testbed, to demonstrate the ability of the cache to accelerate streams delivery over 5G.

In all tests, video playout applications on end user's devices were re-directed to the local cache through a fixed url. Optimisations can be made by improving the efficiency of the transport mechanism by selecting more popular content and improving automatic service discovery in local and metropolitan networks, which are addressed in the second phase of the project.

3.3.2.2.2 Loading tests at the DTH demonstrator at SES

Additional operational tests took place at the DTH demonstrator at SES: loading performance tests. The main question which the SES performance tests wanted to answer was the following:

How many content viewers can stream from a specific webserver under specific network conditions, without any issues?

The number of supported viewers (under specific network conditions) is a critical factor for sizing the resources of a 5G-EMERGE system, e.g. network bandwidth, CPU power of webserver and RAM size of webserver.

Therefore, the following variables were monitored and documented in each performance test:

- CPU and RAM of webserver.
- Type and bandwidth of network connection between server and client(s).
- Presence of absence of reverse proxy (Varnish container) for serving content already delivered to another player in the recent past.
- Number of players (clients) connected to server.
- Presence of errors in the delivery of the files (manifest or segment).
    - Type of error if error is present.
- Total bandwidth used by sum of players.
- Max and average latency time between the request of a video segment and the receipt of the segment.

To simulate the loading of the network a few standard tools were tested without success: Ab – Apache Benchmark tool, Apache Jmeter. It was then decided to develop a simple program which generates a pool of async, concurrent video HLS players.

The loading tests for both the Varnish webserver and the FTA Airstream webserver were repeated multiple times. Up to 220 simulated users were able to stream a live video content of 4.5 Mbps from a local edge via a 1 Gbps connection channel. The following conclusions were reached:

- Network Interface Card Bandwidth is first resource to saturate.
- Varnish container increases system stability.
- Current system is over-sized for DTH scenario.

The next steps are:

- Test with 10Gbps Network interfaces
- Add monitoring on CPU and memory usage.
- Perform load performance tests on integrated FTA Airstream live webserver.
- Generate Docker container of application for fast test deployment.

3.3.2.2.3 Latency between the origin server, CDN server and the mABR server

The mABR server operates in real time, requiring stable responses from the origin server (segmenter) or from the CDN server when the MABR server is connected through a CDN.

During tests, it was observed that the response delay from the RAI origin server to the CDN server and from the CDN server to the MABR server was inconsistent, occasionally taking up to several seconds. This caused reception errors at the far edge as segments were not delivered on time to the playout application (e.g. Nagra app or VLC player). The reason for the inconsistent delay is related to the way CDN servers cache content. CDN servers would cache content once it has been requested by a client so the next client that would request the same, will receive it quickly from the CDN server cache directly. However, in the 5G-EMERGE test setup the CDN server has only one client requesting content – the MABR server. Consequently, all the requests received from the mABR server are the first requests for it and therefore the CDN server won't have it in its cache and will be required to fetch it from the Origin server first.

To mitigate this issue for the 5G-EMERGE testbeds, a 10s buffering was added to the mABR server at the Near Edge. On one hand, the 10s buffering ensures ample time for the MABR server to receive all the segments and maintain smooth video streaming; however, on the other hand, the 10s buffering directly translates into a 10s time-shift for the end user devices. In test environments, such buffer length may be reduced by means of fine tuning against actual maximum segment download time from the CDN, or by "warming-up" the CDN POP artificially i.e. uploading content to the CDN server without waiting for the mABR to request it first. In this case, when the mABR server requests the CDN server for a segment, the CDN server will serve it directly from its cache.

Furthermore, some additional measures for mitigating the issue have been identified:

i) In principle, a possible option could be co-locating the Origin and mABR servers and feeding the mABR server from the Origin directly; however, there are a number of advantages for feeding the mABR server from a CDN (instead of from the Origin directly):
  - CDN significantly decreases the load level on the origin, as it accumulates all the requests on CDN servers, caches and pre-caches content that can serve directly to the mABR servers, reducing the number of requests the Origin needs to handle directly. CDN also reduces the cost of infrastructure as installation costs of the mABR servers and the origin at Data Center are avoided.
  - Gcore CDN has an optimized internal network which helps to find the optimal and fastest routes for the connections.

ii) optimise internetworking between Origin server and CDN

iii) employ the latest Live stream Low Latency protocols instead of the traditional HLS/MPEG-DASH:
  - LL-HLS CMAF - with fragmented MP4 chunks.
  - LL-MPEG-DASH CMAF - where the last segment is uploading constantly via chunked transfer. So segments are not needed even to be fully cached on CDN. This requires all the components of the 5G-EMERGE chain to support LL-DASH and chunked delivery and may imply even stricter requirements in terms of response time from the Origin server to the CDN server.

It was concluded that in test environments, to fully test CDN performance you need to artificially send a lot of requests for the content to “warm up” the cache and see how CDN will behave with the real content. If it’s just a small number of requests, the CDN will go every time to the origin and that will cause delays as happened during the tests.

3.3.3 Additional technical development activities

During the development phase, the consortium identified that to implement the DTH nomadic use case and the DTV car use-case, there was a need for the development of specific antennas for each case as summarised below. Further details can be found in [RD31].

Antenna for vehicles

The design of the antenna for a direct to vehicle scenario is highly crucial and demanding among most use cases. The antenna for this case must be smaller in size, lower in weight and low-cost [RD3, RD5]. This antenna should be able to lock with the satellite during the continuous movement of the car and survive all sorts of weather conditions, achieving the desired gain in all cases. Due to the challenging requirements, LINKS did extensive research to find a solution able to cover the entire Ku-band, while maintaining the overall dimensions as small as possible (specifications in Table below).

A planar phased array antenna has been designed using a stackup configuration consisting of radiating elements fed through series striplines, which have an excellent EMI shielding and low emissions. The passive part of the antenna is divided into identical modules; this modular design helps in faster fabrication and testing, since the entire antenna can be created just combining these modules. In the designed antenna, each module consists of 8x16 radiating elements and the fabricated prototype is obtained by combing two of these modules, resulting in 8 rows of 32 elements. The cost of the proposed antenna is reduced by the use of series feed for one direction. A lot of research has been performed to design this series feed configuration covering the entire Ku-band. The series feed also covers the beam tapering giving a very good beamwidth with reduced side lobe level across the entire band. The modules are connected with a simplified control board via connectors to help ease installation and to keep the electronic and passive part separate.

Table 1: Specifications of the antenna designed by LINKS (8x32 elements)

Parameter	Specification
Link	GEO
Frequency	10.7 to 12.75 GHz
Polarization	Linear
Angular Steering Range	0° to 50° elevation
Antenna Gain over steering field	24 dBi (50°) to 27 dBi (0°)
In-plane dimensions	14x60 cm^2
Height	< 10mm (approx.)

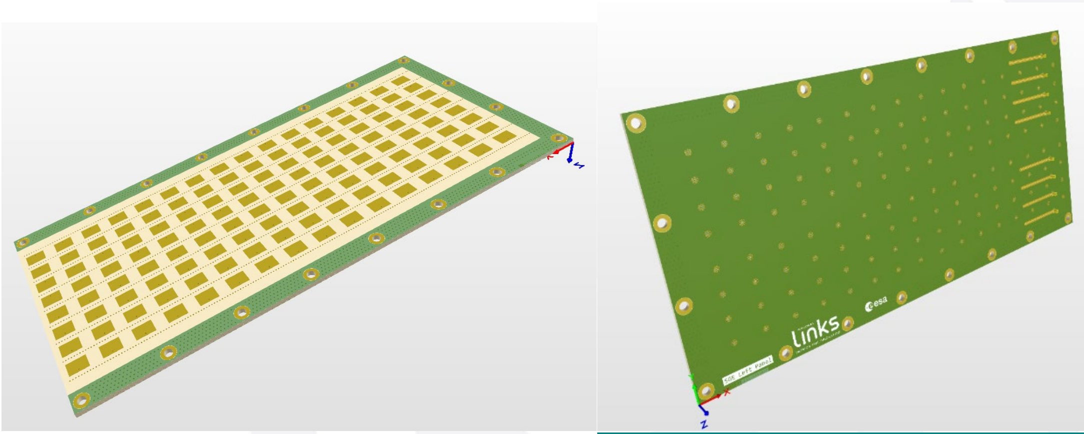

Figure 13: Top view (left) and back view (right) of a 8x16 module forming the fabricated antenna.

Nomadic terminal

The nomadic use-case (see §2.2) requires a low-cost and low-power consumption satellite user terminal that is compact and light enough for fixed and nomadic applications and can automatically locate the satellite position in the sky without requiring a user intervention other than broadly looking towards the satellite arc. The 5G-Emerge project is developing a solution which involves creating a portable terminal with a small laptop-sized reflector that can be broadly positioned towards the sky by a human but fine-tuned automatically using a phased array feed.

The development is based on patented miniaturized meta-filtering antennas, which employ resonant metamaterials to manipulate waves at ultra-compact sub-λ scale and in a full-metal structure with very low loss comparable with other planar antennas. The monolithic integrations of metallic components and their integration into the planar platforms enable to fabricate small and energy-efficient array antenna for the beam steerability. These advantages add a minimal height (usually < λ/2) to the antenna, so a semi-planar structure is obtained. Other notable advantages of the MinWave antenna are the ability to provide switchable linear H/V and circular RH/LH polarizations and integrated miniaturized filters or multiplexers. Integrating MinWave's patented metamaterial diplexer to the wide-band antenna allows the separation of RX/TX in this architecture and the building of a full duplex terminal.

Figure 14: Folded reflector, the overall system package that is about 30x25x5 cm³.

The developments have been structured as follows:

- Detailed design of a feed array capable of both transmitting and receiving signals within the frequency range of 10.7-14.5 GHz.
- Implementation of the feed array system and performance of the modular tests on the feed system.
- Assembling the terminal, carry out the assembly process and perform modular tests, ensuring seamless communication between the antenna system and the modem, and implementation of beam steering algorithm along with the tests in the Anechoic chamber.
- Test the integrated system, prepare the full documentation of the system and also the proposal for the industrialization phase.

3.3.4 Summary conclusions of the development and testing phase

The main outcome of Phase 1 is the successful setup and integration of all technologies brought by the project into a common 5G-EMERGE system, which can be adapted to the different use cases.

Six demonstrators in different locations for the DTH, DTV and DTE use cases were built. Different micro edges were developed and optimised for each use-case. The DTH nomadic use-case and the DTV car use-case triggered the development of specific antennas.

One challenge that was reported is the integration of the 5G components with the rest of the 5G-EMERGE system architecture. The integration highlighted cloud connectivity and interoperability aspects that had to be dealt with. Interoperability tests and common test procedures in 3GPP standardization bodies could help in improving this situation.

Functional tests validated the functionality of the 5G-EMERGE system and checked its conformance to the requirements defined. Additional functional tests validated specific functions developed in each testbed. In the DTV maritime use-case, the TVRO receiving antenna used was on the land and not installed on a ship. Tests onboard a vessel are envisioned in Phase 2.

The demonstrators also proved the operation of the end-to-end functionality of the full delivery chain. Relevant content on the basis of the playout requests is selected and transported over satellite and stored on the distributed caches in the far-edges. The more content is played out from these distributed caches, the more efficient the satellite-enhanced-edge-delivery model becomes.

Operational A/B tests were also defined to compare the Quality of Experience of viewers via the 5G-EMERGE hybrid satellite system (via far edge – local micro CDN) and via a broadband (via internet - CDN) connection. A mixture of Android and iOS devices were used and tests were performed with live content and with VoD content.

When comparing the QoE data from the more centrally located CDN-cache in the network with the playout session data from the local (far) edge cache, there were not substantial differences. Quality perspective of end users is the same when enough internet bandwidth is available. A more operational conclusion drawn from the testbeds is the need for Quality of Service monitoring at different interfaces of the service delivery chain and end-to-end service QoS orchestration and management. Especially when multiple components provided by different vendors/actors are active in the chain, a jointly defined open telemetry protocol to aggregate comparative operational data is essential.

Tests also addressed the case of an internet connection throttled to 2 Mbps. This choice was made to simulate real situations where an internet connection is congested due to the large number of users or where internet speed itself is limited due to suboptimal infrastructure.

The tests showed that via the throttled internet connection of 2 Mbit/s the adaptive bitrate stream of the test content scaled down to 1 Mbps and could only be displayed on one device. The local (far) edge is not limited by the internet connection bandwidth. The cache on this edge could serve the highest available quality streams to multiple devices at the same time, proving one of the advantages of satellite enhanced edge delivery.

Video playout applications on end user's devices were re-directed to the local cache through a fixed url. Optimisations can be made by improving the efficiency of the transport mechanism by selecting more popular content and improving automatic service discovery in local and metropolitan networks, which are addressed in the second phase of the project.

Live video streaming load tests were performed in one testbed. Up to 220 simulated users were able to stream a live video content of 4.5 Mbps from a local edge via a 1 Gbps connection channel. Streaming load tests will also continue in the next phase. The number of supported viewers is a critical factor for sizing the resources of the 5G-EMERGE system, in terms of network bandwidth, including satellite, CPU power and RAM size of the webserver.

3.4 The security posture of 5G-EMERGE

5G-EMERGE is an innovative platform that must comply with various data security requirements. These include, among others:

- Security requirements for audiovisual content
- Personal data protection regulations
- Cybersecurity best practices

5G-EMERGE consists of multiple components, each implementing specific tasks and technologies. A review of the security aspects of the components that process data is provided in document [RD22].

The likelihood and impacts of cybersecurity risks specific to each component is documented, with a focus on multimedia content and personal data. This documentation also includes some aspects related to content tampering for activism or sabotage reasons.

Cybersecurity best practices related to commonly used components by Consortium members have not been listed in detail, as Consortium members are aware of these best practices. The focus has been put on components developed specifically for 5G-EMERGE.

Future cybersecurity testing, such as penetration testing, will need to focus on risks and components identified as high impact, considering operational, reputational and financial consequences.

3.5 Distribution of 5G-EMERGE services using blockchain

5G-EMERGE provides an innovative and flexible content distribution platform. Such innovation must also be reflected in the onboarding process of businesses on 5G-EMERGE.

Use of blockchain provides the flexibility needed, simplifying greatly the access to the platform and the billing process.

The document [RD22] provides a high-level description of 5G-EMERGE architecture and components impacted by the addition of blockchain.

5G-EMERGE architecture does not require major modifications for adding blockchain and only a limited number of components would require modifications to implement the interfaces to the nodes.

The selection of the blockchain technology itself is a business decision that depends on governance, costs and confidentiality aspects.

4 The business development

The 5G-EMERGE ecosystem was designed to address market requirements for media delivery services addressing a range of use-cases (defined in section 2.2). As a result of a careful analysis of the market requirements, available solutions and their shortcomings, a technology stack was selected, a system architecture was designed, and a market proposition was developed. The various prototypes, demonstrators and test campaigns have proven that the selected technologies and system architecture properly address the market requirements and pave the way for putting together an industrialization plan for a commercial 5G-EMERGE platform. In this section the key market requirements, and a successful launch strategy are summarized.

4.1 Market requirements analysis

Interviews conducted with industry experts, both internally within the project and externally, paint a cautious picture of the demand today and in 5-10 years' time when it comes to the different 5G-EMERGE services in isolation (i.e., stand-alone value) and as a competitor to incumbent solutions (i.e., terrestrial infrastructure).

The perceived value and consequent demand for the proposed services are greater when considering the services as complementary both to each other and to existing infrastructure. The business case should consider this in developing the proposed services into a full offering.

Combined with the market sizing assessments conducted in [RD14] we conclude on demand and commercial attractiveness for the proposed services. Below follows assessments of the proposed services in isolation and as components of the 5G-EMERGE ecosystem.

4.1.1 Market size, demand for 5G-EMERGE services, drives of and barriers to adoption

The analysis presented in [RD14] estimates of the total addressable market and potential demand per use case. It shows a large market potential for some use cases and limited evidence for others. It concluded that there are significant synergies that are prevalent when realizing a broad range of media delivery use cases within a common 5G-EMERGE ecosystem, which lowers the passing threshold of a commercial viability level compared with a corresponding level for individual use cases.

The analysis presented in [RD14] concludes that the following are key market data that should be gauged and validated prior to developing a launch strategy for a commercial 5G-EMERGE service:

- Interest from individual users in direct-to-home services
- Interest from the business users in using 5G-EMERGE services, e.g. building owners, hospitality businesses, shipowners, train and bus operators
- Quantified interest from operators and service providers. e.g. number of operators willing to consider launching 5G-EMERGE services, number of broadcasters and other service providers interested in providing services on 5G-EMERGE
- Trends of consumer's media consumption habits and how the 5G-EMERGE ecosystem supports these trends

Key factors for adoption for different players are also highlighted:

- Potential for revenue and profit generation is key for network operators and service providers
- The ability to extend market reach for their live and on-demand content while maintaining coherent, predictable, and manageable costs is key to content providers.
- The ability to benefit from cost savings
- The ability to increase operational flexibility
- Affordable pricing, quality of user experience and an extended set of services is key for end users' service adoption.

4.1.2 Business model and financial feasibility analysis

[RD15] developed an end-to-end cost model for a 5G-EMERGE service based on assumptions for user penetration rates, revenues, CAPEX and OPEX. These assumptions are preliminary and need to be refined for specific deployment scenarios yet allowed to demonstrate that there is a financial feasibility for 5G-EMERGE services.

In further work carried out within the scope of this [RD16], additional key cost factors were identified and could be used for fine tuning the cost model developed under [RD15] and add more weighted business parameters to the model:

- Infrastructure deployment and the associated initial CAPEX required before services can be launched, including for example:
  - The number of satellites (constellations) to be used
  - The number of caches and edge devices which would need to be deployed and orchestrated.
  - Cost and conditions of deployment inside telco networks
- OPEX in comparison with the baseline, expected costs per month/year, e.g. cost per cache installed, infrastructure costs
- Time to market (weighted parameter, e.g. <6 months/6-12 months/>12 months))
- Required number of users to ensure profitability
- Expected revenue per year/month
- Potential for growth of market share of the current services (weighted parameter e.g. low/medium/high)

From the consolidation of the markets and the retrieving of the costs, the cost mode draws those preliminary results:

Table 2: Estimated costs for the different 5G-EMERGE use-cases (from [RD15]).

Use case	Individual home	Nomadic gateway	Residential collective buildings	Moving 5G base station (excl. cars)	Maritime network node	**Total**
Maximum user penetration and time to ramp-up	1% in 8 years	1% in 8 years	1% in 8 years	2% in 6 years	5% in 5 years	
# of edges after ramp-up	500'000	88'000	3'700	49'000	16'000	**660'000**
Revenues after ramp-up	218 M€/year	50 M€/year	17 M€/year	160 M€/year	160 M€/year	**605 M€/year**
Cumulative CAPEX after 10 years	1'100 M€					
OPEX after ramp-up	71 M€/year					
License	56 M€/year					

In these calculations, the following assumptions have been considered:

- Costs are the sum of the costs of specific use cases and the costs incurred along the entire value chain (e.g., satellite cost).
- Penetration rate is preliminary and will need to be refined in Phase 2 with scenarios.
- Other markets are considered as upsides.

4.1.3 Technology readiness and commercial products availability

Commercial availability of equipment and functionality in networks and user devices is a key prerequisite for the launch of 5G-EMERGE which also has a defining impact on the timing of the launch.

4.1.4 Content availability

Another key prerequisite for 5G-EMERGE is access to sufficient amount of attractive content. Apart from the acquisition costs, content availability is defined for specific territories, distribution models, and protection requirements (DRM) imposed by the content owners (see "Commercial strategy and execution" in [RD16]).

4.1.5 Legal framework and regulatory requirements

Requirements in this category include:

- The possibility to obtain the necessary licenses, e.g. for transmission or the provision of media services
- Compliance with 'horizontal' regulation, e.g. user privacy and data protection, security

- Any specific obligations placed on media services providers or network operators (e.g. 'must carry' obligations or universal service obligations).

In some cases, and depending on the scope of deployment, these requirements may be substantial and resource intensive. On top, the legal status of piracy and the efficiency of law enforcement shall be examined for the target territory.

4.2 Launch Strategy

From an operators' perspective the main factors that will influence the adoption of 5G-EMERGE include revenue potential, cost efficiency, and operational flexibility. Content providers also seek to extend the reach of their content and services but with predictable and manageable costs. The end users look to benefit from the coherent pricing, improved quality of experience, convenience and easiness of access to content and the extended service offer.

Launch strategies need to consider the financial aspects (costs vs revenues) associated with the intended deployment as well as a number of non-financial pre-conditions that may influence the business viability. The key KPIs fall into several categories, including

- Market size, demand for 5G-EMERGE services, drives of and barriers to adoption
- Costs and revenues
- Technology readiness and commercial product availability
- Content availability
- Legal framework and regulatory requirements

Many of these KPIs are not easy to quantify. They are specific to a targeted market segment, territory, and deployment scenario and can be fully assessed only in the development of a launch strategy for a specific deployment scenario.

Launch strategies should leverage the capability of the 5G-EMERGE solution to switch between satellite and terrestrial IP delivery based on a set of policy criteria, e.g. delivery over the satellite where this is more cost effective than terrestrial and vice versa. Switching policies can be developed for different criteria related to, for example, coverage, type of content, or type user device.

5G-EMERGE enables different business arrangements within the value chain. For example:

- In the direct to home use cases the edge, located either in individual homes or in collective buildings can be operated either by the satellite operator, the telecom operator, the audiovisual media service provider, or by a 5G-EMERGE service provider.
- The first three options represent an extension of the existing models whereas the fourth option involves a new entity – 5G-EMERGE service provider – which partners with content providers, infrastructure operators, hardware and service providers.
- In some market segments, such as hospitality or collective housing the existing service providers could assume the role of 5G-EMERGE service provider.
- In automotive use cases the edge can be operated by the same operators as in the DTH use case but also by the transport operator (e.g. ship, train, or bus operator) or by the third party, most likely on a business-to-business basis.
- In the direct to network node use case the 5G-EMERGE edge operator and the operator of the network node may or may not be the same organisation.

The 5G-EMERGE ecosystem can serve different market segments and is not limited to media delivery. The edge allows for deployment of specific functionalities to target different use cases that can benefit from satellite delivery.

5G-EMERGE enables different business cases, timelines, and decision points. It also provides flexibility in launch strategies. The key points to consider include:

- The processing power required at the edge depends on the use case and service/application requirements. Scalable approach is possible, for example:
    - Where cost is critical the edge could be designed with a minimum functionality
    - High-end/high capability edge can serve a range of different use cases
- Multi-tenant environment is enabled for the back-end functionality. It is considered not to be necessary for the edge. The requirement is that multiple service providers should be able to reach the users via the same edge device. The edge device will discover the available services and offer them to the user.

It is necessary to consider what would be the optimal size of a deployment of 5G-EMERGE and a sustainable growth rate. If the scope is too small, it will not be able to generate sufficient revenues. On the other hand, too large a deployment or too fast expansion would require large investments and carry additional risks, e.g. in the case of a technical problem the magnitude of a possible impact would be high.

In the direct to home category the retail market for 5G-EMERGE end-user devices different approaches are possible, for example the existing operator or re-seller models, or software-only deployment for the user devices that enable it. Another possibility is to work with service providers that already serve a particular market segment, such as ICT providers in the hospitality sectors or connectivity providers in the maritime sector. And it is likely that all of them will be used in practice.

While commercial deployments are unlikely to start before the end of Phase 2, some project partners consider that after Phase 1 their main efforts should be put into system integration and early deployment.

4.3 Dissemination activities

Dissemination activities are indispensable for making the industry aware of a new technical project, enabling knowledge transfer, fostering collaborations, supporting exploitation and commercialization, and contributing to standardization and policy-making efforts. Effective dissemination ensures that the project's results reach the relevant industrial sectors and stakeholders, increasing the chances of successful adoption and impact.

During Phase 1 of 5G-EMERGE, the following dissemination activities have been undertaken:

– Preparation of technical reports for internal ESA usage delivered by each of the work packages.
– Creation of a 5G-EMERGE web site.
– Creation of public papers, including White Papers.
– Publication of News/Press Releases.
– Presence of the 5G-EMERGE project in industry events and conferences.
– Presence in Social Media.
– Production of videos for testbeds and others.

[RD29] provides further details of each activity.

These activities have been instrumental in reaching many specialists and engaging with industries representing different stakeholders of the whole 5G ecosystem. This has been reflected in the increase of partners that have joined the 5G-EMERGE consortium during Phase 1. Similar dissemination activities with increased use of the website and LinkedIn Project will be essential during Phase 2 of the project to provide the industry and market visibility that will be key in the success and viability of a 5G-EMERGE service.

5 Summary Outcome of Phase 1

This section summarises the major outcome of Phase 1 of the 5G-EMERGE project, including lessons learned that will be considered in Phase 2.

Design and goals before the sprints

The first part of the project was one of the most critical. In this timeframe, the partners worked together to sculpt the basis of what came afterwards. Several iterations of review and reshaping of the deliverables were needed to come to a solid foundation. In this regard, one of the lessons learned was the importance of having every part of the design and goals settled before starting the development sprints.

Starting from the very beginning, the definition of the use cases proved to be one of the most crucial and important tasks. In fact, not only it served as the basic input for the whole value-chain and industrialization strategy identification, but it proved to be critical also for the definition of the target services, their QoS and QoE that needed to be satisfied by the project developments. This work led naturally to the identification of the main scenarios on which the project needed to focus, as well as the main market drivers (i.e. terrestrial networks' congestion, distribution costs, sustainability) addressed by the 5G-EMERGE ecosystem.

Definition of all the fundamental blocks of the chain

Along with the work described so far, the first draft of the 5G-EMERGE ecosystem architecture started to take shape. In retrospective, one of the most useful accomplishments of this task was to have a clear and "simple" high level definition of all the fundamental blocks of the chain, each encompassing a well-defined function of the ecosystem, with clear boundaries and interfaces separating them. This definition, at first, led instinctively to the wrong way of treating the elements of the chain as "self-confined bubbles", an approach that very soon proved to be limiting and ineffective. Only when the partners understood that the target was to have an ecosystem, rather than a collection of products, the quality of the outcome started to rise. While doing this, two other insights became very clear: on one hand, the importance of relying on standards to connect all the SFs and building blocks between them and, on the other, the critical role of different layers of orchestration for the correct management of the ecosystem.

Definition and quantification of the KPIs

Another difficult and time-consuming task was to establish and quantify the requirements and KPIs to be gathered in the RTD [RD5]. The difficulty of this task lay in the definition of the KPIs, especially performance KPIs, for such a vast and heterogeneous ecosystem. The exercise of finding out what was the state-of-the-art of the various "blocks", what could be already leveraged and what was missing, led to the definition of the Critical Technology Element (CTE) document [RD7]. This document and the work behind it proved to be very useful to realize what could be achieved in the project and in which timeframe. It also proved to be very valuable for the requirements' traceability throughout the project, as well as in the definition of the tests to be performed in the different testbeds.

Definition of the system architecture to address the Use Cases

The final 5G-EMERGE system architecture was defined after evaluating and considering the different Use Case scenarios defined. Based on the evaluation of relevant technologies for different components in the 5G-EMERGE ecosystem, the final selection of technologies was provided. Finally, the development requirements and planning for the agile sprints to be performed were defined.

A review of the requirements was done for each of the three Use Cases and showed some critical issues on the system (i.e., functional), service and performance layers that had to be considered.

Availability of the technical components and integration with 5G technologies

One of the critical aspects that all the three Use Cases had to have in common was the installation and configuration of a 5G system including the orchestration framework capable of providing access to the 5G-EMERGE services via 3GPP (i.e. 5G-NR) or non-3GPP technologies (i.e., Wi-Fi or Ethernet cable). Another important aspect to be considered was the caching algorithm, which had to be configured so as to minimize the transmissions over terrestrial network and especially the use of the satellite.

Furthermore, an analysis was carried out to establish the level of availability of the components envisaged for each SF and required for the realization of the 5G-EMERGE eco-system. Most of the components were available, while for others, development or integration activities were required; however, no criticalities had been identified. Although it is important to note that the integration of the 5G components with the rest of the 5G-EMERGE system architecture highlighted cloud connectivity and interoperability aspects to be addressed. Interoperability tests and common test procedures in 3GPP standardization bodies in the future could help in solving this situation.

Development activities

There were two main development activities: the development of the mABR server and of the mABR Gateway.

- The mABR server was developed as a cloud service but can also be installed locally for an on-premises deployment. The mABR server pulls file-based content of any sort of e.g., DASH/HLS streams or any type of file, encodes the files into FLUTE (File Delivery over Unidirectional Transport) stream and generates a multicast stream to carry the FLUTE packets. In addition, it generates certain signalling data of the content carried inside the streams to allow the user playout device to browse through the content and select the content to playout. As 5G-EMERGE decided to adopt the emerging DVB-MABR and DVB-NIP specifications for content delivery over satellite, we followed the evolution of these two new standards and implemented their specifications accordingly.
- The mABR Gateway was developed to receive the satellite mABR stream, extract the FLUTE packets out of the multicast packets, de-encapsulate the FLUTE packets, store the delivered files on a local storage and publish them over an HTTP server for consumption by end-user devices or other edge devices depending on the supported Use Case scenarios. Hence, the mABR Gateway implementation highly depends on the target Use Case scenario the system intends to address.

More information for all the development and integration activities can be found in the Detailed Design Document (DDD) [RD9].

During the development phase, the consortium also identified that to implement the DTH nomadic use case and the DTV car use-case, there was a need for the development of specific antennas for each case [RD32].

Demonstrators and tests

Six demonstrators in different locations for the DTH, DTV and DTE use cases were built. The demonstrators were tested and validated both at the functional and operational levels.

Functional tests validated the functionality of each system function of the 5G-EMERGE system architecture and checked its conformance to the requirements defined. Additional functional tests validated specific functions developed in each testbed.

In operational terms, when comparing the QoE data from the more centrally located CDN-cache in the network with the playout session data from the local (far) edge cache, there were not substantial differences. Quality perspective of end users is the same when enough internet bandwidth is available. However, when the internet connection has bandwidth limitations, the local (far) edge has clear advantages as it is not limited by the internet connection bandwidth. The cache on this edge could serve the highest available quality streams to multiple devices at the same time, proving one of the advantages of satellite enhance edge delivery.

A more operational conclusion drawn from the testbeds is the need for Quality-of-Service monitoring at different interfaces of the service delivery chain and end-to-end service QoS orchestration and management. This will be considered in Phase 2.

Further details of the summary conclusions of the test results are provided in section 3.3.4.

Security aspects and recommendations

The review of the security aspects of the new components developed for 5G-EMERGE and of its overall architecture provided a certain number of Recommendations. In Phase 2 of the project there will be a focus on the improvement of the security of the Operating System (OS) layer of the edge devices implemented in the 5G-EMERGE system. This will enhance the protection of sensitive data stored and passing through the far edge devices.

There will also be improvements for the handling of DDoS attacks at CDN level, moving it from protection to attacks' prevention based on AI and behavioural analysis. This will enhance the security of L3/L4 connections (Layer 3 encryption operates at the network layer (IP layer) and Layer 4 encryption at the transport layer), particularly critical in case of limited satellite uplink capacity and prevent any possible DDoS attacks on the network.

Business viability analysis

To analyse the business viability of the 5G-EMERGE system, an assessment of demand for 5G EMERGE services from the different vertical markets was done. Interviews were conducted with industry experts, both internally within the project and externally, to paint a cautious picture of the demand today and in 5-10 years' time when it comes to the different 5G-EMERGE services in isolation (i.e. stand-alone value) and as a competitor to incumbent solutions (i.e. terrestrial infrastructure). Large market potential was found for some use cases and limited evidence for others. The recommended further assessments included:

- Address cost challenges with value chain cost analysis comparing 5G-EMERGE solutions with costs associated with pure terrestrial IP delivery
- Analyse the value chain to identify the motivations of the actors to contribute to or operate a 5GEMERGE solution
- Identify services and functionalities that involve value-add to increase the potential market uptake
- Develop additional value that can be created by extending the market to worldwide and services outside the media domain

Analysing the current market concluded that "Global distribution leader to the end-user" is the clearest archetype of use cases for 5G EMERGE to address. It is estimated that this archetype builds upon a growing market of €20Bn today, growing at 5% CAGR by year 10. It clusters the targeted use cases: maritime node, 5G moving base station and individual housing with no baseline access. A second archetype "Effective content distribution to the network node" can be deployed gradually which encompasses: collective housing, metropolitan nodes, 5G base station, individual housing with baseline and node in a car.

Market launch strategy

Key market data to be validated prior to developing a launch strategy for a commercial 5G-EMERGE service include interest from individual and business users, operators, and service providers. The 5G EMERGE service providers also need to tap into the consumer's media consumption trends. From an operators' perspective the main factors that will influence the adoption of 5G EMERGE include revenue potential, cost efficiency, and operational flexibility. Content providers also seek to extend the reach of their content and services while maintaining coherent, predictable and manageable costs. The end users look to benefit from affordable pricing, improved quality of experience, convenience and easiness of access to content and the extended service offer.

For 5G Emerge to be a success, all stakeholders of the value chain must be convinced: revenue generation, reach to end-customers and stronger end-user quality of experience have been identified to be key success factors.

6 Phase 2 Roadmap

Phase 2 sets the first step in the industrialization strategy by co-funding of developments that address critical technology elements or KPIs that can improve the commercial viability of the ecosystem. Most development effort will be devoted to product improvements that prepare the involved industries to provide all the 5G-EMERGE ecosystem related operational services. A lot of work also is aimed at demonstration and validation activities in different testbeds for the use-cases defined in Phase 1. The experience gained conducting these activities will be disseminated, since the communication of the results or 'telling the story' is identified as an important pillar of the industrialisation strategy.

Another change is the addition of an extra class of use cases covered by non-terrestrial 5G networks, Direct-to-Device. Where in Phase 1 the consortium concentrated on ground segment services that make use of existing satellite networks, in Phase 2 also 5G NR NTN solutions are considered.

Phase 2 comprises 6 work strands that allow consortium partners to work together in well delineated smaller projects, with project management per stand which allows distribution of PM work co-funded by different ESA ARTES member states.

The first Strand 'Management, Architecture and Dissemination' covers project overarching activities from coordination to dissemination and liaison with standardisation bodies. It hosts the Project Board with representation from the strand leaders; strand 1 is led by the prime, EBU (CH), who is also the chair of the Project Board, strand 2 is led by Broadcast Critical (UK); strand 3 by SES (LU), strand 4 by EBU (CH), strand 5 is led by Telenor (NO) and strand 6 by MediaTek Finland (F). Strand 1 will also update the generic documentation (public and internal) with the goal to detail architecture and interface descriptions further with results of new test-bed experiments, and to share this with industry as part of the adaptation strategy. All work packages of the other strands will contribute to Strand 1 activities as part of their deliverables which are realized in 3 milestones.

The second Strand 'Common edge network functionalities' concentrates on software applications deployed onto, and consumed at, the edges – from service creation, management, orchestration, discovery, consumption by end users, alongside telemetry and reporting. These include critical technologies like discoverability of services at the edge, central management of 5G-EMERGE services, security aspects, content routing optimalisation, specific CDN services, integration with 5G-Networks, onboarding of media application and online video platform solutions. These developments introduce new functionalities, improve performance compared to standard IP-terrestrial methods, or develop features to improve the onboarding of clients/operators of the ecosystem. All these new and existing 5G-EMERGE functionalities and capabilities will be tested in the end-to-end integrated testbeds of strands 3 to 6.

The third Strand 'Direct-to-Home' builds on the DTH specific developments and testbeds. The Luxembourg location combines the testing of a new satellite antenna and gateway, specifically developed in Phase 2 to realise market viable deployments in Direct-to-the home. In this deployment, also specific workflow integration with terrestrial cloud services are developed and tested. The EBU testbed will support, next to the DTH use case already developed in Phase 1, a Nomadic setup with a new foldable antenna developed in the project to enable coverage in remote areas. This is a bi-directional testbed that also allows integration with 5G networks if available. A 12-volt version that can run from a car or solar charged battery of the special developed DTH gateway is used in this scenario.

The fourth Strand 'Direct-to-Vehicle' includes two DTV testbeds, one in Turin (I) concentrating on a car antenna and one in Lausanne (CH) near Geneva aiming at developing an antenna for buses. Both antennas are optimized for use in Phase 2 with the goal to provide the market with lower costs antenna solutions to improve the uptake viability of the 5G-EMERGE ecosystem in DTV. The Gateway developed by FTA in Phase 1 will be optimised for use in cars and busses.

The fifth Strand 'Direct -to-Edge' hosts the DTE or direct to node testbeds. These will look at a firm integration with 5G access networks that are either fixed or on a ship. The Norwegian Telenor setup aims to test a real deployment on a ship with a 5G-base station in non-public network (NPN) mode. Specific 5G network components are developed to reach this goal. When the ship tests are completed, the platform will be further enhanced for the 'easier' use cases of offshore and remote community deployments. The testbed in Luleå, Sweden, will be extended to the Metropolitan use case, where multiple 5G-base stations can be serviced with one reception site to lower investments costs per end-user. At this location more extensive throughput tests will be performed to test delivery efficiency. In Turin, integration with a 5G broadcast tower will be tested and in Geneva lab integrations with 5G-components from partners and the test suite of the 5G-MAG industry forum.

The sixth Strand 'Direct-to-Device' will look at the Direct-to-Device use cases in which end-users will connect with their NR-enabled 5G MBS devices to satellites. This can be NR-NTN MBS mobile phones or for example a NR-NTN MBS enabled MiFi router. The objective of the work is to investigate how NR-NTN MBS could be integrated in 5G EMERGE alongside other networks. There is a Cambridge (UK) testbed looking specifically at technology development with the goal to develop and test a 5G NR UE platform that supports MBS and NTN features. In Finland the focus is the development of an end-to-end test setup with emulated 5G NR-NTN satellite connection, OTA testing and use case analysis. The requirement setting, architecture developments, business modelling, industrialization strategy will be updated with the demands of this use case class.

For more information to the Phase 2 planning, we refer to the Outline Proposal and Draft Contract Change Notification 6 (see also [RD28]).

7 Conclusions

5G-EMERGE combines the respective strengths of broadcast and broadband network infrastructures, leveraging advanced satellite technology, multicast capabilities, and smart edge terminals to create a comprehensive system for content delivery. It represents a significant step forward in the field of ubiquitous media distribution, offering unparalleled access and flexibility.

The system is entirely IP based and is capable of serving users with a compact and self-provisioned user equipment in the direct to home environment. It also aims to serve media use in vehicles and improve content delivery to the nodes in terrestrial networks.

Key features of the 5G-EMERGE value proposition include:

- Full IP multilayer approach which allows seamless interconnection of smart edge devices across broadcast and the internet networks for efficient distribution of media content in a range of different user scenarios.
- Satellite edgecasting combining live IP broadcasting with multicast push delivery directly to intelligent edges
- Extended edge services supporting client-side applications
- Advanced satellite technology supporting gigabits-per-second broadcast/multicast traffic to enable direct delivery of IP streams to the edges.
- Integration with 5G technologies and NTNs providing increased security, quality of service, resilience and reach.
- Intelligent, energy efficient terminals for a range of use DTH and mobile scenarios including compact and self-pointing design for applications on vehicles, airplanes or boats.

The consortium has implemented ecosystem testbeds, located in 3 countries and covering 3 use case classes, using a native-IP hybrid infrastructure, based on open standards. End-to-end test results have been used to evaluate the functioning of the architecture components in the media delivery chain.

The 5G EMERGE consortium was able to successfully prove a solid problem-solution fit through prototyping, a series of demonstrators and testbeds that have been addressing the various media related use cases. The consortium has also undertaken substantial work to identify and study the potential target markets, defining a value proposition and market viability, and validate that a 5G-EMERGE service can meet the market requirements that the players represented in the consortium have identified.

Finally, in Phase 1 a vision and planning for phase 2 was developed on basis of the first year's findings of the project. In this follow up new functionalities, covering Online Video Platform edge developments, business continuity work package, security improvements and multiple 5G-integration deployments. Multiple testbeds are set up for the DTH, DTV and DTE use case with specific development for these deployment areas and integration of the new functionalities. Aside of integration with existing satellite networks Phase 2 starts investigating ground services that can integrate with the near future NR-NTN satellite networks.

In summary, 5G-EMERGE represents a convergence of satellite and terrestrial networks using 5G technologies to create an efficient, scalable, and ubiquitous media distribution ecosystem. Yet, it is a strong solution-market fit that will determine the long-term success and viability of a 5G-EMERGE service.