5G-EMERGE

SATELLITE ENHANCED MEDIA DELIVERY AT THE EDGE

White Paper

A state-of-the-art technology hybrid 5G-satellite networking solution built for cost effective, scalable, efficient, high quality secure and intelligent media delivery.

Abstract

This paper evaluates the viability of a new media delivery ecosystem consisting of distributed edges connected through a satellite backhaul, providing a complementary approach to terrestrial internet. The focus of the paper is a review of the technical architecture and different unique deployment scenarios in realistic trials on different European test-beds. Furthermore, the impact on different media use case classes is analysed for deployments in mobile 5G networks, home networks or in moving vehicles. Besides the technical aspects, industrialization strategy and go to market considerations are touched upon.

Introduction

Broadcasters' content and services are increasingly delivered over fixed or wireless broadband networks, using over-the-top models to reach audiences directly via their own apps or via aggregation platforms. On the receiving side, people use applications on their internet-enabled devices to consume live and on-demand media on the move or at home, changing the paradigm from TV-broadcast-centric to IP-device-centric. These market trends evoke a rethinking of the efficient deployment of different distribution means into a future-proof strategy.

This paper proposes a native IP-based distribution ecosystem, called 5G-EMERGE, that integrates satellite-enhanced edge solutions into standard online delivery mechanisms. 3GPP and DVB specifications and deployment scenarios are considered as future-proof convergence technology. Edge solutions serve the purpose to coordinate services close to the core of the network at the distributed edges of the Content Delivery Network or closer to the end-user e.g. in the residential or mobile environment (5G-EMERGE Far Edge).

The technological convergence of edge and satellite platforms enables efficient delivery of popular content to end-users. With a single satellite transmission, different markets can be reached, and terrestrial IP-networks can be significantly offloaded. The satellite enhancement approach can operate independently or in conjunction with existing terrestrial networks and reach locations that do not have adequate terrestrial IP connection.

Concept and Benefits

The main concept behind 5G-EMERGE ecosystem is to seamlessly feed distributed edges over satellite(s) (with or without return channel), 5G networks and other terrestrial networks with popular media content, both Live and On-Demand.

The novelty behind this satellite-based backhauling system is that being based on a Native-IP hybrid infrastructure and on open standards, end-users will be able to transparently consume their favourite content from their IP devices, retrieving them either from a local edge cache fed via satellite, 5G or wired broadband link. A high Quality of Service (QoS) is also guaranteed to the end-user, who can consume his/her preferred content without noticing differences between the different distribution systems or experiencing service degradation.

From a content provider's perspective, the ecosystem functions as a (multi-)CDN setup. Satellite networks, primarily wide beam GEO (and potentially MEO and LEO) are used as tunnels to deliver multicast streams of popular content, bypassing busy terrestrial interconnection points. The content delivered via the multicast streams is selected by a prefetching engine that predicts popularity in the region covered by the satellite footprint. This logic should enable content and service providers to efficiently deliver video streaming services at scale and cost-effectively, over a combined footprint of satellite and terrestrial networks whilst improving user experience across multiple use-cases. Multiple residential and mobile use cases are supported simultaneously.

The 5G-EMERGE approach, in fact, can improve playout quality and shortening start up times, extending the service providers' offering to locations that have limited or no IP coverage at land, sea or air, as it can fall back to a satellite receive-only mode, if required.

On top of the edge-delivery approach, satellite networks introduce operational advantages as they provide a better quality of service than best-effort internet. The fact that a single IP feed spans a vast area, from spot beams covering 200 km to networks that cover a continent, is very efficient for content requested by a certain threshold of users. This translates to a lower energy footprint per user and lower distribution costs compared to conventional unicast internet traffic. Moreover, this approach will not only relieve expensive or congested network connections in the internet backbone or backhauled base stations of mobile networks and reduce backhauling connectivity costs but will also reduce latency and deliver better user experience to end users. Improving delivery-network resilience is another strategic goal.

Use case classes

Within the 5G-EMERGE ecosystem, we group use cases into classes, which are described below. Additionally, a particular use case, involving a scenario with ships, is described in more detail as it combines elements of two classes.

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 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.

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 fibre ring.

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 network (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.

Direct To Vehicle (DTV)

Travellers in vehicles like cars, busses, 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. This use case is not limited to media/entertainment only. For example, software updates comply with the same delivery profile as they consist of large data files delivered to a large number of user devices.

A complicating factor is the movement of both the vehicles and satellites. Special antennas are needed to optimise the communication between both moving objects. 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.

Maritime Use Case

The 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.

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.

Ecosystem architecture

Overview

The 5G-EMERGE ecosystem combines several cutting-edge technologies spanning from mobile terrestrial to satellite, from application to antenna. The overall architecture has been broken down into five System Functions (SFs) shown in figure 1.

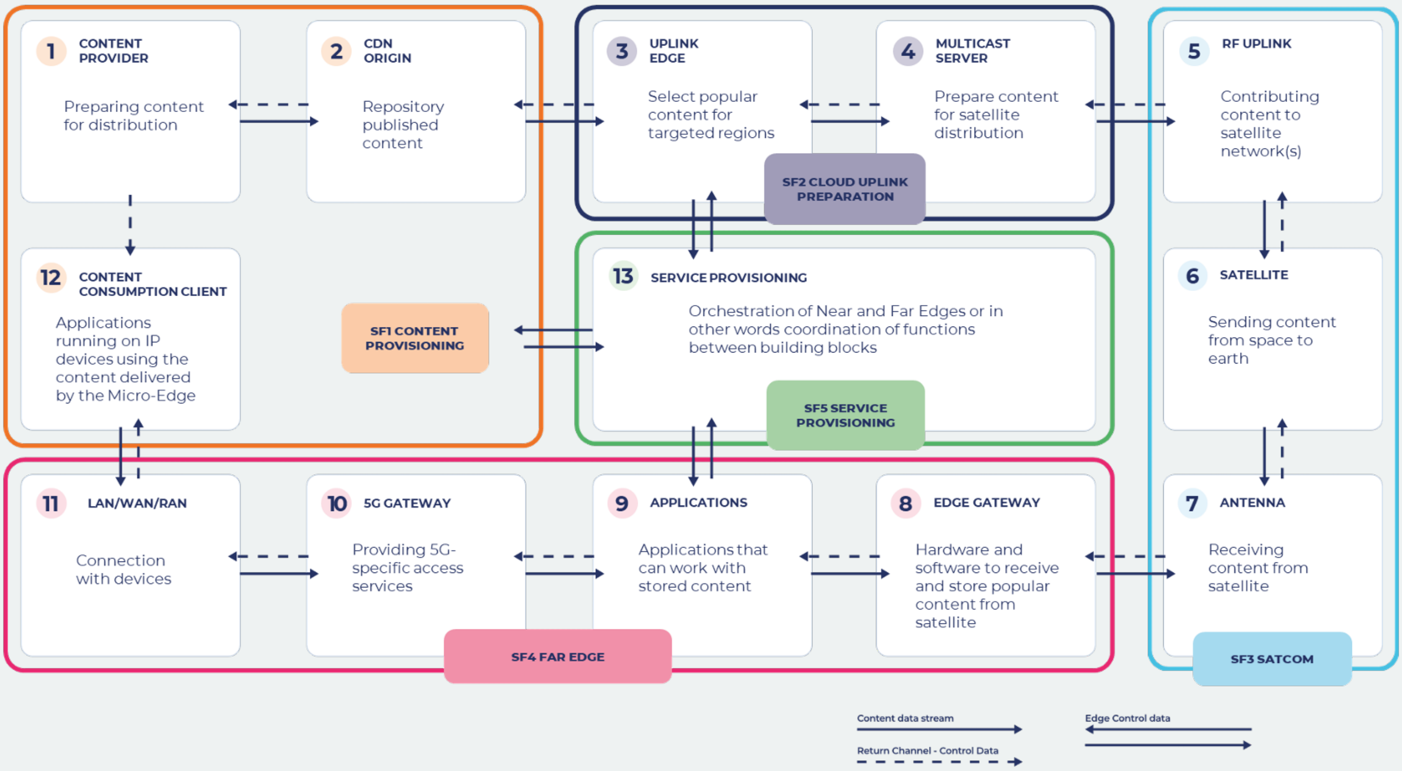

Figure 1: 5G-EMERGE ecosystem high-level system architecture diagram with 12 essential components in the delivery chain categorised in 5 system functions.

Level System Architecture diagram

SF1 deals with the technical aspects required for multimedia content provisioning including encoding, encryption, content publishing via its Origin and over the CDN distribution. On the other side of the communication link, SF1 also includes content consumption through a dedicated client application. This client application is designed to interwork with the distributed 5G-EMERGE edge caches via both a terrestrial broadband and a satellite network, not necessarily relying on a terrestrial or satellite return path.

SF2 is responsible for selecting the content to be distributed via the satellite multicast path to the edge-caches at scale. SF2 performs the conversion from unicast to multicast streaming, using an implementation of the DVB-MABR (Multicast Adaptive BitRate) transmission scheme. SF2 selects which content to multicast based on data collected from the orchestration function in SF5. Part of this data may be collected leveraging a satellite return path and the rest from terrestrial networks. SF2 is a key 5G-EMERGE component that will be described in more detail in the next section.

SF3 represents the satellite communication-specific aspects such as communication with the micro-edge devices via satellite (data backhauling) and encapsulation. This component embeds innovations introduced by 5G-EMERGE to enable a hybrid terrestrial-satellite backhauling for the multimedia distribution in all the target use-cases. It is expected to improve performance and functionalities with respect to either pure satellite broadcast or terrestrial mobile networks (i.e., 5G).

SF4 is another key component of 5G-EMERGE that will also be described in more detail in the next section. It provides all the edge functionalities, including caching, and connects to the end users through use-case-specific access technologies.

SF5 is the service provisioning or operational control plane in charge of managing the edge devices and the locally deployed applications through the cloud orchestrator. This includes application lifecycle management, CDN control settings like content management of the edge storage locations, request routing to re-directing client content access requests to the nearest or least cost cache on a distributed edge, a centralized 5GCore (5GC) if applied, and aggregation of relevant (actionable) operational quality metrics from the distribution chain.

Key Technology Elements

Some of the most innovative elements of 5G-EMERGE are located in SF2 and SF4. This is where algorithms decide which content to distribute in multicast versus unicast, where content is prepared for transmission using technologies such as FLUTE and mABR, and where content is received and made available again in unicast to end-users' applications.

In the next paragraphs, the critical technology elements, dealing with edge-caching, edge-management, and content transmission, will be outlined.

SF2 Uplink Edge Processing

The decision on whether to multicast or not particular content items is based on the following criteria:

- Data on the available Satellite network d 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.

Once the content to be delivered has been identified, it needs to be fetched and prepared for transmission.

Following Figure 2, the Far-Edge content population logic aims to maximize the traffic savings gained from broadcasting a piece of content on a particular beam. The popularity prediction gives an indication about the "value" of content, while the content population logic will decide which content should be pushed via the satellite based on both the value and cost of the content as well as the current state of the Far-Edge caches.

Content retrieved from the multicast feed will be stored on the HTTP storage/server on the Far-Edge as part of the multicast decapsulation application. A cache miss will trigger the cache application to look first on this HTTP storage to check if the content is available there. If not, the cache will fall back to the Far-Edge Population Logic service to request it to be added to the multicast. Without confirmation it is part of the multicast satellite stream, the cache will fall back to the CDN Origin.

Population Logic will be in charge of both efficiently fill the multicast as aggregation of coverage of multiple Far-

Edges and the content that need to be stored at the Far-Edge. The baseline logic of the Far Edge 'Content Population Prediction' function is to pull and prioritize packages based on CDN popularity data (reverse proxy) with the goal to fill available capacity for the multicast stream.

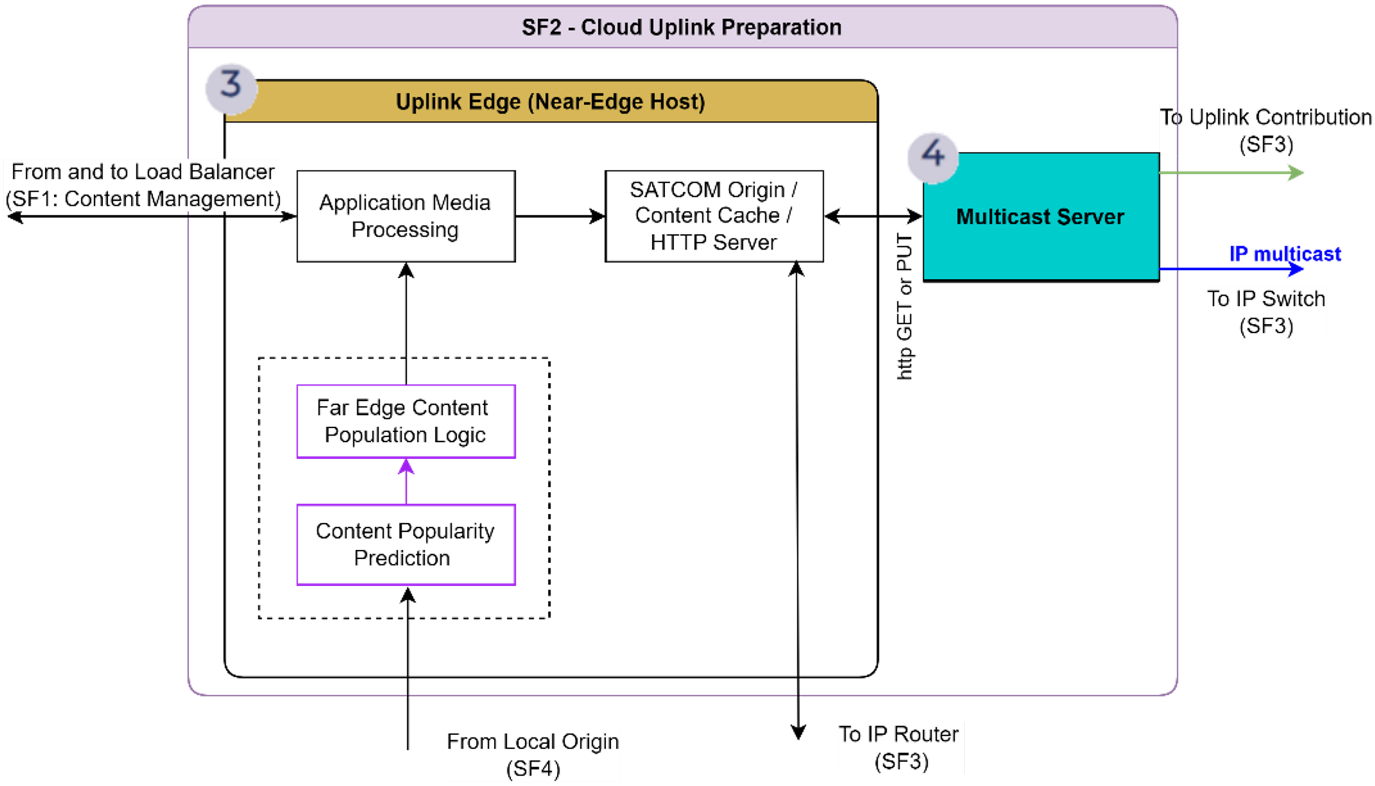

Figure 2: Architectural elements of system function 2, covering the Cloud Uplink Preparation. The numbers 3 and 4 refer to Figure 1.

Based on additional information that can be used to predict popularity, packages/data are prioritized over the baseline content. Playout popularity can be profiled by stating expectations based on usage data gathered from the playout environment (for example people watching a stream or to use a recommendation engine to predict what content is going to be popular in a certain region or scheduling experience). As the ecosystem relies on the efficiencies of multicast streams for distribution of content and as this content is expected to be file-based, files need to be packaged into multicast using so called "reliable multicast file transfer protocols".

SF2 Multicast Adaptive Bitrate Transmission

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[1]. In order to apply DVB-MABR to a satellite broadcast network, another specification, called DVB-NIP (Native IP)[2], is used. DVB-NIP provides the tools to signal and locate multicast streams across multiple satellite transponders and allows to announce such Live, VOD or data streams to satellite reception devices.

The MABR server generates transport sessions carrying the content to be distributed. On the input side, it interacts using HTTP with the local content origin. On the output side, it provides UDP multicast streams that can be directly encapsulated for carriage over the satellite forward path or tunnelled using a VPN to an uplink station if the two are not co-located.

SF4 Far Edge

The Far Edge is the core reception component in the 5G-EMERGE architecture. It deals with incoming multicast content and acts as the counterpart of the DVB-MABR and DVB-Native IP Server. Content received is extracted from the mABR protocol and stored in a local cache. The cache is fronted by a reverse proxy which makes the content available to Clients requesting it over DVB-I compatible interfaces. The cache is uniquely capable of answering unicast requests incoming via HTTP.

Edge caches can be scaled according to the local requirements. Edge caches in a Direct-To-Home scenario only need to be capable of answering requests from a very small number of clients, whereas edge-caches located on a communal network may have to deal with thousands of simultaneous requests.

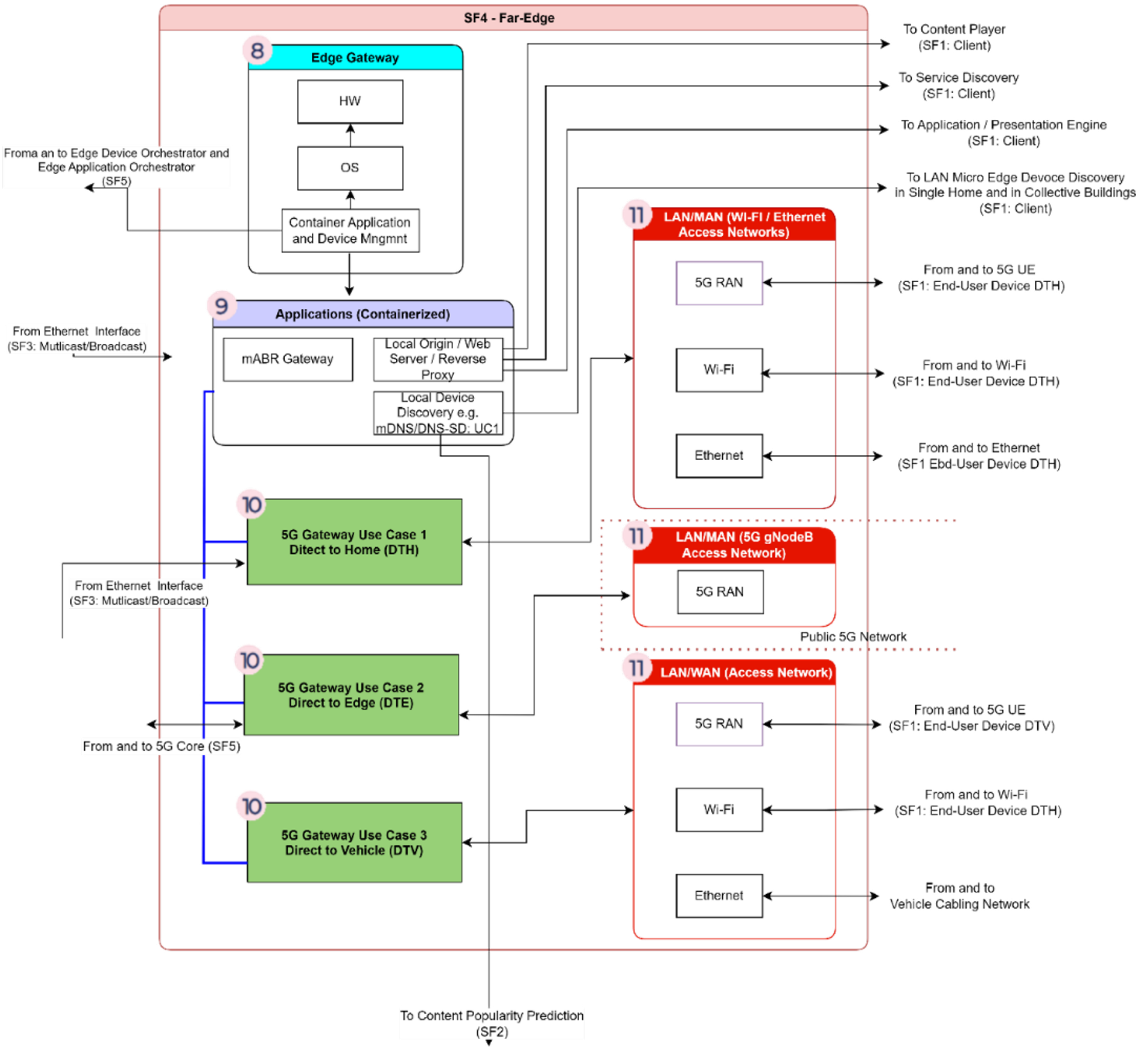

Figure 3: Architecture elements of system function 4, the distributed Far-Edge. The numbers 8 to 11 refer to Figure 1.

SF4 Edge Applications

The actual functionality of Edge Caches is implemented as specific applications running in a virtualised software/ container environment. The setup and maintenance of this virtualisation run-time is part of the 5G-EMERGE architecture and is compatible with the 3GPP SA2 architecture[3]. This environment allows the rapid and simplified deployment and maintenance of containers, each implementing specific functionality. Some of the applications running on the Edge are: the mABR Gateway, the Content Cache Management, the local Origin and Reverse Proxy, the device discovery mechanism, etc. Most of these applications relate to the SF1 Client applications that request data from the local edge cache. The whole edge-based ecosystem acts as a single cloud with distributed resources.

5G Network Interfaces

The 5G-EMERGE architecture deploys specific 5G network interfaces[4,5], which are collectively located in "5G gateways", to allow content delivery via 5G to devices that can be 5G enabled, and for the described use case classes DTH, DTE and DTV.

DTH Use Case

The 5G gateway contains interfaces that need to allow both 5G UEs as well as non-5G (e.g. WiFi) UEs to connect to the 5G-EMERGE system. For the 5G UEs, the 5G gateway provides the standard N3 interface that connects with the User Plane Function (UPF), which is a 5G core network function associated to a remote 5G core network (e.g. from a regional Mobile Network Operator), and that gives the 5G UEs access to remote Data Networks (DNs) as well as to the F-SIM terminal for the satellite return channel and the edge applications located in the local edge via the standard N6 IP-based interface. For the non-5G UEs, the 5G gateway also provides an interface with a Non-3GPP Access Interworking Function (N3IWF)[6], which is in charge to "adapt" access and authentication protocols of the non-3GPP (e.g., Wi-Fi) connected UEs, taking the same role of the 5G RAN towards the UPF.

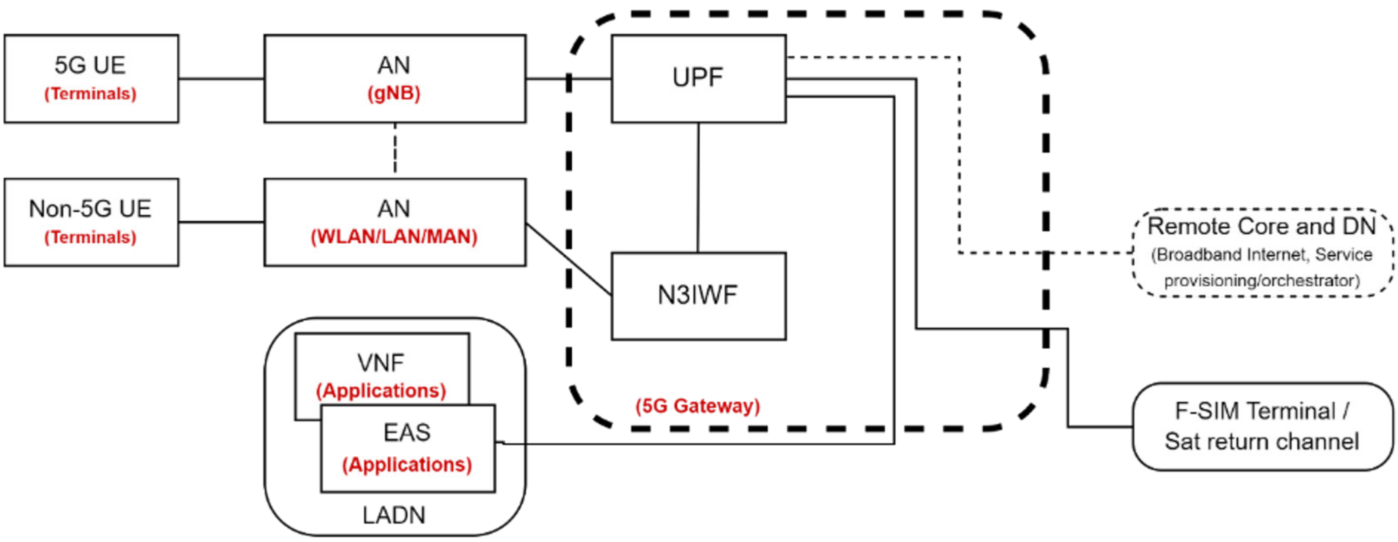

Figure 4: 5G gateway for the DTH use case

DTE Use Case

The 5G gateway only needs to give access to 5G UEs. It provides 5G UEs with the N3 interface only, connecting with a local UPF, with the same interfaces and functions as the UPF in the DTH scenario, except for the connection to the N3IWF.

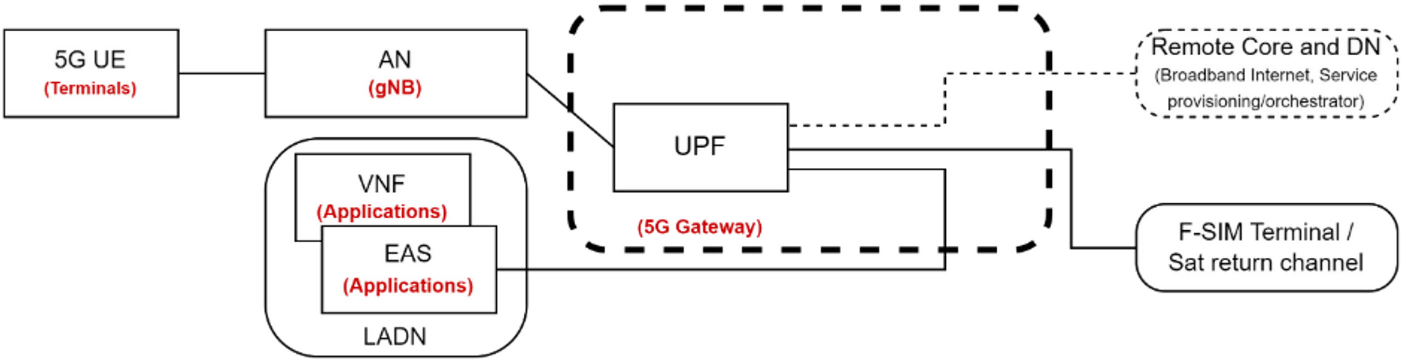

Figure 5: 5G gateway for the DTE use case

DTV use case

The deployment of the DTV use case is very similar to the one of the DTH use case, with the difference that the 5G control plane is located locally on the edge, rather than being remote. The deployment of the DTV use case is very similar to the one of the DTH use case, with the difference that the 5G control plane is located locally on the edge, rather than being remote. Hence, the 5G gateway exposes the same data plane interfaces as for DTH, as well as additional control plane interfaces to connect the UPF to the locally deployed core network.

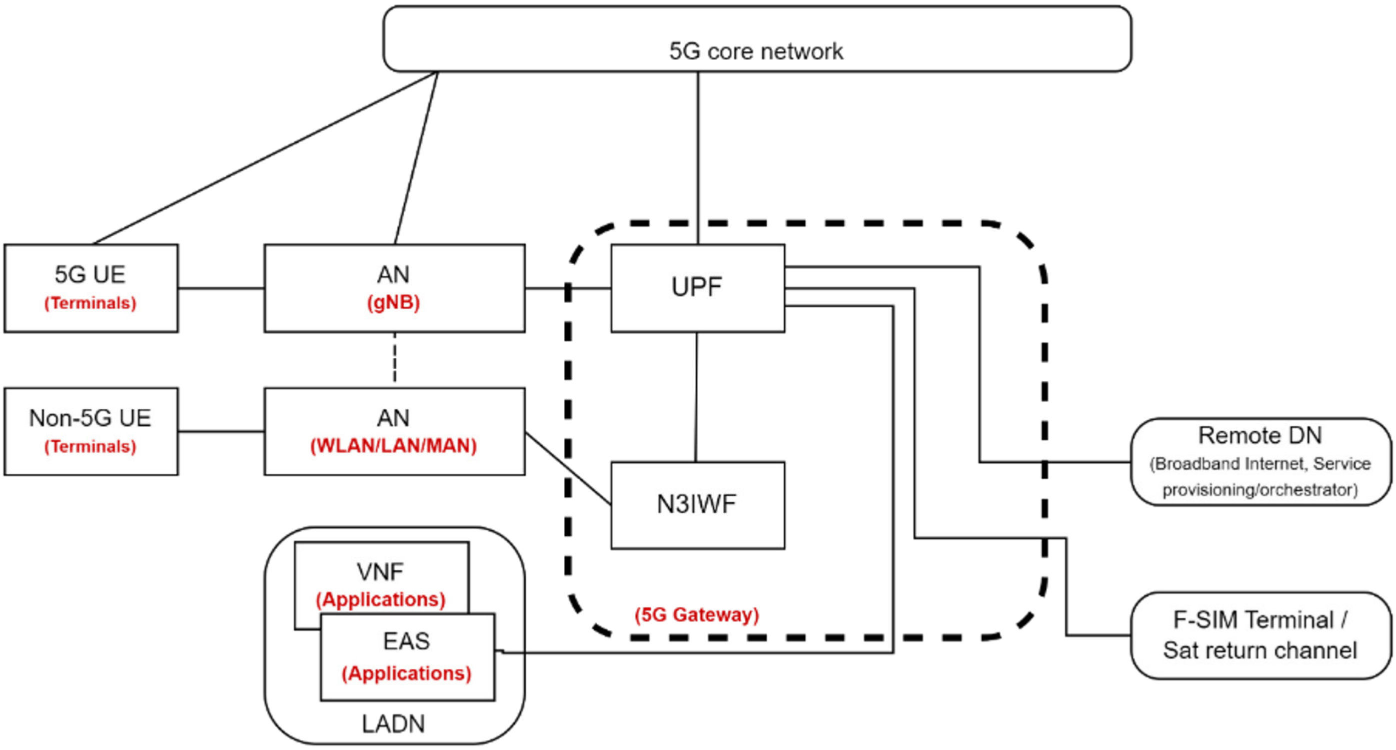

Figure 6: 5G gateway for the DTV use case

Industrialization strategy

5G-EMERGE is a consortium formed by twenty-five companies that provide, often competing, solutions in the depicted ecosystem. The project is co-funded by ESA ARTES programme. In 2023, 5G-EMERGE investigated the state-of-the-art technologies, defined the 5G EMERGE system architecture, and identified the business case. Different testbeds have been created throughout Europe in which consortium partners work on different use cases: DTH operated by SES in Luxembourg and EBU in Switzerland, DTV by Viasat in Switzerland, DTE by Artic Space / Varnish Software in Sweden, while Telenor ASA and Telenor Maritime provide the combined DTE/DTV use case in Norway.

As a next step, the industrialisation strategy foresees the development of new functionalities as a primary driving factor for the market uptake and as a second driver the development of services to improve delivery efficiency (both from a cost and an operational perspectives). The new functionalities include, for example, edge security solutions focusing on 5G NPN deployments, personalised media services, advertisement localisation through manifest manipulation on the edge, antenna developments to create use case specific cost-efficient solutions.
On the other hand, delivery efficiency enhancements include pre-caching optimisations, CDN-optimisations, content steering solutions, terrestrial network offloading for interconnection points or expensive point-to-point microwave data-connections.

Go To Market considerations and products development

Operators of a 5G-EMERGE ecosystem that can bring the envisaged services to the market can be large content providers that operate their own CDN, CDNs specialised in edge services, SATCOM providers with a service model that can be used by CDNs, or Telecom operators seeking to optimise their own network or connect to other networks. A special class are the specialist service providers, like Online Video Platforms (OVP) or companies selling 5G NPN services to business users operating in different geographical locations.

Apart from the services and solutions mentioned above, there are other use case specific considerations to be taken into account. For example, the installation of the reception gateway at home puts specific requirements on the design of such gateway. Low cost and low power consumption are key requirements that can only be reached through high levels of integration. Also, end-users will not be inclined to install large and expensive media cache servers at home, these need to be integrated with existing hardware, like NAS systems or routers.
In this context, an essential DVB-NIP and DVB-I compliant DVB-S2X GSE HEM receiver is developed in the project. The receiver contains basic edge cache capabilities to address the requirements of the DTH use case. The embedded edge cache software is developed using container technologies and can run on hardware of varying in CPU, memory, and persistent storage footprints, both in single households' setups and in larger hospitality TV and multi-user scenarios.

On the same note, another development activity focussed on lower cost antennas using new material for the DTH use case and DTV solutions for busses and cars. Smaller form factor antennas with higher throughput would also be desirable in base-station deployments as they are less intrusive. The cost increase of deploying an edge and an antenna in 5G base stations will need to be compensated by a cost reduction in traffic cost.

Demonstrators, tests and results

Each use-case of 5G-EMERGE required a specific system, which was put in place and tested in one testbed or more – creating use-case-specific demonstrators. Six demonstrators in different locations for the DTH, DTV and DTE use cases were built in total. Different micro edges were developed and optimised for each use-case.

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 (see Figure 1) and checked its conformance to the requirements:

- 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.

During the tests one critical point was the integration of the 5G components with the rest of the 5G-EMERGE system architecture. The integration required to address cloud connectivity and interoperability aspects.

The demonstrators also proved the operation of the end-to-end functionality of the full delivery chain. Relevant content on basis of 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.

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 test-beds is the need for Quality of Service data from the whole chain. 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 large number of users or where internet speed itself is limited due to suboptimal infrastructure.

A mixture of Android and iOS devices were used and tests were performed with live content and with VoD content.
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 enhance 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 to improve 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.

Conclusions

5G-EMERGE realises the full convergence of satellite broadcast and terrestrial broadband networks. Adopting common IP-based technology elements allow bringing the scalability, reliability, quality, and efficiency of the single-transmission (characterizing broadcast/multicast TV) into the personalised world of network and device flexibility that broadband unicast OTT provides. It is a hybrid multichannel approach combing the best of both worlds; SATCOM services provide universal reach, quality of service and delivery efficiency for highly popular content; terrestrial internet excels in delivery of non-popular / long-tail content, interactive services, and an increasing capacity throughput.

With a single transmission multiple markets can be reached simultaneously covering several use cases. Using multiple networks results in resilient delivery, as media services work also if one network would stop operating, for example in a disaster scenario. Operators can deploy flexible rules to steer traffic either over internet or satellite connection based on service, cost, or quality requirements. The ecosystem opens possibilities of new operators to develop services through applications, which do not necessarily need to involve media, running on the distributed edges which are acting as a single cloud.

Testing showed a quality advantage of the satellite enhanced edge delivery approach in situations where there is no fast terrestrial internet connection available, as high-quality content can be served to multiple devices without using the terrestrial connection. From the current testbeds it can also be concluded that this ecosystem can be realised with existing solutions for multiple use cases. Optimisations that improve market viability have been identified and addressed in the 5G-EMERGE project moving forward.

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