Broadcast and Multicast Communication Enablers for the Fifth-Generation of Wireless Systems

Deliverable D2.2

Analysis of the Technical Developments Against the Use Cases

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Abstract

This final version of D2.2 provides an analysis of the technical developments within the project against the use cases and their respective requirements developed in deliverable D2.1. It details how these high-level requirements have been translated by the technical work packages into ones specific to their domain of study. It then goes on to analyse how the technology developed within the project is delivering against those requirements and the KPIs developed within 5G PPP as well as against relevant KPIs defined by the ITU in the IMT2020 process.

The analysis shows that a lot of work was performed to find out the deficiencies and limitations concerning the specifications in Rel-14 in case of LTE and Rel-15 and Rel-16 in case of New Radio. The already defined use cases and requirements have been matched to the developments in WP3, WP4 and WP5. The developments within the project are moving in the right direction but there is some further work to do around real implementations such as interfaces, services and user devices. A further update to this deliverable will be made later on to reflect these developments.

Keywords

5G, Automotive (Auto), benchmark, KPIs, Internet of Things (IoT), Media and Entertainment (M&E), Public Warning (PW), requirements, state-of-the-art, use cases, verticals

Revision History

Revision	Date	Issued by	Description
V1.0	2018/05/11	Clemens, Andrew, Irene	Interim version.
V2.0	2019/01731	Clemens, Andrew, Irene	Final version.

Disclaimer

Executive Summary

The use cases for the project along with their respective requirements were developed in deliverable D2.1 [1]. These were intentionally high-level and it was subsequently the task of the technical Work Packages (WPs) to translate these high-level requirements into something specific to the focus of work within each individual area and to engineer specific solutions based on their domain knowledge.

The present deliverable summarises the outcome of this translation process along with an analysis of the technology being developed within the technical work packages in order to:

- Validate and verify the technical solutions developed in the project against the requirements;
- Ensure that use cases are realizable; and
- Potentially refine the original use cases in light of knowledge gained in the project.

As well as identifying the requirements of most importance to the project, it also defines the priorities for development within the project with the 5G-Xcast solution addressing “mixed-mode multicast” initially followed by “terrestrial broadcast” in a way that minimises the differences between the two.

It is important to note that the deadline of this deliverable is the month 20 of the project and since technical work in the project is on-going, it represents a snapshot of current developments. It will be revised at the end of the project in order to track project progress.

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List of Acronyms and Abbreviations

3GPP	3rd Generation Partnership Project
4G	4th Generation
5G	5th Generation
5GIC	5G Innovation Centre
5G PPP	5G Public-Private-Partnership
ABR	Adaptive Bit Rate
ACK	Acknowledgment
AL-FEC	Forward Error Correction at Application Layer
Auto	Automotive
BBF	Broadband Forum
BC/MC	Broadcast/Multicast
BER	Bit Error Rate
BMSC	Broadcast/Multicast Service Center
BW	Bandwidth
CP	Cyclic Prefix
CUPS	Control and User Plane Separation of EPC nodes
CDN	Content Distribution Network
CSP	Communication Server Provider
DL	Downlink
DOCSIS	Data Over Cable Service Interface Specification
DRM	Digital Rights Management
DVB	Digital Video Broadcasting
E2E	End-to-End
eMBB	enhanced Mobile Broadband
eMBMS	evolved Multimedia Broadcast Multicast Service
EPC	Evolved Packet Core
E-UTRAN	Evolved UMTS Terrestrial Radio Access Network
FEC	Forward Error Correction
FUP	Fair Usage Policy
HARQ	Hybrid Automatic Repeat Request
HbbTV	Hybrid Broadcast Broadband TeleVision
HBS	Hybrid Broadcast Services
HD	High Definition
HPHT	High Power High Tower
HTTP	Hyper Text Transfer Protocol
IMT	International Mobile Telecommunication
IoT	Internet of Things
IP	Internet Protocol
ITU	International Telecommunication Union
KPI	Key Performance Indicator
LDPC	Low Density Parity Check
LTE	Long Term Evolution
m-ABR	multicast - Adaptive Bit Rate
M2M	Machine-to-Machine
MBMS	Multimedia Broadcast Multicast Services
MBMS-GW	MBMS Gateway
MBSFN	MBMS over Single Frequency Networks
MCE	Multi-cell/multicast Coordination Entity
MCS	Modulation and Coding Scheme
MIMO	Multiple Input Multiple Output
ML	MultiLink - multiple link transmission concept
MME	Mobility Management Entity
mMTC	massive Machine Type Communications
MooD	MBMS operation on-Demand
MPEG	Moving Picture Experts Group
M&E	Media and Entertainment

NACK	Negative Acknowledgment
NFV	Network Function Virtualisation
NR	New Radio
O&M	Operation and Maintenance
PMSE	Programme Making and Special Events
PoC	Proof of Concept
PTM	Point-to-Multipoint
PTP	Point-to-Point
PW	Public Warning
QoE	Quality of Experience
QoS	Quality of Service
RAN	Radio Access Network
RAT	Radio Access Technology
Rel	Release
RRC	Radio Resource Control
RRM	Radio Resource Management
SC-PTM	Single Cell – Point-to-Multipoint
SFN	Single Frequency Networks
SDN	Software Defined Networking
SoA	State-of-the-art
SON	Self Organizing Network
TCP	Transmission Control Protocol
TLS	Transport Layer Security
TM	Transmission Mode
TR	Technical Report
TS	Technical Specification
TTI	Transmission Time Interval
TV	Television
UE	User Equipment
UHD	Ultra High Definition
UL	Uplink
UMTS	Universal Mobile Telecommunications System
URLLC	Ultra Reliable and Low Latency Communications
WP	Work Package

1 Introduction

Alongside the references to the original requirements developed in deliverable D2.1 [1], relevant KPIs within the 5G-PPP were also examined. Also, as 5G-Xcast has been one of the 5G-PPP projects working on IMT-2020 evaluation, a summary of these KPIs is also presented here.

This deliverable will additionally look to developments in on-going standardisation, including 3GPP, to make an assessment of the state-of-the-art of work in the project. It is also intended to act as a conduit for on-going feedback from the Advisory Board into the project.

The work in the project, as seen in Figure 1, is structured into the three technical WPs as follows:

- WP3, the Radio Access Network (RAN);
- WP4, the Core Network; and
- WP5, the Converged Content Distribution.

In addition, the designed use cases and requirements defined in WP2 are evaluated through the different demonstrators and show-cases developed in WP6.

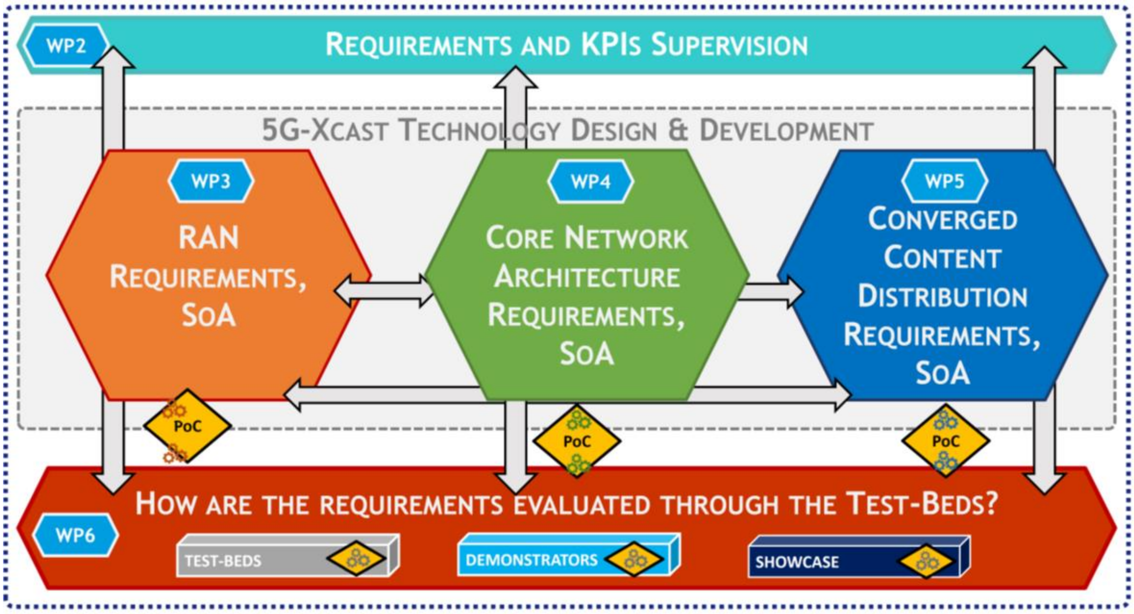

Figure 1: Outline of technical work within 5G-Xcast.

Note that since the deadline for this deliverable is M20 of the project and since technical work in the project is on-going, it represents a snapshot of current developments. A further update will be made later on to reflect the final developments within the project.

Part of the future work and longer-term use cases will be addressed in D2.3 [2].

1.1 Structure of the document

The present document begins by identifying the most important requirements and the prioritisation of technical work within the project.

Each work package is then examined in turn and the high-level requirements developed in D2.1 [1] that are relevant to each of them are identified before assessing which of these requirements are of most importance. For each work package, an assessment of the state-of-the-art is also made along with details of how requirements have been met within the project.

In addition, the relevance of the 5G PPP KPIs to the project use cases and technical achievements is examined.

Finally, the ITU-R IMT-2020 KPIs are analysed considering the 5G-Xcast use cases.

The detail of the interpretation of the high-level use cases by each technical work package is presented in Annex A.

2 Allocation of Use Cases and Requirements to the Respective Technical WPs

The requirements of the use cases developed in D2.1 [1] were intentionally high-level and it has been the task of the individual technical work packages to examine these from their point of view.

The full detail of the process of translation of the high-level requirements into detailed technical ones is given in Annex A along with the results of a prioritisation exercise used to determine which requirements should be the primary focus of the project.

This section highlights the results of this process and presents the most important, high-level requirements that have been identified for the 5G-Xcast project to address.

2.1 The Most Important Requirements within 5G-Xcast

The 5G-Xcast project directly addresses four Verticals: Media and Entertainment (M&E), Public Warning (PW), Automotive (Auto) and Internet of Things (IoT). From those verticals, the M&E and the PW use cases were implemented in the demonstrators. Among the use cases considered in the project, the Hybrid Broadcast Service use case (M&E1) [1] turned out to be the most important one, as its requirements were inherited by the rest of the use cases.

The following Table 1 reproduces the most important requirements for the M&E 1 use case:

Table 1 – Most important requirements for 5G-Xcast from the M&E 1 [1] use case

ID.	Requirement
1	End users have seamless access to audio-visual content both at home and on the move including seamless mobility between access networks, and across different types of devices (stationary, portable/ mobile, mounted in a vehicle). • The user’s device is able to automatically connect to the best available network/s to give the highest QoE to the user, including simultaneous access to multiple networks. • It is desirable to allow using multiple network types together to increase QoS/QoE to any segment of the population that can support this.
3	The network resources required to deliver the service to a given audience should grow much less than linearly with audience size, particularly for large audiences of very popular content. • An audience may be concentrated in a limited geographical area or distributed • Minimising the distribution costs for the content service provider
5	If multiple networks are used it should be possible to offload the traffic between them. • e.g. fixed, mobile and/or broadcast networks
7	It is desirable that the network supports dynamic optimisation of resource allocation based on individual operators’ policies, e.g. automatically initiating the switching between unicast, multicast and broadcast. • Means should be given to allow implementation of various deployment and optimization policies of network resources vs QoE of the population as a whole or segments of.
12	Transition between unicast and broadcast and multicast should be allowed during service, without impact on viewers and other users, and within a minimized transition time (in the order of seconds).

ID.	Requirement
24	Latency: • End-to-end latency is allowed to be in the order of 50 ms or even higher ○ Delay from live should be no worse than other delivery methods • Difference in delay between different streams on the same device shall not be perceivable by the users • Channel change latency should be of the order of 1 second, not excepting additional contributions from latencies that may be outside the scope of the 5G-Xcast system such as communication with a decryption key server
25	Quasi error-free reception: • 1 uncorrected error event per hour
33	The system should have the possibility to provide audience metrics (e.g. number of users, duration, location, QoS experienced), including behavioural and QoE reporting in real-time. • The system should enable monitoring of the performance of the service (session established, content flow as expected) • It should be possible to report audience metrics anonymised or non-anonymised.

2.2 Priorities for Developments within the Project

The 5G-Xcast project targets considering a two-track approach: the first one based on cellular (mobile) networks and the second one based on DTT-like broadcast-only networks.

In the first approach, cellular networks were examined with an implementation that allows mixed unicast and multicast transmissions targeting M&E use cases, such as the Hybrid Broadcast Service where PW services can also be enabled..

Also in the second approach, the terrestrial- broadcast-only network requirements were also considered so that an extension to the mixed mode of the terrestrial-broadcast-only mode is not precluded in future developments. The aim was to allow synchronisation across cells (e.g., in SFN) within areas that can vary in size (including across large areas, e.g. nationwide, and across small areas, e.g. stadium/venue).

The intention is to allow standalone terrestrial-broadcast-only networks support of mixed unicast/multicast/broadcast implementations with the aim of minimising the differences between the two modes. The solution includes support for 100% broadcast based content on the 5G RAN, receive-only devices and standalone broadcast networks.

This approach had the advantage that it aligned well with the two-track approach currently discussed within 3GPP for considering the possible development of eMBMS within Rel-16. More detailed information can be found in [3].

3 Refinement of the Use Cases

In the course of the analysis within this document a number of the use cases have been refined and some additional requirements have been identified, such as the following:

- A new requirement for use case “M&E 1 – The Hybrid Broadcast Service”:

No.	Requirement	Role
M&E1_R38	The 5G-Xcast solution should be flexible enough to allow operation under different spectrum usage frameworks. • This is in addition to the requirement 31 regarding supported frequency band flexibility.	Network operator Public authority

- A new requirement for use case “PW 1 – Multimedia public warning alert”:

No.	Requirement	Role
PW1_R14	An Alert should be delivered Free of Charge to the user.	User Network Operator

- A new requirement for use case “IoT 1 – Massive Software and Updates” which was developed in [4]:

No.	Requirement	Role
IoT1_R5	The system should allow coverage extension capability.	Network operator

The new requirements were included in the updated version of D2.1 [1] delivered to the EC in June 2018.

4 Analysis

This section of the document presents a summary of the analysis of the specific requirements defined in deliverable D2.1 [1] in respect to WP3, WP4 and WP5. Furthermore, an examination of the planned demonstrators and possible showcases defined in WP6 is performed. As previously observed, this examination indicates a snap-shot of the current progress within the relevant work packages at the time of publication.

The requirements demanded by the 5G-Xcast use cases concerning the air interface were investigated in WP3. Several deficiencies were detected in Rel-14:

- The currently available data rate is not sufficient to cope with the demands for M&E2 and M&E3 use cases.
- No feedback mechanisms for user reports are possible in LTE MBSFN mode.
- The 200 µs Cyclic Prefix (CP) for large Single Frequency Networks (SFNs) in High Power High Tower deployments is not long enough (cell radius of up to 100 km according to the on-going Terrestrial Broadcast 3GPP Study Item).
- The mobility for the new eMBMS mode in Rel-14 is limited due to the narrow carrier spacing and cannot support 500 km/h user speed of M&E_R18.

These points are currently not addressed either in the 3GPP LTE specifications or in real implementations.

Furthermore, WP3 examined the RAN logical architecture and identified that in Rel-14 the flexible use of eMBMS is limited, for example, because the dynamic adaptation and the change of area between unicast, multicast and broadcast are not currently available. Further, while the Rel-14 eMBMS supports static resource allocation between multicast and broadcast and unicast, the requirement to support also dynamic resource allocation is limited. These limitations should be addressed in RAN architecture to improve the 5G functionalities. The PW use cases are also not supported by Rel-14, for example the message delivery to targeted groups within a cell and the reliability of high priority alerts in multicast and broadcast mode are not possible. In addition, the battery life of the UEs has to be improved. These items are well described and the exact proposals for a 5G-Xcast RAN architecture are provided in WP3.

The RAT protocol limitations were also studied as well as the flexible and efficient radio resource allocation. To fulfil the requirements in the area of WP3, intelligent algorithms to deliver higher data rates with less signalling overhead were developed.

In WP4 the future 5G converged core network was examined. Flexible session control and resource management were defined to ensure a seamless experience and service continuity for the end user. Several architecture options have been determined by WP4 to fulfil the requirements in the most important M&E and PW use cases. Some requirements in the Automotive and IoT area are still not met in 3GPP Rel-14. Another topic is the support of multicast and broadcast in a converged network while moving between home and outdoor environments and when changing from a fixed reception mode to a mobile reception mode. This is also not supported, neither in Rel-14 nor in Rel-15.

The main task in WP5 comprises the definition of a network-agnostic content distribution network which dynamically combines the available resources; preferably an autonomous, self-organising structure that optimises the multicast, broadcast and caching features. As reference points the DOCSIS and the DVB ABR specifications were evaluated and it transpires that these two specifications do not completely cover the 5G-Xcast requirements. These requirements are based on a mix of IP-based wired and radio type delivery in combined multicast or broadcast modes. Furthermore, WP5 came to the key conclusion that on the application layer not every functionality has to be specified or standardised. This allows the content provider to be more independent from the network implementation. However, as a consequence of this perception, it is challenging to judge in detail whether the M&E(1-3) and the IoT requirements could be satisfied.

To verify the work done in WP3, WP4 and WP5, three test-beds in Turku, Surrey and Munich have been established, highlighting particular features of the 5G-Xcast solution. The most important PW use cases were demonstrated in Turku. The most relevant M&E use cases were represented partly in Surrey and in Munich. Furthermore, a showcase during the European Championships 2018 has been coordinated by the EBU. The showcase was concentrating on free-to-air reception and the combination of unicast and broadcast capabilities. In addition, several demonstrators will be performed during the EuCNC 2019 in Valencia, where the main functionalities of 5G-Xcast will be showed.

In the following sections the realisation of the use cases and requirements in the technical work packages are considered in more detail.

The exact matching of the considered requirements to the work performed in the specific WPs can be found in Annex A.1 to A.3. The most important requirements for the demonstrators and the showcase are summarized in Annex A.4.

5 5G-Xcast Technical developments against the 5G-Xcast Use Cases by WPs

5.1 WP3: 5G-Xcast RAN

5.1.1 Initial objectives of the 5G-Xcast RAN

WP3 aims to provide a highly efficient 5G-Xcast RAN baseline solution that fulfils the requirements and use cases developed in WP2 across different verticals (M&E, Auto, IoT, and PW). It has been designed paying special attention to a group of selected KPIs, such as data rate, spectral efficiency, latency or mobility.

The objective of this solution is to design a comprehensive and holistic 5G PTM RAN framework, including the main RAN aspects such as the radio interface, architecture and radio access technology (RAT) protocols. Such a framework considers the RAN designed in different standardization groups, including 3GPP RAN, and leverages the results of 5G PPP phase-1 and on-going work in 3GPP related to PTP transmissions.

More specifically, WP3 first identifies the promising candidate 5G transmission techniques for PTM scenarios and evaluates them towards novel transmitter and receiver designs of the 5G PTM air interface. The different 5G spectrum options for PTM network deployments are also considered. Secondly, WP3 provides a multi-service, multi-band RAN architecture to support the coexistence of PTP and PTM transmissions and different 5G-Xcast services with a variety of diverse requirements, while considering the architectural compatibility with 5G New Radio (NR). Moreover, WP3 investigates novel RAT protocols, radio resource management (RRM) and self-organizing network (SON) functions tailored for PTM services.

Finally, WP3 prototypes the promising 5G-Xcast RAN designs for proof-of-concept, e.g., via system-level simulations. Coverage estimation exercises are also executed in order to assess the potential gains of the 5G-Xcast radio access technologies.

5.1.2 Air-interface

The 3GPP Rel-14 specification was evaluated in D3.1 [4] against different requirements for PTM communications. The solutions adopted in LTE are characterized by a static configuration that cannot be dynamically adapted to different users and network operator requirements. The LTE air-interface design presents a limited spectral efficiency due to the low-efficiency coding schemes. The use of eMBMS in SFN deployments lacks sufficient CP duration to provide large area coverage in HPHT networks. Moreover, some eMBMS modes may reduce mobility performance due to the reduced sub-carrier spacing. SC-PTM can only be configured at cell level but, on the other hand, offers the possibility to implement MIMO to increase data rates, although with large overheads due to the presence of control regions in the subframes.

Rel-14 cannot meet most of the requirements specified for the 5G-Xcast M&E, PW, Automotive and IoT use cases. As an example, the limited bandwidth for LTE eMBMS as well as the low number of available antennas in MIMO schemes hamper the fulfilment of high-data rate requirements, in particular for media delivery (M&E2_R1, M&E3_R1). The lack of feedback mechanisms prevents from meeting requirements where user reports may be of interest (M&E1_R7, IoT1_R2). The lack of sufficient CP duration and the short range of possibilities make it impossible to adapt transmission to different scenarios and network topologies (M&E1_R14, M&E1_R30). The configuration of large-area SFN results in a limitation in terms of mobility (M&E1_R18,

M&E3_R4). Finally, only SC-PTM can enable concurrent reception of multicast and unicast on the same subframe (partial fulfilment of M&E1_R10).

Due to the LTE limitations previously identified, the current developments in NR are focusing on eMBB and URLLC use-cases. In particular, NR Rel-15 offers the possibility of large BW carriers (up to 100 MHz below 6 GHz) to increase peak data rates, enhanced channel coding with the introduction of LDPC to enhance reliability or the support of different numerologies that reduce the TTI to meet more stringent latency requirements. For the 5G-Xcast use cases, NR will fulfil high-data rate requirements (M&E1_R28, M&E1_R30). NR is also being defined to provide increased performance in terms of latency for URLLC, (M&E2_R2, M&E3_R2, Auto1_R1, Auto1_R2). Mechanisms to decrease power consumption are also being discussed in the framework of LTE-IoT (IoT1_R1, IoT1_R3).

Despite the aforementioned enhancements, some of the D2.1 requirements are not fulfilled with 5G NR Rel-15. These requirements still need the definition of the new PTM modes that have been addressed within the 5G-Xcast project. The air-interface solutions described in D3.2 [5] are able to adapt to the requirements of the different 5G-Xcast use-cases, thanks to their flexible and configurable designs. One of the key design principles is to reuse as much as possible of the existing physical layer of NR in Rel-15, so that PTM can be seamlessly introduced. By having a common air interface, peak data rates and peak spectral efficiencies for eMBB PTM are preserved, as well as low latencies and high-speed tolerances for URLLC PTM. Among the enhancements, WP3 has investigated the use of new numerology options in order to support different network topologies. The designs can adapt PTM transmissions to different environments (M&E1_R14, M&E1_R28, M&E1_R30) and to extend coverage to different scenarios (M&E1_R17), with a granularity from cells to wide areas (PW1_R4). 5G-Xcast has also studied the provision of feedback mechanisms for PTM transmissions to enable the switch between allocated resources according to user and network demands. 5G-Xcast has targeted a spectral efficiency for PTM to match that available for PTP, leveraging the current developments in NR, where they have also considered the possibility of using MIMO schemes (M&E1_R29, M&E1_R34) .

5.1.3 RAN Logical Architecture

The 3GPP Rel-14 eMBMS RAN logical architecture covers solutions where services can be provided either using a Single Frequency Network mode (MBSFN) – on a frequency layer shared with non-MBMS services or on a frequency layer dedicated for MBMS – or MBMS transmission using Single-Cell Point-to-Multipoint transmission. The Rel-14 specification was evaluated in 5G-XCast deliverable D3.1 [4] including technical details impacting the RAN logical architecture such as RAN synchronization, RAN coverage area adaptation & extension, adaptation between unicast/broadcast multiplexing and adaptation between MBSFN and SC-PTM transmission modes.

Current MBSFN and SC-PTM solutions are based on a static configuration to deliver the broadcast/multicast traffic to predefined areas. In Rel-14 the MBSFN area is statically configured regardless of user distribution. It is not possible to dynamically create an SFN area on a cell or multi-cell level basis and it is not possible to use PTP, single cell PTM or multiple cell SFN/PTM in different areas of the network to deliver the same service.

When evaluating the RAN logical architecture against the use case M&E 1 The Hybrid Broadcast Service (and especially requirements M&E1_R3, M&E1_R10, M&E1_R20), it was observed that even if the required RAN architecture for a generic broadcast/multicast is supported in Rel-14, there are limitations in concurrent delivery and reception of broadcast/multicast and unicast traffic for end-to-end multicast traffic.

This limitation is mainly present due to the dedicated and static eMBMS architecture, which does not reuse the flexibility of the unicast-based architecture. The 3GPP Rel-14 RAN logical architecture contains limitations in terms of service area definition and support for dynamic adaptation between unicast, multicast and broadcast transmission modes. Furthermore, it is not possible to change the MBSFN area without relaunching the service, thus causing interruption in broadcast/multicast reception.

5G-XCast project WP3 Task 3.3 has considered Cloud-RAN deployments, which allows supporting dynamic adaptation between unicast, multicast and broadcast transmission modes. The NR Rel-15 RAN architecture functional split into Centralized Units (CU) and Distributed Units (DU) entities allows RAN architecture with centralized processing of RAN functions. In the developed solution the DU(s) closer to the deployed cells receive information about a set of UEs to which the multicast data should be transmitted and based on this information the distributed unit configures the needed unicast channels and multicast transport channels. The eMBMS RAN architecture consists of E-UTRAN nodes, namely the eNodeB and the Multi-cell/multicast Coordination Entity (MCE), a logical entity that can be deployed as a centralized network node or distributed into eNodeBs. In eMBMS, the PTM group data is carried through an eMBMS session and forwarded to the MCE, which then multicasts the data to multiple eNodeBs using the selected Modulation and Coding Scheme (MCS).

The MCS must be selected so that the service level agreement of the broadcast/multicast service is met for all users, taking into account the most limiting radio conditions. Rel-14 is lacking radio channel feedback mechanisms (M&E1_R7) to optimize radio resource allocation, optimum MCS and optimal use of broadcast/multicast or unicast bearers. The RAN architectural solution is thereafter impacted depending on whether the MCE node is centralized (controlling multiple eNodeBs) or distributed (controlling a single eNodeB). The functionality and realization of MCE functionality in 5G has been investigated to enable optimisation of use cases of broadcast/multicast and unicast and adaptation between these transmission modes.

Furthermore, MBSFN resource allocation is static and cannot adapt to the network traffic load. Subframes of defined frame structure reserved for MBSFN operation are transmitted regardless of the user demand, thus consuming resources both from the air interface and the RAN nodes. To overcome this limitation, LTE Rel-14 allows mapping of unicast data over the MBSFN subframes even in the case that there is no broadcast content available. However, only devices implementing Transmission Mode TM-9/10 are able to decode this data. This limitation was addressed as part of the RAN logical architecture design, which should allow dynamic SFN areas.

Rel-14 eMBMS control plane signalling and user plane data packets are distributed from the EPC to E-UTRAN through dedicated interfaces M2/M3 and interface M1 respectively. M2 and M3 are pure control plane interfaces where the M3 between the MME and MCE carries the session management signalling for MBMS interfaces with the M1 interface as a pure user plane interface. The dedicated architecture of eMBMS presents additional complexity to the network, which according to 5G requirements should be maximizing the usage of unicast RAN architecture for broadcast/multicast services leading to a common and flexible architecture and deployment.

The Rel-14 MBSFN architecture allows deployment for IMT-2020 requirements to support all mobility classes defined in IMT-2020, including speeds of 250 km/h (M&E1_R17, M&E1_R18). However, these deployments don’t allow for the dynamic adjustment of the Multicast/Broadcast area based on e.g. the user distribution or service requirements and, furthermore, it is not possible to seamlessly adapt the services to outdoor, indoor or vehicular scenarios due to a static configuration and the dedicated RAN architecture. In this case the further challenge from an architecture perspective in MBSFN is to support efficient multiplexing with unicast transmissions in frequency domain and time domain resources.

The use case PW1 (Multimedia public warning alert) is not supported in the Rel-14 RAN architecture where rich media provisioning to targeted groups of users with a dynamic cell level granularity is required (PW1_R4, PW1_R5, PW1_R12).

The RAN architecture should be capable of defining dynamic multicast areas where the multicast content is available. In Rel-14 eMBMS the service areas are static and configured using network vendor specific O&M interfaces. The 5G-XCast project has designed dynamic RAN multicast areas in D3.3 [6] which can allow selection of the most efficient transmission method, thus enabling a very low probability of failure of delivery of the message to the receiver over broadcast/multicast. The resulting reliability should be comparable to the reliability of existing public warning solutions as well as to unicast delivery but with added flexibility in deployment.

Rel-14 eMBMS supports broadcast/multicast reception in both Idle and Active modes of the RRC state machine. The devices in Active mode consume significantly more power compared to devices in Idle mode. Rel-14 doesn't allow for always connected devices with low power consumption, whereas Rel-15 NR has introduced the RRC_INACTIVE state where the device can stay in low activity mode from an RRC perspective while the NR Core and Connection Management sees the device as always connected in CM-Connected state. This approach in NR enables dramatically increased battery life compared to the current state-of-the-art while the control plane latency from the power efficient state to an active connection is dramatically decreased. The introduction of the RRC_INACTIVE state allows also dynamic RAN multicast procedures, which increase the flexibility of RAN procedures and allow dynamic multicast service areas according to number of users, their geographical distribution and service requirements. This solution allows the device receiver to sleep efficiently during low activity unicast periods while being able to receive IP Multicast services without interruption.

3GPP Release 14 and 15 for eMBMS have the same content, i.e. Release 15 doesn't specify new multicast/broadcast functionality for LTE nor NR.

Rel-14/15 are not able to meet most of the RAN logical architecture requirements specified for the M&E, PW, Automotive and IoT use cases. The main limitation is present in the static configuration of broadcast/multicast and dedicated the eMBMS architecture including dedicated network nodes in RAN, Core and dedicated RAN-Core interfaces. The lack of feedback mechanisms prevents it meeting requirements where user service usage and related feedback reports may be of interest for network optimization and/or to the service provider (M&E1_R7, IoT1_R2).

3GPP NR Release 15 has specified the new RAN logical architecture and RAN-Core interfaces. The 5G-XCast project evaluates the Release 15 NR RAN architecture and RAN-Core interfaces, takes the new scenarios and requirements into account [7] and addresses the above listed limitations of RAN logical architecture design during the project.

5.1.4 RAT Protocols

Design and implementation of RAT protocols and the relevant radio resource management are very crucial to fulfil the requirements of new emerging technologies. The major RAT protocol limitations of 3GPP's Rel-14 specification have been highlighted in D3.1 [4]. Among other things, the limitations on the radio resource management, latency and service scheduling have been elaborated.

In respect of radio resource management, the specifications provide limited support for feedback systems to assist the network to optimize the radio resources leading to challenges in terms of providing the required spectral efficiency and packet loss rates which create constraints on requirements such as M&E1_R7, M&E1_R23, M&E1_R29, Auto1_R2. Moreover, the lack of a seamless transition between PTP and PTM schemes as well as handover procedures between MBSFN areas create challenges on service continuity which in turn could constrain requirements such as M&E1_R24, Auto1_R1 and PW1_R12. Furthermore, there is limited flexibility on the trigger for MBMS service access where a trigger must come from the network side to wake up the MBMS reception for saving UE power which is relevant for such requirements as PW1_R5 in PW applications.

The 5G-Xcast RAT protocol study in D3.4 [8] has included investigation of feedback systems for PTM transmissions via link adaptation as well as HARQ with consideration of the trade-off among spectral efficiency, packet loss rates and signalling overhead for the feedback messages. Moreover, the use of a second layer of forward error correction scheme has been investigated in order to provide improved spectral efficiency and packet loss rates (M&E1_R7, M&E1_R23, M&E1_R29, Auto1_R2). Feedback systems with lower signalling overhead have been tailored with a second layer of FEC for further improvements in spectral efficiency and packet loss rates. Furthermore, the radio access design has included intelligent logic to flexibly apply error correction schemes depending on whether PTP or PTM is used for the delivery of multicast and broadcast data.

The 5G-Xcast RAT protocol design has targeted the provision of flexible and efficient radio resource allocation methods while considering QoS requirements for all services. The protocol functions take into account seamless transition between PTP and PTM transmission modes to guarantee service continuity requirements (M&E1_R24, Auto1_R1 and PW1_R12). Moreover, a flexible and intelligent scheme provides optimized content delivery by exploiting the adaptation of PTM transmission schemes with a possibility of a RAN-level multicast area to be defined dynamically. Furthermore, various aspects of the radio resource management will be investigated by using practical and heuristic approaches.

One flavour of efficient radio resource management is the use of triggers from the network to initiate MBMS reception in order facilitate PW applications. Herein, a trigger from the network eliminates the need for the UE to continuously monitor the MBMS channels which in turn is expected to lower UE power consumption (PW1_R5).

5G-Xcast, along with other 5GPP projects, is participating in the evaluation of 3GPP's NR that is set to meet IMT-2020 requirements. The first step of the evaluation process is to calibrate the system level simulator. The system-level simulation calibration results focusing on enhanced mobile broadband use cases are included in D3.4 [8]. The final IMT-2020 system-level evaluation process is ongoing and results will be included in the final D3.4 report.

5.1.5 PoC

System level simulators from the project partners have been used in WP3 to develop and analyse the RAN techniques and protocols, perform the proof-of-concept of the proposed 5G-Xcast RAN methods, as well as execute the system-level simulation-based evaluation of 3GPP's 5G NR proposal for IMT-2020. One PoC is to verify the benefits of using a second layer of FEC coupled with feedback to request transmission of FEC packet data units. Results show that the proposed scheme considerably reduces the packet loss rate with negligible cost on the user spectral efficiency. Other on-going PoCs include the evaluation of link adaptation techniques with broadcast and multicast, the analysis of 5G single cell PTM schemes in comparison to LTE-A 4G single cell PTM schemes and, finally, an IMT-2020 system-level evaluation of NR.

5.2 WP4: 5G-Xcast Core Network

5.2.1 Initial objectives of the 5G-Xcast Core Network

The mobile core network is studied by the 5G-Xcast project in WP4. The main objective of WP4 is to define the 5G converged core network architecture that combines fixed, mobile and broadcast networks and uses a mix of unicast, multicast, broadcast transports and caching capabilities to achieve optimal network efficiency. This 5G converged core network architecture allows 5G-Xcast autonomous MooD. The design has also considered NFV/SDN technology where required broadcast modules and entities will be activated on demand and deployed at the right place to meet network optimal operation requirements.

WP4 has also proposed flexible session control and resource management to meet the needs of new and diverse 5G use cases. The signalling for the session announcement should be defined to reduce the signalling overhead and avoid the need for the devices to continuously monitor multicast/broadcast sessions on the air interface to save battery consumption.

5.2.2 Mobile Core Network

Although multicast/broadcast capabilities have been specified for LTE (up to 3GPP Rel-14), some of the requirements specified for the M&E, PW, Automotive and IoT use cases cannot be met. For instance, a seamless experience can be achieved only within a mobile network (as a result of service continuity specified in 3GPP TS 26.346 [9]) but not for the case of different networks and device types (M&E1_R1).

For the PW use case (e.g. PW1_R2), rich content types (e.g. picture, audio, video) cannot be delivered by Cell Broadcast which is able to deliver only messages with a very small size (e.g. short text). When a massive software update for IoT devices having limited memory size, processing power and storage is required, the MBMS protocols and codes specified in 3GPP TS 26.346 [9] Rel-14 are inefficient due to, amongst other things, a large message size, the need for XML processing, and a heavy HTTP/TCP protocol stack.

Rel-15 (a.k.a. 5G phase 1) is not able to meet most of the requirements specified for the M&E, PW, Automotive and IoT use cases. Indeed, the 3GPP 5G architecture specified in Rel-15 has not yet taken multicast/broadcast capabilities into account and these capabilities are necessary for multiple requirements such as M&E1_R1, M&E1_R3, M&E1_R16.

WP4 has defined several architecture options in D4.1 [10] based on the current 5G architecture specified in 3GPP TS 23.501 [11] that enable multicast/broadcast capabilities to meet the requirements (e.g. M&E1_R1, M&E1_R3, M&E1_R16). More specifically, this WP has defined the call flows that enable MooD in mobile network, multilink to fulfil the requirements (e.g. M&E1_R1, M&E1_R3, M&E1_R12, M&E1_R16, PW1_R2).

5.2.3 Converged Core Network

WP4 has defined a converged architecture in D4.2 [12] that can dynamically exploit unicast, multicast and broadcast delivery modes as well as local caching. 5G-Xcast technologies are fundamental in the progression towards a converged 5G architecture to provide a seamless user experience.

3GPP in previous releases (14 & 15) on the mobile side and Broadband Forum (BBF) on the fixed network side have worked on convergence solutions in the past. Typically, these activities have progressed in isolation and have resulted in a number of technologies that offer partial convergence, but none of which we consider to offer full network convergence. Although this work continues to progress within the standards bodies, WP4 aims to address this shortfall by addressing requirements M&E_R1 and M&E_R2:

- End users have seamless access to audio-visual content both at home and on the move including seamless mobility between access networks, and across different types of devices (stationary, portable/ mobile, mounted in a vehicle).
    - The user's device is able to automatically connect to the best available network/s to give the highest QoE to the user, including simultaneous access to multiple networks.
    - It is desirable to allow using multiple network types together to increase QoS/QoE to any segment of the population that can support this.
- End users have a single set of credentials (e.g. single user name and password) in order to access a consistent set of content, services and policies across different access networks.

The architectures specified in D4.2 and the call flows in D4.3 were enhanced with the addition of multilink as an option. Especially in converged networks, 5G-Xcast introduced the concept of multilink, i.e using both the mobile network and the fixed network to provide benefits in seamless transition between the networks according to the UE location, delivery of personal objects to specific users in unicast, and enhancing the QoE for UEs who are in position to enjoy the service from both networks at the same time.

5.2.4 Session Control and Management

In the case of session control and management, there are several key requirements that are not met neither by 3GPP Rel-14 nor Rel-15, as follows:

- the 5G-Xcast M&E use cases call for a seamless transition between Multicast/Broadcast and unicast under different conditions such as moving between the home and outdoors and between fixed and mobile networks, in order to provide QoS and service continuity
- support of multicast/broadcast in a converged network across fixed and mobile
- support of different QoS to different users
- delivery of various media elements ("objects") in synch with the BC/MC content
- broadcast/multicast of protected (or encrypted) media.

NR does provide low layers support of flexible configuration of the broadcast areas (3GPP TR 38.913 [7]).

In the PW use cases, for example, 3GPP Rel 14 & 15 do not support requirements to send targeted alerts to groups of users based on cell ID or similar geolocation standards and others.

Task T4.3 included the definition of the session management and control in the core to work with the T4.2 architecture alternatives in view of the WP2 defined requirements and incorporating the technologies that address them, such as MooD and m-ABR or multi-link, this work was performed in D4.3 [13].

The following work flows have been defined to address the use cases identified in WP2:

- MooD for 5G-Xcast architectural options (M&E1)
- Multicast ABR on fixed broadband network which is part of the seamless switch in converged fixed mobile network (M&E1)
- Public Warning (PW1)
- Multilink (M&E1)

In addition, the current implementation of multilink is in unicast due to gateway implementation. This means that some of its benefits, such as the bandwidth enhancement, may currently be enjoyed by specific UEs rather than by all.

5.2.5 PoC

This work aims for a faster delivery of PW alert in a system where the capacity can be increased by taking into account the use of dynamic spectrum resources. In addition, the communications capacities are combined by using the multilink concept. Multilink is a technology to simultaneously use connections of more than one network for a single service while dynamic spectrum management allows changes in spectrum capacity locally and temporarily. The PW alert will be a multimedia message (e.g. text, photo, audio, video) as compared to only text message within Cell Broadcast.

5.3 WP5: Converged Content Distribution

5.3.1 Initial objectives of the 5G-Xcast Converged Content Distribution

The 5G-Xcast Converged Content Distribution Framework is defined by WP5 and the 5G-Xcast vision is presented in D5.1 [14]. The main objective of WP5 is to produce a network-agnostic content distribution framework which can combine unicast, multicast, broadcast and caching to optimise network resources dynamically, whilst:

- keeping the interface between the content service provider and the network operator as simple as possible;
- assuming that any requirement that can be met by content service provider alone will be provided using the content distribution framework, rather than using the network features; and
- treating multicast, broadcast and caching as built-in internal network optimisations, not as a service to be offered to a content service provider. These can be applied in an autonomous, self-optimising way, without the need for the content service provider to be aware of their use.

5.3.2 Top-level End-to-End Architectural Vision

The technical WPs 3, 4 and 5 have generated benchmarks of current media delivery technology, focused on the requirements of 5G-Xcast, and this benchmarking is presented in deliverable D5.2 [15]. In that deliverable, we also discuss two state-of-the-art standards: the CableLabs multicast-ABR architecture and the multicast-ABR DVB framework, and discuss the gap between the 5G-Xcast requirements and the state-of-the-art. We present a summary of that information in this deliverable.

CableLabs multicast-ABR

The CableLabs reference architecture uses the Cable-based DOCSIS local network, although the design goals are relevant to other distribution technologies that support bidirectional traffic over reliable connections and the principles could be applied to a mixed 5G/broadband network. The goal of the specification is that the client always receives unicast contents. However the content may traverse the network as either unicast or multicast, with the decision being an internal optimisation.

Multicast is delivered at a fixed, constant rate – it is pushed to the multicast clients. However, unicast clients will generally pull content: the clients parse the content manifest, request the referenced segments by HTTP and expect the segments to be delivered faster than the playout rate (i.e when the segment is decoded and presented to the viewer).Clients maintain internal buffers, allowing throughput variation to be smoothed out. This presents a problem when content may be routed via either type of network, since the multicast path cannot supply content faster than the 'natural' delivery rate (delivery rate when using a unicast transport) To avoid this problem, CableLabs recommends that the embedded multicast client in the Residential Gateway modifies the manifest before supplying it to the client on the end device, commonly removing the reference to the final segment. The embedded multicast client therefore has more knowledge of the stream than the end client, and thus has some headroom to decide whether to fetch the 'missing' segment over unicast or multicast. With Cablelabs, the NORM protocol [16] is used as the encapsulation format for multicast transmission, and FEC or NACK are supported for packet loss repair.

Whilst being a useful reference, the Cablelabs specification does not meet the needs of 5G-Xcast because:

- Cablelabs uses a relatively tightly integrated ecosystem, to deliver multicast-ABR. As such, there are many data- and control-plane interfaces and these complicate the business logic and relationships. Whilst this provides useful information to the system, it implies a commercial arrangement that may not exist in the open world of 5G-Xcast;
- Cablelabs assumes a uniform access network. The specification relates to DOCSIS cable delivery (although it could in principle be extended to other access network types), where access are managed using frequency division multiplexing and specific modulation schemes. 5G-Xcast, in contrast, will have a mix of IP-based wired and Wi-Fi, unicast and multicast plus 3GPP radio delivery, in broadcast or unicast modes;
- 5G-Xcast also needs to interface with multiple Content Providers, Network Operators, CDN Operators and mobile networks, requiring a more open, flexible approach.

DVB multicast-ABR framework

The DVB group is working on both a specification for multicast-ABR [17], as well as file-casting technology, to transfer file-based media over the broadcast interface. The DVB's m-ABR task is mindful of mobile networks, however defining how media should be transported over them is not core to its work. As to the DVB activities on file-casting technology, no decision has been made at the time of writing with respect to the protocol to adopt (e.g., the NORM protocol).

5.3.3 Content Distribution

5G-Xcast is both contributing to standards and also proposing demonstrators and PoCs. These are two very different situations, and as such, they way that the D2.1 [1] requirements are identified and addressed will differ.

The philosophy with the requirements for content distribution is to treat them as high-level features that are needed in order to deliver video and other types of content to end users. As such, they serve as guidelines for the technical work packages and avoid specifying specific parameters, values or technology as far as possible. It is the job of the other work packages with their domain knowledge to suggest the engineering solutions that will meet the requirements.

It may also be impractical to fully meet every requirement, given the complexities of emerging technology, future standardisation and the need to demonstrate and publicise our work over a short, two-year timescale. Some of the requirements (such as sub-5ms radio network latency) are out of scope from a WP5 perspective. However, the requirements will be used throughout the work as a check that the project as a whole is progressing in the desired direction.

An assessment of the requirements from the perspective of the various technical work packages 3, 4, & 5 is available Annex A, which also discusses the relative priority and scope of the requirements further.

The requirements are grouped into the three main use cases: M&E, PW and IoT. The tables in Annex A summarise the most relevant requirements from the WP5 perspective, with those that are out of scope omitted. In the tables, the term 'framework' refers to the 5G-Xcast Content Delivery Framework.

5.3.4 Application Layer Intelligence

WP5 concerns itself with what we have loosely called "Application Layer Intelligence" as a recognition that content service providers will implement various mechanisms within the components directly under their control in order to manage and improve the Quality of Experience of their service. Although the goal of WP5 is to avoid changing the functional aspects of current delivery solutions, it does impact non-functional aspects, such as the dynamics of data delivery, packet loss rate etc. It is therefore important to consider the impact of the WP5 framework on such mechanisms, and conversely, whether these mechanisms impact the effectiveness of the framework.

It is not the goal of WP5 to develop new application-layer techniques.

Firstly, one has to remember that being an application layer, by definition WP5 subject matter is outside the scope of some standards, including 3GPP. The standard sometimes defines mechanisms that may support application layer implementations. Specifically, for the application layer intelligence, several key requirements are not met by Rel-14 and 15. The first one is to implement broadcast/unicast as an overlay to the 3GPP and the fixed network cores and independently of them as much as possible, so that service deployment becomes easy and up to the content provider rather than depending on network equipment deployments and service setup.

Another key requirement of relevance is that 5G-Xcast requirement M&E1_R1 calls for seamless transition between multicast/broadcast and unicast under many conditions such as moving between the home and outdoors and between fixed and mobile networks, in order to provide QoS and service continuity. While 3GPP TR 22.816 (Hybrid networks) [18] addresses some of the relevant issues, it does not provide a full solution for the intelligence of when and how to control the transitions between the two networks, nor is there support for two or more operators rather than a single one.

Another important requirement in 5G-Xcast M&E1_R7 is to support differentiated QoS driven by the content provider and viewer relationships and/or momentary viewing conditions. This too is not supported by Rel-14 and 15. Other such requirements (M&E1_R3, M&E1_R5, M&E1_R12 and M&E1_R13) are the support of different QoS to different users, delivery of various media elements ("objects") in synch with the BC/MC content, BC/MC of protected (or encrypted) media.

T5.3 has defined in D5.3 [19] the application intelligence as independently as possible of the networks cores and in alignment with other relevant standardization bodies such as the DVB and Broadband forum for the fixed network; incorporating the technologies that enable that such as MooD-like operation, m-ABR, transport protocol and addresses resolutions and multi-link.

5.3.5 PoC

One of the key principles behind the framework proposed in WP5 is to isolate the content services from the use of multicast, to minimise any integration issues and allow for as much dynamic optimisation as possible. The Proof of Concept demonstrator proposed for WP5 will prove the validity of the concept by showing that a standard, commercial application can be made to work with multicast by introducing an "adaptation layer" in the UE whose purpose is to hide the complexities of multicast from the client application. Moreover, the same technique will be used on the fixed network to demonstrate the opportunity that this presents for moving towards a converged solution.

WP5 will also demonstrate the impact on QoE of using dynamic multicast by an extension to a simulator built by one of the partners.

6 Demonstrations of Use Cases

The following section outlines how the use cases of the project are realised on the different test beds and trials as well as demonstrators. The initial planning of those trials and demonstrators is explained in D6.1 [20]. D6.2 [22] and D6.3 [21] contain relevant information related to the development and integration of demonstrators and trials, respectively [21].

6.1 Trials and Test-Bed development

6.1.1 Turku

The Public Warning (PW 1) use case is implemented in the test network of the Turku University of Applied Sciences in Turku utilizing PW components developed by One2Many. These technical components include BMSC, MBMS-GW, PWP, software for public warning message creation and an app for the end devices to receive and display the alerts.

The reception of the alert is triggered by HTTP push message in the demonstration using 4G radio, and it is considered it will be updated to more suitable 5G NR mechanisms for triggering when available. The requirements considered to be addressed (in the order of priority) are: PW1_R1, PW1_R2, PW1_R4, PW1_R6, PW1_R8, PW1_R10, PW1_R11, PW1_R12, PW1_R13.

Another set of trials in this test-bed are related to spectrum sharing. This aspect can be considered to relate to several use cases, whenever dynamic spectrum use is required. The technical solution being tested is a spectrum manager developed by Fairspectrum. The first demonstrations were related to the use cases M&E1 – Hybrid broadcast service and especially M&E3 – Remote live production. Spectrum sharing between mobile network operators, private LTE network (that can be used by a PMSE stakeholder for production for example) and conventional PMSE equipment is demonstrated. The requirements addressed by spectrum demonstrations are M&E1_R38 and M&E3_R1.

6.1.2 Surrey

The planned test-bed demonstration in the 5G Innovation Centre (5GIC) of the University of Surrey is a part of M&E1 (the Hybrid Broadcast Service) implementation. More specifically, an interactive broadcasting technical solution is being tested, namely object-based broadcasting as described in [1].

In principle, the requirement M&E1_R13 is being addressed in this demonstration, i.e., enabling both conventional and object-based delivery. In addition, the requirement M&E1_R12 is also being taken into account, where it requires the transition between unicast and broadcast and multicast during service within a transition time in the order of seconds, without impact of viewers and other users.

Aligned with the requirements listed in clause 5.1, from the RAN perspective, the potential requirements being addressed includes M&E1_R3, M&E1_R7, M&E1_R10, M&E1_R16, M&E1_R17, M&E1_R24, M&E1_R28, M&E1_R29, M&E1_R31 and M&E1_R36. The requirements also include M&E1_R4, M&E1_R7 and M&E1_R16 from the core network perspective, and a similar requirement as 12 in Table 3 of [1] from the content distribution network perspective.

6.1.3 Munich

The IRT test-bed trials are mainly focused on the M&E1 (Hybrid Broadcast Service) where a variety of technological aspect are analysed. Trials show how users can benefit from the concurrent delivery of content via unicast and multicast. The implementation focuses on specific requirements such as (M&E1_R3, M&E_R7, M&E1_R10, M&E1_R36, M&E1_R3, M&E1_R15). Practical tests are being conducted to evaluate coverage performance aspects and available capacity against TV delivery quality criteria (M&E1_R23, M&E1_R25, M&E1_R26).

As part of the work conducted in the project to combine fixed, mobile and broadcast networks the test-bed integrates multi-link and MooD functionalities. Multi-link enables the bonding of content provided by means of multiple networks and also the seamless transition between unicast and multicast transmissions. This feature permits to evaluate system performance against KPIs such as data rate and latency. The requirements involved in these trials are (M&E1_R1, M&E1_R4, M&E1_R5, M&E1_R6, M&E1_R12, M&E1_R23).

MooD functionalities also enable testing the adaptation of the content delivery according to user density by autonomously setting up multicast or unicast transmission layers on demand. Additional requirements covered in this trial are (M&E1_R33, M&E1_R16).

6.2 Showcase: European Championships 2018

The showcase in connection with the European Championships 2018 (see D6.2 [22] and D6.5 [23]) has focused on the 5G-Xcast media and Entertainment Use Case 1 (Hybrid broadcast service). It uses audio-visual material produced in the state-of-the-art formats and illustrate how a new appealing European broadcast media service could be provided to large audiences in the 5G environment, including the following aspects:

- Fixed/mobile convergence.
- Combination of unicast and broadcast capabilities.
- Use of standardized 3GPP interfaces to encapsulate legacy DVB transport stream and service information.
- Free-to-air reception.
- Mobile/portable user equipment and traditional TV-sets.

The showcase explores the ability of current and future 3GPP based 4G/5G specifications to provide a HBS user experience in a fully wireless environment combining broadcast and unicast transmission to, first, access the broadcast signal and, later, establish a point-to-point connection to access on-demand and added value content from the HBS-server on HbbTVs and smartphones. Live audio-visual content from the event encodes and multiplexes into MPEG Transport Stream together with additional HbbTV data information; such stream is then broadcasted through an LTE eMBMS carrier. An HbbTV App located on an HbbTV server is available via a unicast LTE connection; two HbbTV applications (tailored to TV sets and mobile devices) are delivered to engage a bigger audience by handling the problem of heterogeneity of devices.

Given that the 5G-Xcast solution was not completely developed before the start of the sporting event, the showcase at the European Championships 2018 has partially addressed a subset of requirements specified for the Media and Entertainment Use Case 1, as depicted in Table 2 below.

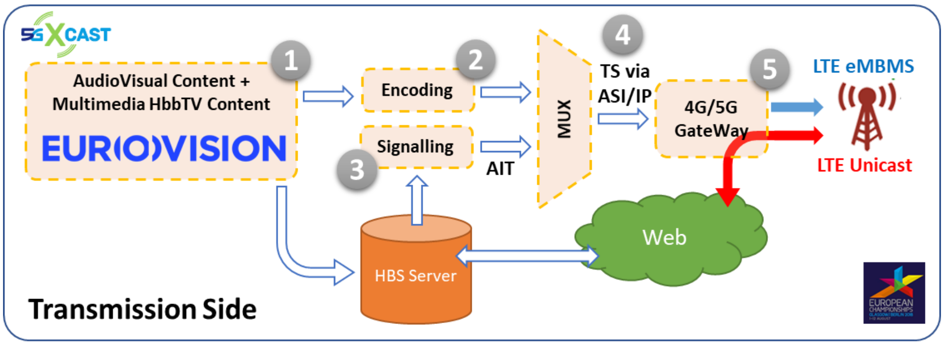

Figure 2: Architecture of the showcase at European Championships 2018.

Table 2 – Requirements addressed at the European Championships 2018

Addressed requirements	
M&E1_R1	The system supports seamless transitions between home based and mobile devices, by resorting to *ad hoc* HbbTV applications for mobile devices and TV sets.
M&E1_R3	eMBMS allows for an efficient multicast session, with traffic growing less than linearly with the number of receivers.
M&E1_R9	The eMBMS enabled UE (Bittium Tough Mobile) receiving the broadcasted content is able to exploit the basic network services (e.g. voice, data) while participating to eMBMS communication process.
M&E1_R10	The eMBMS enabled UE (Bittium Tough Mobile) receiving the broadcasted content can realise concurrent non-broadcast data session.
M&E1_R17	The solution supports indoor, outdoor and in-vehicle coverage.
M&E1_R34	The solution does not need excessive updates to the hardware capabilities of the UE.

Due to the absence of 5G-enabled devices on the market and the fact that at the time of the European Championships 2018 the 5G-Xcast solution has not yet been fully developed, the showcase was based on LTE compliant with the 3GPP Release 14. Furthermore, the available spectrum capacity for the showcase was rather limited (i.e. total of 2 x 8 MHz paired in the 700 MHz band).

Despite these constraints it was demonstrated that the above-mentioned requirements can be successfully met. It can, therefore, be assumed that with 5G equipment and more spectrum the system capacity can be scaled up to support the delivery of the required number of HD and UHD channels along with the on-demand content.

6.3 Project Demonstrators

During the execution of the 5G-Xcast project several demonstrators [22] were developed to show the innovative steps towards a 5G implementation and the potential of broadcast and multicast capabilities in future 5G networks. These demonstrators are set-up according to agreements between the partners involved targeting different public events and conferences. On the one hand, these demonstrators are used permanently on the premises of the respective companies in order to evaluate different aspects of the technologies involved. On the other hand these demonstrators help to showcase the progress of the project on major events and international workshops and conferences. The following table summarizes the planned demonstrators and their relevance to the use cases defined in WP2.

#	Demonstrator / Showcase	Location / Event	Involved WP
1	**Dynamic spectrum management and spectrum sharing**	EUCNC 2018	WP3
	This demonstrator relates to the work in WP3 to evaluate spectrum options for 5G deployments. Although the demonstrator is transversal to different use cases, PW1 will benefit of the features implemented on it in order to evaluate and adapt the transmission to the most adequate spectrum band for the delivery of PW messages.		

#	Demonstrator / Showcase	Location / Event	Involved WP
2	**EC'2018 – Hybrid Broadcast Service**	IBC 2018 (Amsterdam) Medientage (Munich) EBU Forecast (Geneva)	WP6
	This demonstrator relates to the delivery of Terrestrial Broadcast content and the potential to offer a Hybrid Broadcast Service with add-on content via unicast. Based on pre-Release 14 functionalities, the demonstrator is able to show how broadcast (traditional linear TV services) and unicast (add-on content) combine in the smartphone. A natural extension of the concept to a 5G network will require the combination of a 100% downlink only carrier with additional unicast traffic from a regular unicast carrier. The concepts presented in this demonstrator mainly relate to D2.4.		

#	Demonstrator / Showcase	Location / Event	Involved WP
3	Unicast, Multicast ABR or eMBMS	IBC 2018	WP4 WP5
	This demonstrator illustrates 3 examples of how the delivery path can be adapted to the user context considering: In-house reception where the home gateway is not equipped with a multicast to unicast agent (unicast delivery); in-house reception where the home gateway embeds a multicast to unicast agent (delivery via mABR and multicast to unicast conversion); and, on the go via eMBMS. The demonstrator is based on technologies developed in WP4 and WP5 for a 5G unified content delivery framework.		

#	Demonstrator / Showcase	Location / Event	Involved WP
4	Extended European Championships demonstration including MooD	MWC 2019	WP4 WP5
	This demonstrator extends the concept of a Hybrid Broadcast Service by considering that the network is able to dynamically adapt the delivery mode (unicast or broadcast) according to the user demand and user QoE. The main technology enabler to realize the migration of traffic is 3GPP-MooD and the work related to this in WP4 and WP5. This demonstrator is also related to essential KPIs discussed in the project such as coverage and connection density.		

#	Demonstrator / Showcase	Location / Event	Involved WP
5	Extended European Championships demonstration including multilink	EuCNC 2019	WP4 WP5
	Based on the Hybrid Broadcast Service, the demonstrator illustrates the benefits of multilink technology (developed as part of WP4 and WP5) in order to increase the data rate of the delivered service, by means of the bonding of two or more different radio access technologies, and/or extend the coverage when e.g. a user abandons the coverage area of one technology and is able to be provided with the content coming from		

	another path. The KPIs related to this demonstrators are coverge, reliability and data rate.

#	Demonstrator / Showcase	Location / Event	Involved WP
6	Converged, autonomous MooD in fixed/mobile networks	EuCNC 2019	WP4 WP5
	This demonstrator aims at integrating eMBMS with MooD capabilities into an existing app to visualize sport content. The demonstrator will integrate mABR delivery so that the delivery mode can be dynamically adapted and allocated to eMBMS or mABR according to traffic analysis.		

#	Demonstrator / Showcase	Location / Event	Involved WP
7	System Level Simulator including integration of MPEG-DASH, QoE monitoring & multilink (packet duplication & split bearer across RATs)	EuCNC 2019	WP3 WP5
	This demonstrator proposes a combination of the work developed in WP3 in term of system level simulations for 5G RAN and part of the technologies in WP5 related to media content delivery and the use of multilink to increase reliability, data rate and coverage.		

#	Demonstrator / Showcase	Location / Event	Involved WP
8	mABR demonstrator (joint with Sat5G) including multilink (TBC)	EuCNC 2019	WP4 WP5
	This demonstrator is developed in cooperation with the 5G-PPP Sat5G Project by extending the concept of demonstrator 3 using a combination of different paths such as terrestrial and satellite components. The demonstrator has a clear relation to WP5 in terms of a unified 5G delivery framework, which may also include satellite.		

#	Demonstrator / Showcase	Location / Event	Involved WP
9	Object-based Broadcast - Forecaster5G	EuCNC 2019	WP5
	This demonstrator is related to the Hybrid Broadcast Service and the converged content delivery framework as per WP5. The demonstrator highlights the potential of Object-based Broadcasting where different components of the signal are transmitted using different paths (even with different delivery modes as unicast/broadcast) that are later on rearranged at the receiver (or close to the network edge) according display and receiver capabilities as well as user demand.		

#	Demonstrator / Showcase	Location / Event	Involved WP
10	Public warning	EuCNC 2019	WP3 WP4
	The Public Warning demonstrator aims at developing part of the concepts investigated in the project (in WP3 and WP4) in order to deliver multimedia public warning messages with high reliability and coverage.		

7 KPIs and the Use Cases

7.1 5G-PPP KPIs

5G-Xcast aims to provide the cost-efficiency, scalability and ubiquity required by the core 5G PPP KPIs by defining broadcast and multicast capabilities in 5G. The project will not only aim to fulfil the technical requirements of the media vertical but also consider other verticals (i.e. public warning, automotive, and IoT). Novel KPIs such as ultra-high transmission reliability, reduced receiver power consumption and very low latencies have also been considered for delivering immersive media content such as virtual reality.

Some of the most challenging requirements and corresponding performance KPIs that have been identified against the relevant 5G-Xcast use case are as detailed in the table below.

Table 3 – Summary of key 5G PPP KPIs in 5G-Xcast use cases

Use Case	Most Challenging 5G PPP KPIs
Use Case M&E 1: Hybrid Broadcast Service	• Coverage: Nationwide network coverage; >99 % of the populated areas, roads and railways • Connection Density: ≥ 10000 devices per km² (crowded venues, hotspots) • System Scalability: ≥ 10^6 concurrent access links • U-plane E2E DL Latency: 50 ms or even higher • UE Speed: 500 km/h
Use Case M&E 2: Virtual /Augmented Reality Broadcast	• Peak Data Rates: ~5 Gbps • Connection Density: < 1000 devices per km² (crowded venues, hotspots) • U-plane E2E UL/DL Latency: 7 ms
Use Case M&E 3: Remote Live Production	• U-plane E2E UL/DL Latency: <10 ms • Peak Data Rates: ~9 Gbps (uncompressed video) • U-plane Reliability: 10^{-11} Bit Error Rate
Use Case PW 1: Multimedia Public Warning Alert	• Connection Density: up to 10000 devices / km² • Battery Consumption: No additional impact due to PW alert
Use Case Auto 1: V2X Broadcast Service	• Connection Density: 3000 vehicles / km² • U-plane E2E Latency: 5 ms • Reliability: 10^{-5} packet loss rate
Use Case IoT 1: Massive Software and Firmware Updates	• Connection Density: >10000 devices / km² • Battery Consumption: battery to last up to 15 years

Thus, the key 5G PPP KPIs can be summarized as follows:

- connection density;
- traffic density;
- UE experienced data rate;
- u-plane reliability;
- u-plane maximum end-to-end uplink / downlink latency;
- UE speed;
- minimum expected coverage; and
- battery consumption.

The relevant 5G-PPP performance and societal KPIs are as follows, which are then mapped to the project KPIs in Table 4.

- 5G PPP Performance KPIs
  - P1: Providing 1000 times higher wireless area capacity and more varied service capabilities compared to 2010
  - P3: Facilitating very dense deployments to connect over 7 trillion wireless devices serving over 7 billion people
  - P4: Creating a secure, reliable and dependable Internet with a "zero perceived" downtime for services provision
- 5G PPP Societal KPIs
  - S2: Reduction of energy consumption per service up to 90% (as compared to 2010)
  - S3: European availability of a competitive industrial offer for 5G systems and technologies
  - S4: Stimulation of new economically-viable services of high societal value like U-HDTV and M2M applications

Table 4 – Relevant 5G PPP KPIs and their mapping to 5G-Xcast

5G-Xcast KPIs	5G-PPP Performance KPIs			5G-PPP Societal KPIs		
	P1	P3	P4	S2	S3	S4
Connection Density		X			X	X
Traffic Density	X				X	X
UE Experienced Data Rate	X				X	X
U-plane Reliability			X		X	
U-plane Max E2E UL/DL Latency			X		X	
UE Speed					X	
Minimum Expected Coverage		X			X	
Battery Consumption				X	X	

7.2 IMT-2020 Validation of Use Cases and KPIs

One of the goals in the 5G-Xcast project is to verify how successful the transformation of selected use cases into demo sites / showcases have been accomplished. As benchmark the KPI values defined in the 5G-PPP, 3GPP and IMT-2020 documents are applied.

The 5G-Xcast project is involved in the 5GIA IMT-2020 Evaluation Group**,** which is one of the 11 evaluation groups created for the ITU-R evaluation process for Radio Interface Technologies (RITs). So, the procedures developed in this evaluation group are utilised to assess the KPIs achieved in the 5G-Xcast project. Out of the many KPIs defined for the IMT-2020 evaluation process those KPIs relevant for the 5G-Xcast were selected. Due to the specific orientation of 5G-Xcast project towards unicast, multicast/broadcast and terrestrial broadcast issues some more KPIs were also selected. This results in two evaluation domains. The first one comprises the general KPIs from 5G-PPP (marked with an A) and the second consists of the special KPIs dealt within 5G-Xcast (marked with a B). The following table shows these two domains:

Table 5 - Allocation of performance KPIs to 5G-PPP and 5G-Xcast.

#	Characteristic KPI	Assessment Method	A: 5G-PPP related	B: 5G-Xcast specific
1	Peak data rate	Analytical	X	X
2	Peak spectral efficiency	Analytical	X	X
3	User experienced data rate	Simulation	X	
4	5th percentile user spectral efficiency	Simulation	X	X
5	Average spectral efficiency	Simulation	X	X
6	Area traffic capacity	Analytical	X	
7	User plane latency	Analytical	X	X
8	Mobility	Analytical / Simulation	X	X
9	Bandwidth	Inspection	X	X
10	Coverage	Analytical/Simulation		X

Concerning the assessment methods as shown in the table above a classification into three different classes seems to be reasonable for the evaluation of the KPI:

1. KPI Assessment by analysis
2. KPI Assessment by simulation
3. KPI Assessment by inspection

Apart from this classification into three assessment methods, some KPIs could be later evaluated by means of measurements.

In the next paragraphs the results of the KPI assessments following the proposed classification are depicted. As done in other 5G-PPP projects a template for each specific KPI evaluation was employed. As shown in Table 5 the KPI evaluation for 5G-PPP is marked with an A, whereas the specific KPI evaluation in 5G-Xcast is marked with a B.

7.2.1 KPI Assessment by analysis

In WP3 some new a new numerology for NR in 3GPP has been developed. In four cases the KPI assessment was made by analysis, both or partly for PTP (5G NR) and PTM (5G-Xcast) scenarios.

Peak data rate 5G NR (A1)

Table 6 – Peak data rate 5G NR (A1).

KPI Definition	Maximum number of received data bits per second (bps) assuming error-free conditions assignable to a single mobile station, when all assignable radio resources for the corresponding link direction are utilized (i.e. excluding radio resources that are used for physical layer synchronization, reference signals or pilots, control region, guard bands and guard times).
Use Case	Media & Entertainment
Enhancement	5G NR Rel'15 allows to reach values up 173.57 Gbps (Downlink) and 94.57 Gbps (Uplink) to thanks to the use of MIMO and Carrier Aggregation in both frequency ranges.
Reference	WP3 Deliverable 3.2 - Section 4.1.2 [5].
Evaluation	By means of an expression valid for NR and defined for DL and UL transmissions combined with TDD (Time Division Duplex) and FDD (Frequency Division Duplex) techniques. Further details included in the WP3 Deliverable.

Peak data rate 5G-Xcast (B1)

Table 7 – Peak data rate 5G-Xcast (B1).

KPI Definition	Maximum number of received data bits per second (bps) assuming error-free conditions assignable to a single mobile station, when all assignable radio resources for the corresponding link direction are utilized (i.e. excluding radio resources that are used for physical layer synchronization, reference signals or pilots, control region, guard bands and guard times).
Use Case	Media & Entertainment
Enhancement	5G-Xcast Mixed Mode and Terrestrial Broadcast provides a clear PTM data rate gain compared to PTP services thanks to the use of a fixed CORESET, especially for high numbers of users. The gain can reach values up to 9.15 Gbps.
Reference	WP3 Deliverable 3.2 - Section 5.1.2 [5].
Evaluation	Same PTP peak data rate expression is used.

Peak spectral efficiency 5G NR (A2)

Table 8 – Peak spectral efficiency 5G NR (A2).

KPI Definition	Maximum data rate under ideal conditions normalized by the channel bandwidth. Expressed in bit/s/Hz.
Use Case	Media & Entertainment.
Enhancement	5G NR Rel'15 allows to reach values up 48.78 bit/s/Hz (Downlink) and 24.99 bit/s/Hz (Uplink) to thanks to the use of MIMO and Carrier Aggregation in both frequency ranges.

Reference	WP3 Deliverable 3.2 - Section 4.1.3 [5].
Evaluation	By means of an expression valid for NR and defined for DL and UL transmissions combined with TDD and FDD techniques. Further details included in the WP3 Deliverable.

Peak spectral efficiency 5G-Xcast (B2)

Table 9 – Peak spectral efficiency 5G-Xcast (B2).

KPI Definition	Maximum data rate under ideal conditions normalized by the channel bandwidth. Expressed in bit/s/Hz.
Use Case	Media & Entertainment.
Enhancement	There is a direct relationship between spectral efficiency and data rate and therefore PTM gains up to 23.51%.
Reference	WP3 Deliverable 3.2 - Section 5.1.3 [5].
Evaluation	Same PTP peak spectral efficiency expression is used

User plane latency 5G NR (A7)

Table 10 – User plane latency 5G NR (A7).

KPI Definition	User plane latency (ms) is the contribution of the radio network to the time from when the source sends a packet to when the destination receives it [24].
Use Case	Media & Entertainment, Automotive.
Enhancement	Without retransmission, the analysis has provided a minimum latency of 0.23 ms, with numerology 2. This number increases to 0.27 ms if the probability of a retransmission is 0.1. With 1 complete retransmission, the user plane latency goes up to 0.66 ms. In any case, the IMT-2020 requirement of 1 ms is met with 5G NR.
Reference	WP3 D3.2 (Air Interface), see section 4.2.2 [5].
Evaluation	The transmission and HARQ retransmission between UE and BS can be modelled as follows: $$t_{UP} = t_1 + p(t_2 + t_3)$$ where t_1 represents the time needed to transmit from the gNB to the UE, t_2 is the time required for a HARQ request, t_3 is the time needed to retransmit the content and p is the probability of a retransmission.

User plane latency 5G-Xcast (B7)

Table 11 – User plane latency 5G-Xcast (B7).

KPI Definition	User plane latency (ms) is the contribution of the radio network to the time from when the source sends a packet to when the destination receives it [24].
Use Case	Media & Entertainment, Automotive.
Enhancement	The Mixed mode keeps latency values obtained with NR if numerology

	0 is selected. The mixed mode additionally introduces new functionalities. Minimum latency of 0.56 ms. With Terrestrial Broadcast, although it is DL only with no retransmission, latencies are higher (1.21 ms).
Reference	WP3 D3.2 (Air Interface), see section 5.2.2 [5].
Evaluation	The transmission and HARQ retransmission between UE and BS can be modelled as follows: $t_{UP} = t_1 + p(t_2 + t_3)$ where t_1 represents the time needed to transmit from the gNB to the UE, t_2 is the time required for a HARQ request, t_3 is the time needed to retransmit the content and p is the probability of a retransmission.

Mobility 5G NR(A8) – partly analytical/simulations.

Table 12 – Mobility 5G NR (A8).

KPI Definition	Maximum mobile station speed at which a defined QoS can be achieved (in km/h) [24].
Use Case	Media & Entertainment, Automotive
Enhancement	700 MHz: All possible numerologies and DMRS signals fulfil the requirement with low MCS. 4 GHz: Numerology 1 with more than 2 DMRS symbols is at least required. The requirement of 500 km/h is not fulfilled in any case with numerology 0.
Reference	WP3 D3.2, see section 4.2.1 [5].
Evaluation	Theoretical Doppler shift and user speed associated to target frequency bands. In order to evaluate the mobility performance of NR in the IMT-2020 evaluation context, a Typical Urban (TU-6) channel model with variable speed has been selected.

Mobility 5G-Xcast (B8) – partly analytical/simulations.

Table 13 – Mobility 5G-Xcast (B8).

KPI Definition	Maximum mobile station speed at which a defined QoS can be achieved (in km/h) [24].
Use Case	Media & Entertainment, Automotive.
Enhancement	Mixed Mode designed to reach speeds higher than 500 km/h at 700 MHz if the MCS selected is robust enough. Speeds up to 250 km/h for 4 GHz. Terrestrial Broadcast, although focused on large SFN coverage, supports maximum speed values up to 400 km/h @ 700 MHz band
Reference	WP3 D3.2, see section 5.2.1 [5].
Evaluation	Theoretical Doppler shift and user speed associated to target frequency bands. In order to evaluate the mobility performance of NR in the IMT-2020 evaluation context, a Typical Urban (TU-6) channel model with variable speed has been selected.

Coverage 5G-Xcast (B10) – partly analytical/simulations.

Table 14 – Coverage 5G-Xcast (B10).

KPI Definition	99% Population with 95% Location Availability and 99% Time Availability.
Use Case	Media & Entertainment.
Enhancement	A set of extended CPs is proposed beyond those considered in LTE FeMBMS targeting, among others, better SFN coverage for HPHT networks (with e.g. 400 µs - 120 km ISD). The solution to enhance the coverage capability is to use numerologies with negative µ factors (in general) and extended CP with extended OFDM symbol for static reception.
Reference	WP3 D3.2, see section 5 [5].
Evaluation	Analytical and simulations for different inter-site distances (echo delays) and CP/OFDM parameters. SFN coverage is expressed as the variation of the available SINR in the network depending on the relative echo delay and CP/OFDM parameters.

7.2.2 KPI Assessment by simulations

The following KPIs are analysed by simulations. Particularly, by system level simulations.

User experienced data rate 5G NR (A3)

Table 15 – User experienced data rate 5G NR (A3).

KPI Definition	User experienced data rate is the 5% point of the cumulative distribution function (CDF) of the user throughput. User throughput (during active time) is defined as the number of correctly received bits, i.e. the number of bits contained in the service data units (SDUs) delivered to Layer 3, over a certain period of time.
Use Case	Media & Entertainment.
Enhancement	Main enhancements compared to LTE to improve user data rate are the use of MIMO for PTM, improved layer 1 and possibly layer 2 FEC schemes and advanced receivers and increased bandwidth.
Reference	WP3 D3.4 [8].
Evaluation	Following system level simulation methodology of ITU-R M.2412-0 in indoor, urban and rural scenarios. For a single frequency band it can be analytically computed as a product of the 5th percentile user spectral efficiency and the channel bandwidth.

5^{th} Percentile Spectral Efficiency 5G NR (A4)

Table 16 – 5th Percentile Spectral Efficiency 5G NR (A4).

KPI Definition	The 5th percentile user spectral efficiency is the 5% point of the CDF

	of the normalized user throughput. The normalized user throughput is defined as the number of correctly received bits, i.e. the number of bits contained in the SDUs delivered to Layer 3, over a certain period of time, divided by the channel bandwidth and is measured in bit/s/Hz.
Use Case	Media & Entertainment
Enhancement	Main enhancements compared to LTE to improve spectral efficiency are larger (massive) MIMO antenna arrays, improved FEC schemes and advanced receivers.
Reference	WP3 D3.4 [8].
Evaluation	Following system level simulation methodology of ITU-R M.2412-0 in indoor, urban and rural scenarios.

5^{th} Percentile Spectral Efficiency 5G-Xcast (B4)

Table 17 – User experienced data rate 5G-Xcast (B4).

KPI Definition	The 5th percentile user spectral efficiency is the 5% point of the CDF of the normalized user throughput in PTM mode. The normalized user throughput is defined as the number of correctly received bits, i.e. the number of bits contained in the SDUs delivered to Layer 3, over a certain period of time, divided by the channel bandwidth and is measured in bit/s/Hz.
Use Case	Media & Entertainment.
Enhancement	Main enhancements compared to LTE to improve spectral efficiency are the use of MIMO for PTM, improved layer 1 and possibly layer 2 FEC schemes and advanced receivers.
Reference	WP3 D3.4 [8].
Evaluation	Following system level simulation methodology of ITU-R M.2412-0 in indoor, urban and rural scenarios.

Average spectral efficiency 5G NR (A5)

Table 18 – Average spectral efficiency 5G NR (A5).

KPI Definition	Average spectral efficiency is the aggregate throughput of all users (the number of correctly received bits, i.e. the number of bits contained in the SDUs delivered to Layer 3, over a certain period of time) divided by the channel bandwidth of a specific band divided by the number of TRxPs and is measured in bit/s/Hz/TRxP.
Use Case	Media & Entertainment
Enhancement	Main enhancements compared to LTE to improve spectral efficiency are larger (massive) MIMO antenna arrays, improved FEC schemes and advanced receivers.
Reference	WP3 D3.4 [8].
Evaluation	Following system level simulation methodology of ITU-R M.2412-0 in indoor, urban and rural scenarios.

Average spectral efficiency 5G-Xcast (B5)

Table 19 – Average spectral efficiency 5G-Xcast (B5).

KPI Definition	Average spectral efficiency is the aggregate throughput of all users (the number of correctly received bits, i.e. the number of bits contained in the SDUs delivered to Layer 3, over a certain period of time) divided by the channel bandwidth of a specific band divided by the number of TRxPs and is measured in bit/s/Hz/TRxP.
Use Case	Media & Entertainment.
Enhancement	Main enhancements compared to LTE to improve spectral efficiency are the use of MIMO for PTM, improved layer 1 and possibly layer 2 FEC schemes and advanced receivers.
Reference	WP3 D3.4 [8].
Evaluation	Following system level simulation methodology of ITU-R M.2412-0 in indoor, urban and rural scenarios. As transmission errors cannot be corrected under all circumstances, packet loss rates are evaluated, as well.

Area traffic capacity 5G NR (A6)

Table 20 – Area traffic capacity (A6).

KPI Definition	Area traffic capacity is the total traffic throughput served per geographic area (in Mbit/s/m2). The throughput is the number of correctly received bits, i.e. the number of bits contained in the SDUs delivered to Layer 3, over a certain period of time.
Use Case	Media & Entertainment
Enhancement	Main enhancements compared to LTE to improve area traffic capacity are the use of MIMO for PTM, improved layer 1 and possibly layer 2 FEC schemes and advanced receivers and increased bandwidth.
Reference	WP3 D3.4 [8].
Evaluation	Following system level simulation methodology of ITU-R M.2412-0 in the indoor scenario. For a single frequency band it can be analytically computed as a product of the average spectral efficiency, the channel bandwidth and the density of TRxP per area.

7.2.3 KPI Assessment by inspection

Bandwidth 5G NR (A9)

Table 21 – Bandwidth 5G NR (A9).

KPI Definition	Maximum aggregated system bandwidth including frequency guard bands. The maximum supported bandwidth may be composed of either a single or multiple radio frequency (RF) carriers. It is measured in Hz.
Use Case	Media & Entertainment, Public Warning, Automotive, Internet of Things.

Enhancement	5G NR Rel'15 defines a scalable bandwidth solution where different system bandwidths are enabled depending on the frequency range and the numerology option. System bandwidths up to 100 MHz for the 450 MHz - 6 GHz band and up to 400 MHz for the 24.25 GHz - 52.6 GHz are allowed.
Reference	WP3 Deliverable 3.2 - Section 4.1.1 [5].
Evaluation	By looking to the 3GPP TR 38.817-01 – Section 4.5.

Bandwidth 5G-Xcast (B9)

Table 22 – Bandwidth 5G-Xcast (B9).

KPI Definition	Maximum aggregated system bandwidth including frequency guard bands. The maximum supported bandwidth may be composed of either a single or multiple radio frequency (RF) carriers. It is measured in Hz.
Use Case	Media & Entertainment, Public Warning, Automotive, Internet of Things.
Enhancement	5G-Xcast Mixed Mode and Terrestrial Broadcast define a scalable bandwidth solution where 50 MHz is defined as the maximum value for all narrower subcarrier spacings defined in new PTM numerologies.
Reference	WP3 Deliverable 3.2 - Section 5.1.1 [5].
Evaluation	PTM bandwidth configuration is inherited from numerology $\mu = 0$ in 5G NR Rel'15. For further references look at the same field within the PTP bandwidth KPI.

8 Conclusions

A lot of valuable work has been done during the first twenty months of the 5G-Xcast project. In the technical WPs an extensive inspection on the state-of-the-art has taken place. Furthermore, the limitations and the deficiencies of 3GPP and other specifications have been elaborated. These findings resulted in the new 5G-Xcast proposals and innovations which have paralleled the two tracks proposed as study items within 3GPP Rel-16 at the time relating to broadcast/multicast; one track based on improvements to LTE eMBMS beyond Rel-14, the other based on NR development in Rel-15 and Rel-16.

In the course of these investigations the use cases and requirements defined in D2.1 [1] were matched against the work devised in the technical work packages – WP3, WP4 & WP5. Those requirements pertaining to each of their respective domains have been identified and a number of these requirements have been analysed and addressed by the project. However, there are some requirements still to be dealt with in the remaining months of the project and a complete treatment of the requirements will be presented in a later update to D2.2. This future update of the deliverable will also include further results from the demonstrators that are to be developed in the remaining months of the project.

KPIs from 5G-PPP and IMT-2020 that are relevant to the 5G-Xcast use cases have also been identified and the benefits brought by the 5G-Xcast solution analysed and quantified.

The work in the first part of the project was targeting cellular networks and it has been followed by work to support terrestrial-broadcast-only networks in the second year of the project. It has been important to ensure support for all the network types envisaged for the 5G-Xcast solution. Work was carried out within WP2 and WP4 to further clarify the terminology around broadcasting introduced and defined in deliverable D2.1 [1] and this resulted in a revision of D2.1.

Work within the interim version of this present deliverable (published in M11) also suggested that it would be beneficial to provide more detail on the specific solutions targeting terrestrial broadcast in the project and this has resulted in the development of a new deliverable, D2.4 [25] (due M24) entitled “Analysis and Deployment of Terrestrial Broadcast in 5G-Xcast”. In addition, Public Warning will also be covered in more detail by its own deliverable, D2.5 [26] entitled “Analysis and Development of Public Warning in 5G-Xcast”.

A Allocation of Use Cases and requirements to the respective technical WPs

A.1 5G-Xcast RAN Requirements

These requirements where analysed in [1].

No.	Use case M&E 1 – The Hybrid Broadcast Service
M&E1_R3	• Broadcast/multicast support required.

M&E1_R7	• Feedback mechanisms to optimize radio resource allocation
	  ○ Optimisation of choice of Modulation and Coding Scheme (MCS) for broadcast/multicast
	  ○ Optimisation of use of broadcast/multicast or unicast bearers
	• Support for broadcast/multicast and unicast for interactivity

M&E1_R10	• Concurrent reception of broadcast/multicast and unicast
M&E1_R14	• A range of cyclic prefixes to cover different scenarios in rural, sub-urban and urban areas
M&E1_R15	• Broadcast/multicast will fulfil user density requirements but design of unicast radio access technology will need to take this into account
M&E1_R16	• Broadcast/multicast will fulfil concurrent user requirements but design of unicast radio access technology will need to take this into account
M&E1_R17	• Should focus on coverage to outdoor, indoor and to vehicles.
M&E1_R18	• Should fulfil all mobility classes defined in IMT-2020, including speeds of 250 km/h
M&E1_R20	• End-to-end (i.e. from content service provider to end user) transport layer security of multicast traffic must be equivalent to that of unicast traffic.
M&E1_R23	• Video bit-rates for UHD (Ultra High Definition) are higher than for HD (High Definition). Therefore, the RAT (Radio Access Technology) should target delivery of UHD content within the same resources as HD today through the use of, e.g. higher order constellations, improved error coding, time interleaving, MIMO (Multiple-Input and Multiple-Output) or better frequency re-use within the network.
M&E1_R24	• End-to-end latency is not highly critical in this use case. However, design of any time interleaving mechanism shall ensure that channel change latency is less than 1 second.
M&E1_R25	• Quasi-error free reception implies 1 uncorrected error per hour. In the case of a 50 Mbit/s stream, equating to a target BER (Bit Error Rate) of approximately 5^{-12} for broadcast/multicast. Note that in the case of unicast, re-transmission mechanisms may be used to achieve this.
M&E1_R28	• Support for delivery of regional content, i.e. different transmitter may deliver different content removing the possibility to always use large-scale single frequency networks.
M&E1_R29	• Spectral efficiency for the PTM should be at least as good as current state-of-the-art systems.
M&E1_R30	• The system shall be flexible to support different network topologies including existing High Power High Tower and Low Power Low Tower deployments.
M&E1_R31	• The system should be as flexible as possible regarding which frequency bands it supports.
M&E1_R33	• Support an uplink channel for audience metrics and service performance monitoring.
M&E1_R34	• The 5G-Xcast solution should be designed in a way as to minimise the need for excessive updates to the hardware capabilities of consumer equipment, including UEs

No.	Use case M&E 1 – The Hybrid Broadcast Service
	○ There is opportunity to take advantage of capabilities used for unicast but not currently used for broadcast such as multiple antennas.
M&E1_R36	• The radio access networks in 5G-Xcast system should maximize the system's spectral efficiency when unicast and multicast/broadcast services are deployed in the same frequency.

No.	Use case M&E 2 – Virtual/augmented reality broadcast
M&E2_R1	• For fully immersive VR (Virtual Reality) content delivery at 5 Gbit/s, techniques such as mmWave, carrier aggregation and MIMO could be examined.
M&E2_R2	• To achieve the low latency requirement for unicast the latest developments such as URLLC should be considered and for broadcast/multicast constraints on time interleaving depths and feedback techniques should be considered
M&E2_R3	• Broadcast/multicast will fulfil user density requirements but design of unicast radio access technology will need to take this into account.

No.	Use case M&E 3 – Remote live production
M&E3_R1	• For mezzanine quality (e.g. 100 Mbit/s) and uncompressed (e.g. 9 Gbit/s) video content, techniques such as mmWave, carrier aggregation and MIMO could be examined.
M&E3_R2	• To achieve the low latency requirement for unicast the latest developments such as URLLC should be considered and for broadcast/multicast constraints on time interleaving depths and feedback techniques should be considered.
M&E3_R3	• A very high quality of service delivery is required with a target BER of $<10^{-11}$.
M&E_R4	• Should fulfil the stationary mobility class defined in IMT-2020.

No.	Use case PW 1 – Multimedia public warning alert
PW1_R4	• Transmission of messages targeted to groups of users with a cell level granularity.
PW1_R5	• The RAN should be designed such that receiver algorithms do not dramatically decrease battery life compared to current state-of-the-art and the frame structure so designed so as to allow a receiver to sleep efficiently.
PW1_R12	• For very high priority alerts, the RAN solution should ensure a very low probability of failure to deliver the message to the receiver over broadcast/multicast and be comparable with the reliability of existing public warning solutions and to unicast delivery.

No.	Use case Auto 1 – V2X broadcast service
Auto1_R1	• To achieve the low latency requirement for unicast the latest developments such as URLLC should be considered and for broadcast/multicast constraints on time interleaving depths and feedback techniques should be considered.
Auto1_R2	• A high quality of service delivery is required with a target packet loss rate of $<10^{-5}$.
Auto1_R3	• Broadcast/multicast will fulfil user density requirements but design of unicast radio access technology will need to take this into account.

No.	Use case IoT 1 – Massive Software Updates
IoT1_R1	• The RAN should be designed such that receiver algorithms do not dramatically decrease battery life compared to current state-of-the-artstate-of-the-art and the frame structure so designed so as to allow a receiver to sleep efficiently.
IoT1_R2	• Support an uplink channel for successful delivery reports.
IoT1_R3	• The RAN frame structure should be designed so as to allow a receiver to sleep

No.	Use case IoT 1 – Massive Software Updates
	efficiently.
IoT1_R4	• Broadcast/multicast will fulfil user density requirements but design of unicast radio access technology will need to take this into account.
IoT1_R5	• The system should allow coverage extension capability.

A.2 5G-Xcast Core Network Requirements

No.	Use case M&E 1 – The Hybrid Broadcast Service
M&E1_R1	• A logic in the UE to handle the complexities seen by UE's application due to mobility, access network switching, simultaneous network handling • Use of multiple network types at the same time (e.g. multilink)
M&E1_R2	• Maybe impact on session control as a session may relate to specific users
M&E1_R3	• Support multicast/broadcast capability inside the core network. • Deliver multicast/broadcast traffic to flexible geographical area. • Optimize network resource allocation and management.
M&E1_R4	• Deliver all content's elements to the UE in only one network type • Deliver part of content's elements on a given network type
M&E1_R5	• Support traffic offloading between network types.
M&E1_R6	• Use of multiple network at the same time (e.g. multilink) • Switch between networks; either by an entity in the infrastructure aware of all such networks and connections, or by the UE
M&E1_R7	• Flexible and optimised resource allocation. • Switch from unicast to multicast/broadcast according to policies and vice versa. • Support local operator QoS policies & global QoS policies across operators.
M&E1_R11	• Dynamic and flexible QoS policies for different geographical area.
M&E1_R12	• Service continuity and seamless transition.
M&E1_R14	• Scalable and flexible non uniform geographical area
M&E1_R15	• Support multicast/broadcast capability
M&E1_R16	• Use of multicast/broadcast capability as a scalable solution • Guarantee QoS • Switch from unicast to multicast/broadcast on demand and vice versa
M&E1_R20	• Support secured data delivery for both unicast, multicast/broadcast traffic (e.g. IPSec)
M&E1_R22	• Support user identification and authentication
M&E1_R23	• Explore limitations. E.g. cell edge, during mobility, indoors, …; In some such cases the solution may require transiting to multilink UC.
M&E1_R24	• Support content synchronisation • Support mobile edge computing for low-latency applications
M&E1_R25	• Support data protection and recovery mechanism (e.g. retransmission, AL-FEC).
M&E1_R27	• Support data protection and recovery mechanism (e.g. retransmission, AL-FEC) • Guarantee QoS
M&E1_R28	• Scalable and dynamic geographical area.
M&E1_R32	• Expose simple and unified interfaces to the content provider
M&E1_R33	• Logics or network functions for audience measurements (number of users, duration, location, QoS experienced) • Apply for both fixed and mobile network types.
M&E1_R34	• Prefer softwarerization and NFV/SDN solutions

No.	Use case M&E 1 – The Hybrid Broadcast Service
	• Logic in UE to handle different delivery modes (e.g. unicast, multicast/broadcast).
M&E1_R35	• Customized QoS for different subscription models.
M&E1_R37	• Mark eligible content for multicast/broadcast on demand • Simplify the bearer setup for both point-to-point and point-to-multipoint

No.	Use case M&E 2 – Virtual/augmented reality broadcast
M&E2_R1	• Support high throughput data delivery • Support multilink to increase the throughput
M&E2_R2	• Support mobile edge computing.
M&E2_R3	• Support multicast/broadcast capability.

No.	Use case M&E 3 – Remote live production
M&E3_R1	• Support high throughput data delivery.
M&E3_R2	• Support low latency delivery • Support multilink to increase the throughput.
M&E3_R3	• Guarantee QoS.

No.	Use case PW 1 – Multimedia public warning alert
PW1_R1	• Low latency data delivery and announcement • Ability to request the delivery adhoc broadcasts (versus planned/scheduled)
PW1_R2	• No restrictions on the type of content to transmit
PW1_R3	• Interface to trusted authority shall support Authentication and Authorization
PW1_R4	• Flexible definition of the geographical area • Alert system may not know operator network / location of cells • Alert system is not required to know the identities of the subscribers addressed by the message in the area • Support multicast/broadcast capability.
PW1_R5	• Efficient announcement or triggering mechanism (which may or may not reside in the RAN only).
PW1_R7	• There shall be no restriction to support roaming users.
PW1_R10	• Similar as PW1_R12, ability to prioritize alert main content over other alert content
PW1_R12	• Ability to prioritize Alert content over other types of content

No.	Use case Auto 1 – V2X broadcast service
Auto1_R1	• Low latency delivery • Mobile edge computing.
Auto1_R2	• Support data protection and recovery mechanism (e.g. repetition, retransmission, AL-FEC).
Auto1_R3	• Support multicast/broadcast capability.

No.	Use case IoT 1 – Massive Software Updates
IoT1_R1	• Simplified and low-complexity data delivery procedure.
IoT1_R2	• Ability to request reporting.

No.	Use case IoT 1 – Massive Software Updates
IoT1_R3	• Simplified announcement mechanism.
IoT1_R4	• Support multicast/broadcast capability.

A.3 5G-Xcast Content Distribution Requirements

No.	Use case M&E 1 – The Hybrid Broadcast Service
M&E1_R1	• For many content services, it is possible to handle session handover at the application layer. There is often sufficient buffering on the end device to allow time to detect that one connection has been broken and to establish a new one, without interrupting the session from the user's perspective. • If it is wished to use a point to point network in combination with a point multipoint network, or combine different independent networks in a way that is hidden from the application, then a function must be introduced which aggregates these access networks into a single logical port that the application can use. On the mobile network, this aggregation function would need to reside on the UE. On the fixed network, it could reside in the Residential Gateway. Multipath TCP would be an example of such an aggregation technology.
M&E1_R3	• The network resources required to deliver the service to a given audience should grow much less than linearly with audience size.
M&E1_R4	• Related to M&E_R1. The content service may be constructed from multiple elementary streams which could be delivered over different, and even independent, networks. It falls to the application to assemble these elementary streams into a coherent user experience. • If the application needs to control the selection of network (and implicitly network type), then it will need to override the default behaviour of most operating systems and explicitly select the network device associated with that network type.
M&E1_R5	• This puts the decision of which of the delivery mechanisms available to the network operator should be used for a particular stream of traffic. • This is central to the framework. It will allow the network operator to switch between point to point and point to multipoint networks according to the network operator's own policies.
M&E1_R6	• This does not introduce any new implications beyond those discussed for M&E requirements 1 and 4
M&E1_R7	• Same as M&E1_R5
M&E1_R8	• The framework is not directly involved in indicating the availability of services to the end user. However, there needs to be a mechanism to signal to the devices at the edge of the network what networks they will need to connect to in order to receive all the elements of a content service.
M&E1_R9	• This requirement has implications for network resource management and the device operating system, but is out of scope for the framework.
M&E1_R11	• Partitioning the audience for a given piece of content according to QoS/QoE requirements will have an impact on the benefit that would be achieved by using point to multipoint networks. This requirement may encourage the use of scalable coding in order to avoid this.
M&E1_R12	• This is a core requirement for the Content Delivery Framework. Particularly for live event-driven viewing (sports matches) audiences may grow very large very quickly, then at the end of the event drop to very low levels just as quickly.
M&E1_R13	• HTTP streaming delivers content as data files, to be concatenated by the client player. So, in this sense, the delivery framework would already have to deal with delivery of files. One of the differences is that there might not be an obvious sequence of files, as there is with a video stream.

No.	Use case M&E 1 – The Hybrid Broadcast Service
M&E1_R14	• It should be able to support global coverage. This will imply that the framework will use a mix of technologies for different coverage regions. It could be anticipated that this will mean the use of a CDN to achieve global reach, then a point to multipoint network technology at the edge, where CDN nodes are not cost-effective.
M&E1_R16	• This requirement might be difficult to guarantee without generously over-dimensioning the network, apart from special cases. • If content is being delivered by unicast and there is a sudden demand for which the network does not have sufficient capacity, then there will be a degradation of Quality of Service. • If the content is being delivered by a point to multipoint technology, then bandwidth used will depend on the number of distinct streams being viewed. Again, if the network has capacity for a certain number of distinct streams, and this number of streams is exceeded, there will be degradation of the Quality of Service. • It could be argued that current broadcast networks are a counter-example. However, they only deliver a relatively small number of popular channels, and so can be sure that they are not over-dimensioned (i.e. there are unlikely to be long periods of time where fewer than the total number of channels is being watched). However, 5G-Xcast cannot limit itself to this scenario. • This requirement might need to be relaxed so say that, the Quality of Experience of a service must either degrade with increasing number of users, or it must degrade gracefully.
M&E1_R19	• Much content is encrypted and there is no reasonable way to intercept it. The hosting service could be subject to a court order, and the legal implications are outside the scope of WP5.
M&E1_R20	• Security is normally assured at several levels. The media payloads can be encrypted as part of a DRM system. The content delivery framework should be agnostic to this. • Transport Layer Security may be used. At a minimum this requires that the edge servers have a certificate that matches the domain name and that they have the private key that matches the public key in the certificate. • The content delivery framework will certainly need to consider TLS and will need to consider the degree of trust between the content service provider, the CDN operator and the network operator. • Above this, there is often an authentication layer, where a device, customer etc. would be authenticated and they would then be authorised to access a given service. • The content delivery framework must support a federated authentication model, where a content service provider will authenticate their customer and indicate the services for which they are authorised to the delivery network without the delivery network having to manage user accounts.
M&E1_R24	• The framework is likely to introduce extra request redirections, proxies and format conversion functions. These must be designed in such a way that latency is kept within tight bounds.
M&E1_R25	• Point to multipoint networks inherently have not reliability mechanisms. These need to be introduced as an overlay re-transmit capability or by adding FEC. Further, the selection of packaging format for the point to multipoint network will have an impact on the user impact of data loss. • Both the mechanism for enhancing the underlying reliability of the point to multipoint hops and the impact of the selection of packaging formats need to be addressed as part of the framework.

No.	Use case M&E 1 – The Hybrid Broadcast Service
M&E1_R26	• The infrastructure should be agnostic to the media formats used. The only relevant implication for the framework should be in terms of ensuring that elements of a service are delivered in a timely manner.
M&E1_R27	• The framework should not modify the content in any way. It should deliver exactly the media objects that are created by the content service provider.
M&E1_R28	• The two primary mechanisms used to identify location are the IP address of the end device, or residential gateway, and the location services available directly to the end device. • The framework could obscure the IP address of the end device as a result of the use of proxies. However, most content requests will initially be directed to the CSP for authentication and authorisation before the request is signed and re-directed. It could be anticipated that part of this authentication and authorisation step could be to validate the geographic region of the content.
M&E1_R30	• The only implication for the framework is to recognise that there is a requirement for regional optimisation of the delivery mode.
M&E1_R32	• This is one of the most important requirements for the framework. A key objective is to encourage the use of point to multipoint delivery by simplifying this interface.
M&E1_R33	• Metrics of this type will be essential to enable the self-optimising capability of the framework. Further than optimising the framework itself, such metrics may also need to be passed on to CDN operators or CSPs for their own billing and analytics.
M&E1_R35	• Some of this relates to providing network metrics for billing, FUP etc. • Business concerns relating to QoS could be more of a challenge. One of the goals of the framework is to avoid the need to expose direct network control to third parties by treating resource allocation as an internal optimisation problem, so we would consider the direct exposure of fixed bandwidth connections to be out of scope. • However, it will be considered a means to exert influence over the QoE of a service from the server and application, without need an explicit interface with the network operator.
M&E1_R36	• Spectral efficiency is outside the scope of the framework. However, it should be possible to take into account any differences in spectral efficiency when selecting the deliver mode.

No.	Use case M&E 2 – Virtual/augmented reality broadcast
M&E2_R1	• This is an issue for the underlying network technology, rather than the framework.
M&E2_R2	• Several measures of timing are important: end to end delay, round trip time, inter-device delay, service start up time (e.g. time to first frame) etc. • The framework may well introduce extra re-direct operations, proxies etc. It should be careful that these have a minimal negative impact on the various timings.
M&E2_R3	• The framework needs to be able to take into account that it might optimise the delivery mode at different granularities.

No.	Use case M&E 3 – Remote live production
M&E3_R2	• Support low latency delivery (not add latency).

No.	Use case IoT 1 – Massive Software Updates
IoT1_R1	• The most relevant aspect of IoT to the framework is the need to deliver firmware updates efficiently. This implies that it should not only be able to delivery streamed media using the framework, but that it should also be able to deliver large monolithic files (perhaps by segmenting). • It should not be forced devices to wake up if this is undesirable.

A.4 Prioritization

Prioritization Table from 1 to 3 (1 for highest priority):

Table 23 – Requirement prioritization list.

ID	WP3	WP4	WP5	WP6
M&E1_R1	2	1	1	1
M&E1_R2	NA	2	2	3
M&E1_R3	1	1	1	1
M&E1_R4	NA	2	2	2
M&E1_R5	3	1	1	2
M&E1_R6	NA	1	1	1
M&E1_R7	2	1	1	2
M&E1_R8	1	NA	3	NA
M&E1_R9	1	NA	NA	1
M&E1_R10	1	NA	NA	1
M&E1_R11	NA	1	NA	NA
M&E1_R12	1	1	1	1
M&E1_R13	NA	NA	2	3
M&E1_R14	1	2	2	NA
M&E1_R15	1	2	NA	NA
M&E1_R16	1	1	3	NA
M&E1_R17	1	NA	NA	1
M&E1_R18	1	NA	NA	2
M&E1_R19	NA	NA	3	NA
M&E1_R20	NA	2	NA	NA
M&E1_R21	NA	NA	NA	NA
M&E1_R22	NA	NA	NA	NA
M&E1_R23	1	NA	NA	2
M&E1_R24	1	1	1	2
M&E1_R25	1	NA	2	3
M&E1_R26	NA	NA	3	NA
M&E1_R27	NA	1	1	3
M&E1_R28	2	1	2	NA
M&E1_R29	1	NA	NA	NA
M&E1_R30	1	NA	3	3
M&E1_R31	2	NA	NA	NA
M&E1_R32	NA	2	2	NA
M&E1_R33	1	1	1	3
M&E1_R34	NA	2	NA	NA
M&E1_R35	NA	2	2	NA

M&E1_R36	1	NA	3	3
M&E1_R37	NA	1	2	NA
M&E2_R1	1	2	2	2
M&E2_R2	1	1	2	3
M&E2_R3	1	1	2	NA
M&E3_R1	1	NA	NA	NA
M&E3_R2	1	NA	NA	2
M&E3_R3	1	NA	NA	NA
M&E3_R4	1	NA	NA	NA
PW1_R1	1	1	NA	1
PW1_R2	1	NA	NA	1
PW1_R3	NA	NA	NA	NA
PW1_R4	1	2	NA	1
PW1_R5	3	2	NA	NA
PW1_R6	NA	NA	NA	2
PW1_R7	NA	2	NA	NA
PW1_R8	NA	NA	NA	2
PW1_R9	NA	NA	NA	NA
PW1_R10	NA	NA	NA	3
PW1_R11	NA	NA	NA	3
PW1_R12	2	2	NA	3
PW1_R13	NA	NA	NA	3
V2X1_R1	2	NA	NA	NA
V2X1_R2	1	NA	NA	NA
V2X1_R3	1	NA	NA	NA
IOT1_R1	2	NA	NA	NA
IOT1_R2	3	NA	NA	NA
IOT1_R3	2	NA	NA	NA
IOT1_R4	1	NA	NA	NA
IOT1_R5	1	NA	NA	NA

Where NA refers to Not Applicable.

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