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

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Abstract

This document presents the evaluation of the technical enablers of the projects that are part of the trials, demonstrators and showcase of the project. In particular, it covers the different results obtained from the trials in Munich covering the evaluation of multi-link and the features of eMBMS such as MooD, Surrey with spectral efficiency analysis of Object-based Broadcasting and Turku with the validation of multimedia public warning using eMBMS, multilink and also dynamic spectrum usage. In addition, results obtained from the demonstrators of the project have been included in those setups able to provide data.

Keywords

5G, trials, demonstrators, showcase, evaluation, validation

Executive Summary

Deliverable 6.4 provides information about the final setup of the test-beds and demonstrators elaborated in the project and the related trials performed.

5G-Xcast has contributed to the further development of the existing test-beds in Munich, Turku and Surrey with the integration of the latest state-of-the-art technology to enable the experimentation with the technical enablers associated to multicast and broadcast communication capabilities in 5G.

With the demonstrators and the showcases elaborated in 5G-Xcast, it has been possible to show the impact of the technology behind the project in technical forums, conferences as well as public-domain events.

In summary the project has delivered:

- A showcase in Munich around the Hybrid Broadcast Service at the European Championships 2018
- A trial in Surrey Test-bed in 2019 related to Object-based broadcasting
- A trial in Turku test-bed on the use case of multimedia public warning
- A trial in Munich test-bed on the delivery of media content using eMBMS and MooD
- 2 demonstrators for the IBC 2018 about the Hybrid Broadcast Service and the use of mABR
- A demonstrator for EuCNC 2018 on the initial integration of the spectrum-related component of multimedia public warning
- A demonstrator for the MWC 2019 around media distribution using MooD and eMBMS.
- A total of 6 demonstrators for EuCNC focused on the main technical components and use cases of the project.

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List of Acronyms and Abbreviations

AAS	Active Antenna System
ABR	Adaptive Bitrate
AF	Application Function
AIT	Application Information Table
AMF	Access and Mobility Function
AP	Access Point
AR	Augmented Reality
AUSF	Authentication & Security Function
BBU	Baseband Processing Unit
BC	Broadcast
BMSC	Broadcast/Multicast Service Center
BTS	Base Transceiver Station
BW	Bandwidth
CA	Carrier Aggregation
CC	Cluster Controller
CDN	Content Delivery Network
COTS	Commercial Off the Shelf
CP	Cyclic Prefix
DASH	Dynamic Adaptive Streaming over HTTP
DN	Data Network
DRM	Digital Rights Management
DTT	Digital Terrestrial Television
DVB-T	Digital Video Broadcasting - Terrestrial
DWDM	Dense Wavelength Division Multiplexing
EC	European Commission
eMBMS	Enhanced MBMS
eNB	Enhanced Node B
EPC	Evolved Packet Core
EPG	Electronic program guide
EU	European Union
FDC	Flat Distributed Cloud
FDD	Frequency Division Duplex
FEC	Forward Error Correction
FFT	Fast Fourier Transform
FLUTE	File Delivery over Unidirectional Transport
FPS	Frames Per Second
GPRS	General Packet Radio Service
GPS	Global Positioning System
GTP	GPRS Tunneling Protocol
GW	Gateway
HD	High Definition
HDR	High Dynamic Range
HFR	High Frame Rate
HTTP	Hypertext Transfer Protocol
HW	Hardware
IMS	IP Media Subsystem
IoT	Internet of Things
IP	Internet Protocol
ISD	Intersite Distance
LAN	Local Area Network
LOS	Line-of-sight
LPWAN	Low Power Wide Area Network
LSA	Licensed Shared Access
LTE	Long-Term Evolution
LTE-A	Long-Term Evolution Advanced
MABR	Multicast ABR
MBB	Mobile Broadband

MBMS	Multimedia Broadcast Multicast Service
MBSFN	Multicast Broadcast Single Frequency Network
MC	Multicast
MCCH	Multicast Control Channel
MCE	Multicell/Multicast Control Entity
MCH	Multicast Channel
MCS	Modulation and Coding Scheme
MEC	Mobile Edge Computing
MIMO	Multiple-Input and Multiple-Output
MIP	Multicast Ingestion Point
ML	Multi-link
MME	Mobility Management Entity
MNO	Mobile Network Operator
MPEG	Moving Picture Experts Group
MTCH	Multicast Traffic Channel
MW	Middleware
NAS	Non-Access Stratum
NFV	Network Functions Virtualisation
NR	New Radio
OAM	Operations and maintenance
OBB	Object Based Broadcasting
OFDM	Orthogonal frequency-division multiplexing
OTN	Optical Transport Network
OTT	Over-the-Top
PCF	Policy Control Function
PDCCH	Physical Downlink Control Channel
PDN	Packet Data Network
PMSE	Programme Making and Special Events
PPDR	Public Protection and Disaster Relief
PW	Public Warning
PWS	Public Warning System
QCI	QoS Class Identifier
QoS	Quality of Service
QPSK	Quadrature Phase Shift Keying
RAN	Radio Access Network
RF	Radio Frequency
RRH	Remote Radio Head
RRM	Remote Radio Module
RRU	Remote Radio Unit
RTP	Real-time Transport Protocol
RTSP	Real Time Streaming Protocol
SC-PTM	Single Cell – Point-to-Multipoint)
SD	Standard Definition
SDL	Supplemental Downlink
SDN	Software Defined Network
SDR	Software Defined Radio
SFN	Single Frequency Network
SISO	Single-Input and Single-Output
SMF	Service Management Function
STB	Set-top-box
SW	Software
SYNC	Synchronization
TCP	Transmission Control Protocol
TDD	Time Division Duplex
TEID	Tunnel Endpoint ID
TS	Transport Stream
TV	Television
TVWS	TV White Space
UDM	User Data Management

UDP	User Datagram Protocol
UE	User Equipment
UHD	Ultra-High Definition
UPF	User Plane Management
URL	Uniform Resource Locator
vEPC	virtual EPC
VoD	Video on Demand
VPN	Virtual Private Network
VR	Virtual Reality
WiFi	Wireless Fidelity
WRR	Weighted Round Robin

1 Introduction

This deliverable provides information about the final setups of the test-beds and demonstrators part of 5G-Xcast development during the project duration.

The document is organized around the three main use-cases of the project: Hybrid Broadcast Service, Object-Based Broadcasting and Public Warning Service [1]. For each, a subset of trials and demonstrators are explained with information about the final setup achieved in the project, the impact on the existing architectures when integrating technical enablers developed in the project, and results of the tests and measurements conducted.

The Hybrid Broadcast Service has been part of the trials in the Munich test-bed based on MooD and Multilink.

Object-based Broadcasting has been trialed in Surrey test-bed with the delivery of components over multicast and unicast

Public Warning Service has been the main topic tested in Turku test-bed in which eMBMS has been used for the delivery of content to massive audiences together with multi-link and a dynamic spectrum manager.

In addition, the European Championships 2018 was the scenario for a trial in Munich around the Hybrid Broadcast Service providing broadcast content with additional unicast services.

In terms of demonstrators, the project has elaborated the following:

- Initial components of the public warning service demonstrator for EuCNC 2018
- Hybrid Broadcast Service to smartphones and TV-sets for the IBC 2018, EBU Forecast 2018 and Munich Medientage 2018.
- A demonstrator around mABR for the IBC 2018.
- A demonstrator on the use of MooD and the latest commercially-available releases of eMBMS for the MWC Barcelona 2019.
- The “Forecast 5G: Object-based Broadcasting over multicast and unicast” demonstrator for the EuCNC 2019
- The “Content Distribution Framework in 5G Converged Networks” demonstrator for the EuCNC 2019
- The “Reliable Multicast Delivery in 5G Networks” demonstrator for the EuCNC 2019
- The “Efficiently delivering Public Warning messages with multimedia contents” demonstrator for the EuCNC 2019
- The “Hybrid Broadcast Services with Multi-Link” demonstrator for the EuCNC 2019
- The “Over-the-Air multicast over satellite or video caching and live content delivery” demonstrator, jointly developed between Sat-5G and 5G-Xcast for the EuCNC 2019.

Note that this deliverable focuses on the final setups and the results and measurements conducted to validate the technology and the use cases developed in the project. More information about the development of demonstrators and the integration of test-beds can be found in [2] and [3], respectively.

2 Hybrid Broadcast Service: Trials in Munich Test-Bed

2.1 Description of Hybrid Broadcast Service Trials

The Hybrid Broadcast Service Trials have been focused on the evaluation and benchmarking of eMBMS for media distribution. The Munich test-bed hosted by IRT has been further developed in order to include the latest 3GPP releases (Rel 14 ePC and MBMS network functions) to operate eMBMS for large area distribution [3]. This has been enabled by Nokia and Expway in collaboration with IRT. Together with LiveU, IRT has also conducted an integration of a Multi-Link unit for testing.

The trials conducted comprise the evaluation of eMBMS in the context of the preparation for the European Championships showcase, the evaluation of MooD as a result of the test-bed update and the assessment of multi-link between 3GPP RAT and WiFi.

2.2 Benchmarking on eMBMS Distribution

The performance of 4G Broadcast (eMBMS) has been extensively evaluated in literature by numerical calculation, however practical implementations can differ significantly from these. Multiple eMBMS field trials have been carried out worldwide but, due to the complexity of these, it can be difficult to examine the performance of individual parts of the system in a detailed way [4][5]. Broadcasters have broad experience in practical performance measurements of DVB-T/T2 but the particular characteristics of eMBMS make it necessary to adapt and translate some of this experience to evaluate this new system.

This section describes the construction of eMBMS chains within the laboratory to carry out physical-layer measurements within a controlled environment. It presents a methodology to measure the signal-to-noise-ratio (SNR) of eMBMS signals (that can time multiplex both unicast and broadcast parts). The SNR thresholds at different modulation and coding schemes are then measured in the laboratory and compared with the results obtained with numerical evaluations. While Release-14 has enabled three different physical layer configurations (numerologies), practical equipment availability at the time the work was commissioned has meant that this paper focusses on one of those numerologies also available in earlier 3GPP releases. The laboratory measurements are performed independently in the facilities of BBC R&D and IRT to compare and validate the proposed methodology and evaluations.

2.2.1 Measurements, Evaluation and Results

The experiments are carried out using a 3GPP Release-11 base station transmitting eMBMS signals that time multiplex, in the same carrier, unicast (Physical Downlink Shared Channel - PDSCH) and broadcast (Physical Multicast Channel - PMCH) transmissions. In particular 60% of the subframes (note that a subframe has a duration of 1 ms) are allocated to broadcast while the remaining 40% of subframes are allocated to unicast transmissions (cf. Figure 1).

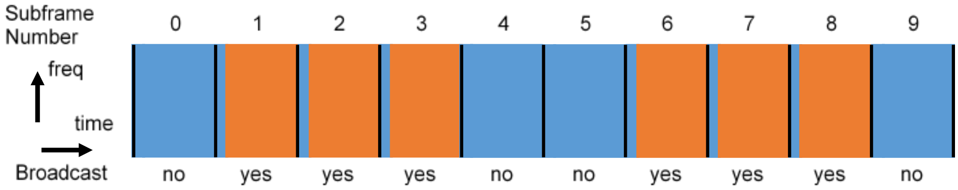

Figure 1: LTE eMBMS subframe allocation to unicast (PDSCH) and broadcast (PMCH) channels.

The devices used in the experiments are off-the-shelf tab lablets (at the BBC) and smartphones (at the IRT lab) with the necessary eMBMS middleware incorporated to allow reception of broadcast as well as unicast signals.

The selected bandwidth for the transmitted signal is 5 MHz (25 Resource Blocks) operating at band 28 with a downlink carrier frequency of 769.5 MHz and a paired uplink carrier with a carrier frequency of 714.5 MHz. The PMCH channel uses a subcarrier spacing of 15 kHz with the extended cyclic prefix of 16.7 us with the addition of one OFDM symbol in the non-MBSFN subframe region (i.e. OFDM symbols dedicated to control information and not available for data).

It is worth noting that although, in the context of eMBMS, the 3GPP Release-14 has introduced modifications to the physical layer (e.g. the introduction of a new cyclic prefix of 200 µs to enable SFN configurations with larger cell sizes and the possibility to use all subframes for broadcast), there have not been significant modifications from Release-11 to the main procedures in multiplexing & channel coding (i.e. CRC attachment, segmentation, channel coding, rate matching and concatenation as in TS 36.212) and physical channels and modulation (scrambling and modulation as in TS 36.211). This means that the evaluations conducted in this experiment are representative of performance results for the 3GPP Release-14 specification for the studied transmission modes.

A block diagram representing the laboratory setup used for the experiments to evaluate the physical layer performance of LTE eMBMS is presented in Figure 2.

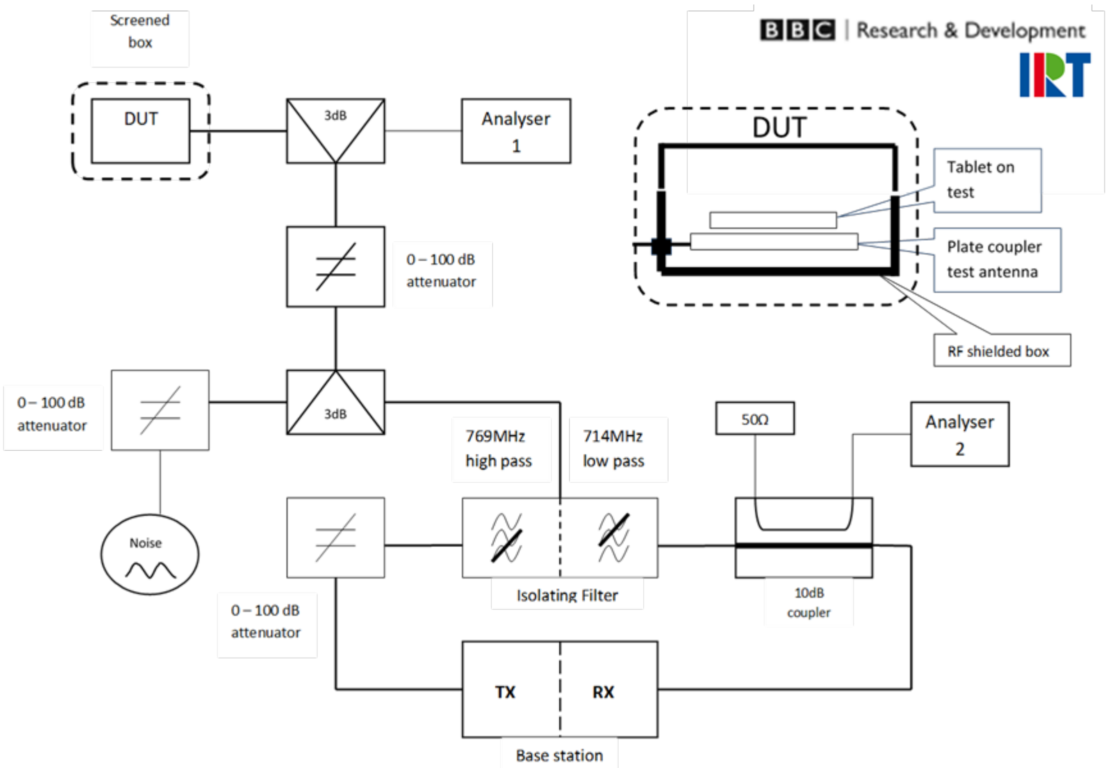

Figure 2: LTE eMBMS laboratory setup

The transmitted LTE eMBMS is combined with an external noise source to conduct tests at different levels of received Signal to Noise Ratio (SNR). The resulting degraded signal goes through a splitter and the same signal is injected into the Device Under Test (DUT) and to a spectrum analyser. The tablet or smartphone is enclosed within a screened box to minimise interference to/from other nearby devices or transmissions operating on the same frequencies. Inside the screened box the user equipment is placed on a plate coupler. The spectrum analyser permits the measurement of the power levels of the wanted and interfering signals to estimate the SNR that is observed by the receiver that decodes the eMBMS services. The output power levels of the LTE eMBMS and noise sources can be controlled by variable attenuators. The signal levels measured in the laboratory for the LTE eMBMS signal at the spectrum analyser were in the order of -36 dBm. It is worth noting that the signal levels received by the tablet or smartphone will be lower than the ones measured at the spectrum analyser due to the losses of the plate coupler. However the SNR measured at the spectrum analyser is maintained at the tablet since both the wanted and interfering signals experience the same coupling loss and provided that the operating point is well above the noise floor of the receiver.

The transmit and receive ports of the base station are isolated by a duplex filter tuned to the relevant operating frequencies. While we have focused on the downlink in the set of experiments featured in this paper, the uplink signals coming from the user equipment can also be displayed on a spectrum analyser for monitoring purposes.

The evaluation of the performance of the physical layer of a candidate communication system is commonly assessed in the research literature in terms of bit-error-rate (BER) or block-error-rate (BLER) at the output of the channel decoder at the receiver. However, with the off-the-shelf equipment used in the experiments conducted in this paper, it is not possible to gain direct access to the output of the channel decoder and hence the only output available to evaluate errors that occur during the transmission is the final output video.

Two error criteria are used in this paper to evaluate the performance of LTE eMBMS in the laboratory. The first one is the “onset of failure”, i.e. the operating point at which errors start appearing at the decoded video stream. The second one is “complete failure”, i.e. the operating point at which the decoded video stream is completely corrupted.

In the laboratory experiments at BBC R&D three live MPEG-DASH video streams of the same content are used that are encoded at different bit rates. The bit rates of the aggregated video and audio streams used in the experiments are 452, 715 and 1427 kbps and the same segment duration of 3.84 s.

At IRT, three different MPEG transport streams with 500 kbps, 800 kbps and 1 Mbps are used. In this case, the streams are delivered using RTP (Real Time Protocol) encapsulation.

The three live video streams are mapped to different LTE eMBMS system configurations that provide different physical layer transmission capacities.

The goal is to obtain a methodology to measure the SNR of a LTE eMBMS signal with a spectrum analyser with standard frequency and time domain processing but that does not rely on specific software to demodulate the complete (or part of the) received LTE eMBMS signal (e.g. using the reference signals or other specific channel or signals in the specification). Since the 3GPP LTE eMBMS specifications orthogonally multiplex unicast and broadcast subframes in the time domain, the spectrum analyser is configured in zero span as shown in Figure 3. In this paper we are interested to measure the signal power of the MBSFN subframes i.e. the ones carrying the broadcast content. Since the base station is not serving users with unicast content, those subframes dedicated to unicast are mostly idle and therefore have lower power levels.

Before any performance measurements are done the output power levels of the LTE eMBMS signal and the external noise source need to be configured to a known value that provides a reference SNR (e.g. SNR equal to 0 dB). To obtain a reference SNR value, the signal power of the MBSFN frames is first measured in zero span mode (time domain) without the external noise source (Figure 4). Secondly the power of the external noise source in the data carriers (e.g. 4.5 MHz for 25 resource blocks) without the presence of the LTE eMBMS signal is measured in the frequency domain (Figure 4). For the measured power levels of both the LTE eMBMS signal and the external noise source, the powers can be adjusted with the variable attenuators to obtain the same level which then provides the reference value of SNR=0 dB. If the transmission system is configured to use all the subframes for broadcast (as it is specified in 3GPP Release-14), the powers of both LTE eMBMS signal and the external noise source could both be measured in the frequency domain (or in the time domain with adequate resolution bandwidths adapted to the transmitted signal bandwidth).

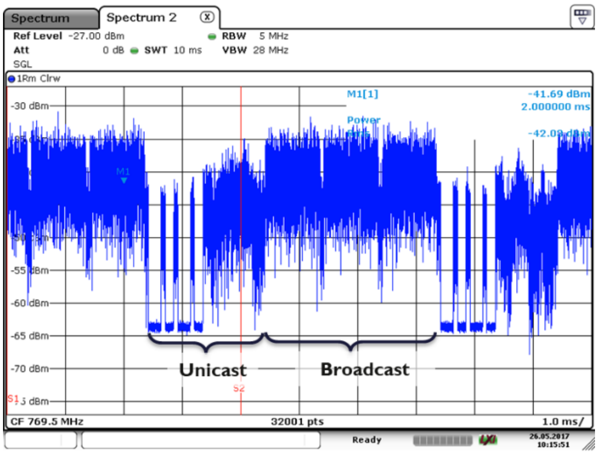

Figure 3: Measured time domain LTE eMBMS signal showing time multiplexed unicast and broadcast subframes.

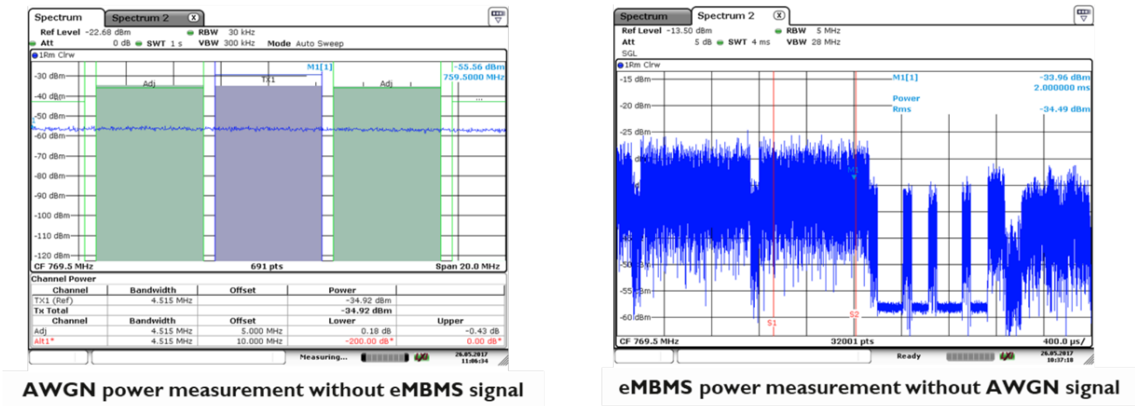

Figure 4: LTE eMBMS SNR measurement procedure – separate power measurements of MBSFN subframes and noise.

Table 1 shows the results of the laboratory experiments done at BBC R&D and IRT to evaluate the performance of LTE eMBMS for different MCS values. For each measurement, two SNR values are reported in the table corresponding to the two error criteria specified in the first section of this paper, namely “onset of failure” and “complete failure”. The results are compared with the simulation results at a BLER equal to 10^{-4}, which can be considered as a transmission with a low percentage of errors and we expect this BLER criteria to be close to the “onset of failure” error criteria.

It can be seen that the results obtained at both laboratories are well aligned with differences of only around 0.5 dB for both error criteria. As expected the measured results are always worse than the simulated, particularly for the “onset of failure” criteria where the differences with simulation are around 1-2 dB. For the “complete failure” which requires higher error rates the differences compared with simulation are closer within 1 dB. This performance degradation of the laboratory experiments compared to simulation is expected due to implementation margins. The measured values for MCS 24 from BBC R&D have a significantly higher difference compared to simulation and this needs further exploration and verification with further measurements.

MCS Index	Data rate Video Stream BBC/IRT [kbps]	Simulated SNR at BLER 10^{-4} [dB]	Measured SNR at “On Set Failure” [dB]		Measured SNR at “Complete Failure” [dB]	
			BBC	IRT	BBC	IRT
5	452/500	0.1	1.7	2.3	-0.2	0.3
9	452/500	4.4	5.2	5.7	4.7	5.1
11	715/800	4.6	6.8	6.3	5.5	5.7
16	715/800	10.0	11.2	11.9	10.5	10.8
18	1427/1000	10.5	13.0	12.7	11.2	11.6
24	1427/1000	17.2	24.2	19.6	20.8	18.3

Table 1: Measured performance of LTE eMBMS in AWGN channel in the laboratory of BBC R&D and the laboratory of IRT and comparison with simulated results.

2.3 Update of Munich Test-Bed and Integration of MooD

During the set-up of the 5GXcast testbed the existing Radio network, consisting of 4 cells was upgraded several times from initially 3GPP Rel. 11 compatibility up to 3GPP Rel.14 compatibility [3]. The existing core deployment [6], which was dedicated lab test software, was replaced by a commercial product, the Nokia Micro Core Network which is a unique integrated – SW only - solution that provides all the Core vNFs in addition with management tool that can be deployed on only one server. The modular architecture allows integration into experimental set-ups.

Expway’s software is installed on a virtual machine that comprises the following components:

- The BMSC: the core multicast/broadcast functionalities that receives the content through the xMB interface in unicast and converts into multicast data and sends to the MBMS-GW

- The MBMS-GW receives the multicast data and forwards it to all relevant eNBs in the network.

- The BPM: the provisioning manager that provides the web interface to schedule the eMBMS services and control the BMSC

- The Consumption Report and Analytics receive the consumption report messages from the middleware on the phones, analyse the audience size and decide when to switch between unicast and eMBMS delivery.

- The emulated MME is used to handle the control plane setup of the eMBMS session. Its purpose is to bypass the MME in case the operator’s MME does not support eMBMS.

Expway has provided the Bittium phones with the latest Expway's middleware version that supports MooD functionality. All Expway's software in both terminal and network is compatible with the eMBMS functionalities specified in 3GPP Release 14.

Note that the complete test-bed is Release 14 compliant. However, the RAN only supports the configuration of a 15 kHz sub-carrier spacing with extended CP.

A diagram of the test-bed architecture is shown below.

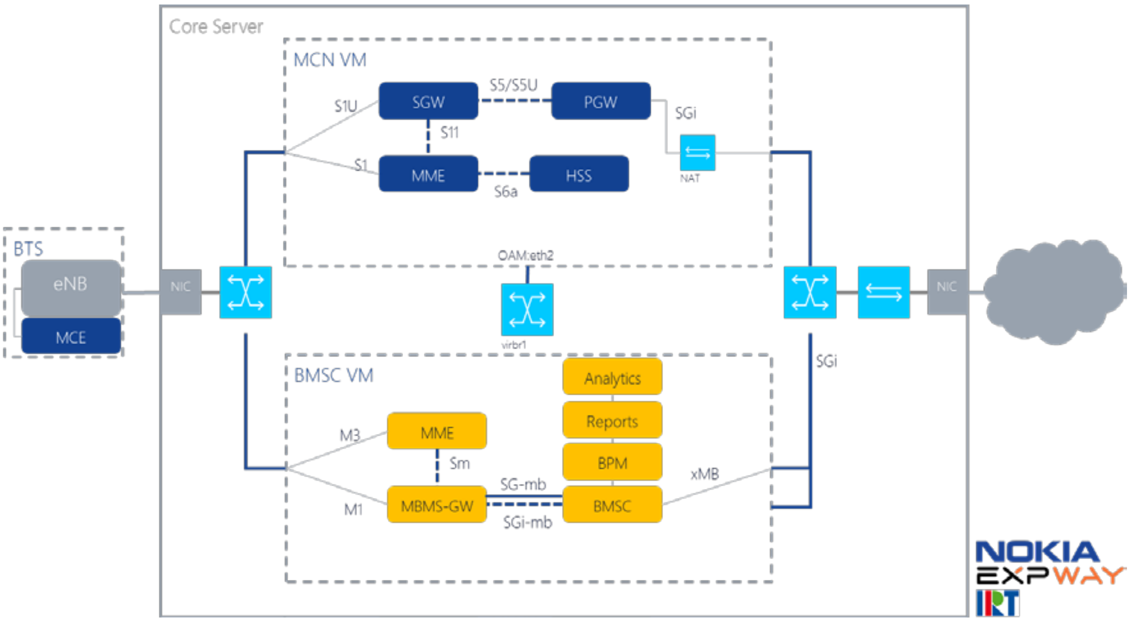

Figure 5: Integration of MooD features and update of ePC in the Munich Test-bed

Figure 6: Equipment at the IRT premises showing the Bittium phones employed for the trials, the server that allocates the virtualized network functions of the core provided by Nokia and Expway and the base station provided by Nokia.

2.3.1 Measurements, Evaluation and Results

This section covers the different measurements conducted in the Munich test-bed to validate the use of different eMBMS functionalities. Given the opportunity of playing with different configuration options a series of tests were performed mainly focused on the validation of MooD and the assessment of the coverage when using eMBMS, eMBMS with AL-FEC or unicast.

2.3.2 Validation of MooD and Evaluation of Coverage Areas

The ability of MooD to offload traffic when users are concurrently consuming the same content has been tested. A total of three phones were used for such purpose, configuring a threshold for the switching for the load of 3 phones. Therefore, one or two phones will remain in unicast while when a third phone is connected, an eMBMS session will be created and all phones will be driven to broadcast without interruption. If the third phone is disconnected, the other two users will again be passed to unicast and the broadcast session will be off.

Figure 7: Bittium phones equipped with the latest version of Expway middleware and Player App showing independent unicast connections just before the broadcast service is activated (left) and when, after a few second, the users are switched to broadcast (right).

Under this test, it was checked that the interval between the activation of the third phone requesting the same unicast content until the three phones are then passed to broadcast is about 30 seconds. The release time was proved to be similar. The system can be configured to shorten the switching time, however a high margin of 30s was chosen to ensure the system stability during the measurement, This means that there is a margin for which the decision to activate or deactivate the eMBMS sessions will take place.

Regarding data rate, there is a clear benefit for using broadcast to deliver media content. With the test, video streams with an average data rate of 1.5 Mbps were used. When more users are connected to the same content via unicast, the data rate that the network is supporting will increase proportionally. With three users a total of 4.5 Mbps will be delivered. When the users are switched to broadcast the total amount of data is reduced to about 1.8 Mbps from which about 300 kbps come from the signaling of eMBMS, for example the carousel service announcement. In practical deployment, the eMBMS signaling traffic will be minimized depending on the size of the metadata as well as the interval between two consecutive service announcements. Therefore, even with 2 users, the benefit is already apparent.

2.3.3 Evaluation of Coverage

Given the possibility to configure eMBMS services in the test-bed, this has been used to assess the coverage around Munich when using different MCS indexes for eMBMS, a comparison between unicast delivery and the use of AL-FEC in order to increase the robustness of the service.

The tests were made by means of attaching two Bittium phones to a city bike which was driven along one of the most popular areas of Munich, the Englisher Garten. In each phone, a different delivery mode is configured so that a one-to-one comparison can be established (e.g. one phone receiving eMBMS without AL-FEC and another phone with AL-FEC). The traces are stored containing GPS information and signal level, measured over the reference signals of the unicast region of the carriers in terms of RSRP. However, this measurement would be insufficient to assess the actual QoE of the video visualization at the player. Therefore and given the support from Expway, it was possible to record the middleware logs in order to accurately obtain information about the playout. By merging GPS data with MW data, it is possible to draw maps in which the good and bad quality of the video presentation on the screen is evaluated. The following figures present an example of the kind of routes followed in the experiment and the result.

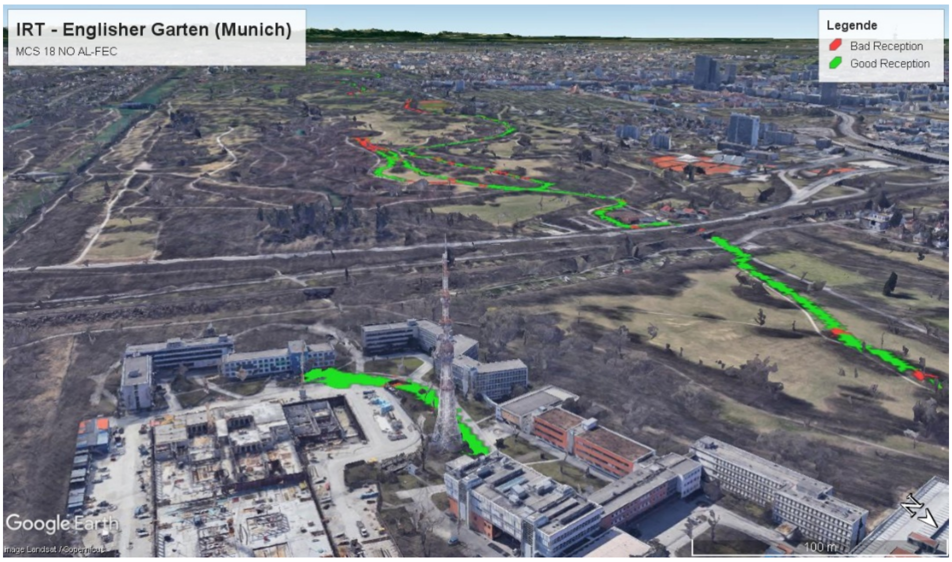

Figure 8: Example of measurement route showing the starting point at the premises of IRT (with the tower at the front).

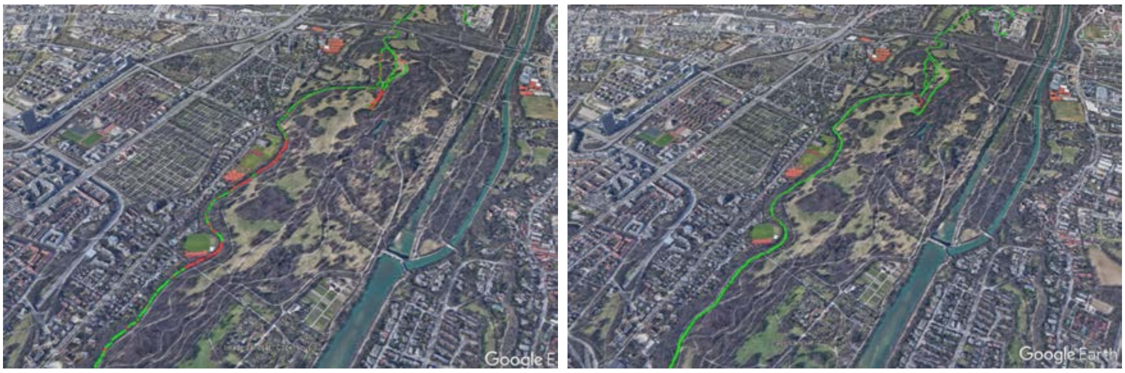

Figure 9: Side by side comparison of the registered QoE when using MCS index 13 without AL-FEC (left) and with AL-FEC with an overhead of 20% (right)

Although at the time of completing the deliverable there are still measurements to be processed, an example of the results is included here.

In general, the use of AL-FEC is beneficial (in some cases extremely beneficial) in order to avoid drops in the visualization of the video stream thus providing a more stable reception. Even within the theoretical coverage area, the nature of mobile reception and the lack of time interleaving in eMBMS causes the signal to drop constantly when moving the device. AL-FEC permits to cope with these effects by effectively enlarging the coverage area and closing gaps within it.

The following table covers an example of the configurations tested. From the total amount of measurements taken along a route and comparing the delivery without AL-FEC and with AL-FEC with a 20% overhead it can be seen that for MCS Index 13, the number of drops with AL-FEC or without is quite similar, so MCS Index 13 seems to be robust enough for the tested area. In the case of MCS 18, which provides a less robust transmission mode, the use of AL-FEC with a 20% overhead can compensate for the losses experienced when AL-FEC is not used.

	Ratio of correct vs total delivered MPEG-DASH segments	
MCS Index	No AL- FEC	AL-FEC 20%
13	86%	88%
18	72%	95%

When comparing eMBMS with respect to unicast, it should be noted that in those cases in which enough buffering is configured at the player and when the phone is not totally disconnected from the network (the phone is always connected), it is possible to receive almost 100% of the packets without disruption. Therefore, a mixture of broadcast with additional unicast in those areas where packets might be lost is recommended in order to provide a stable QoE to users.

2.4 Integration of Multi-Link in Munich Test-Bed

The realization of the Hybrid Broadcast Service involves the fulfillment of multiple requirements which the 5G-Xcast solution shall provide. Amongst others, user devices shall be able to automatically connect to the best available networks in terms of quality of experience (QoE). Network resources should adapt to the audience size and geographic area to be served minimizing distribution costs and enabling that, when using multiple networks, it should be possible to offload the traffic between them (e.g. fixed, mobile and/or broadcast networks). Content delivery may use multiple networks at the same time and switch between networks including when operated by different operators, supporting the dynamic optimization of resource allocation by automatic switching between unicast, multicast and broadcast. The 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). The 5G-Xcast solution should be able to provide a sufficient data rate to deliver audiovisual content up to ultra-high definition (UHD) quality while minimizing end-to-end latency and managing difference in delay between different streams on the same device.

The HBS may provide numerous benefits to the main actors in the M&E value chain. Users may benefit from the continuity of the experience when switching between networks enabling seamless access to audio-visual content both at home and on the move. Content and service providers benefit from the delivery of content to a wide range of user devices over the 5G infrastructure with reduced complexity and cost. From the network side, operators can benefit from a more efficient use of network resources and topologies to enhance cost efficiency of content delivery.

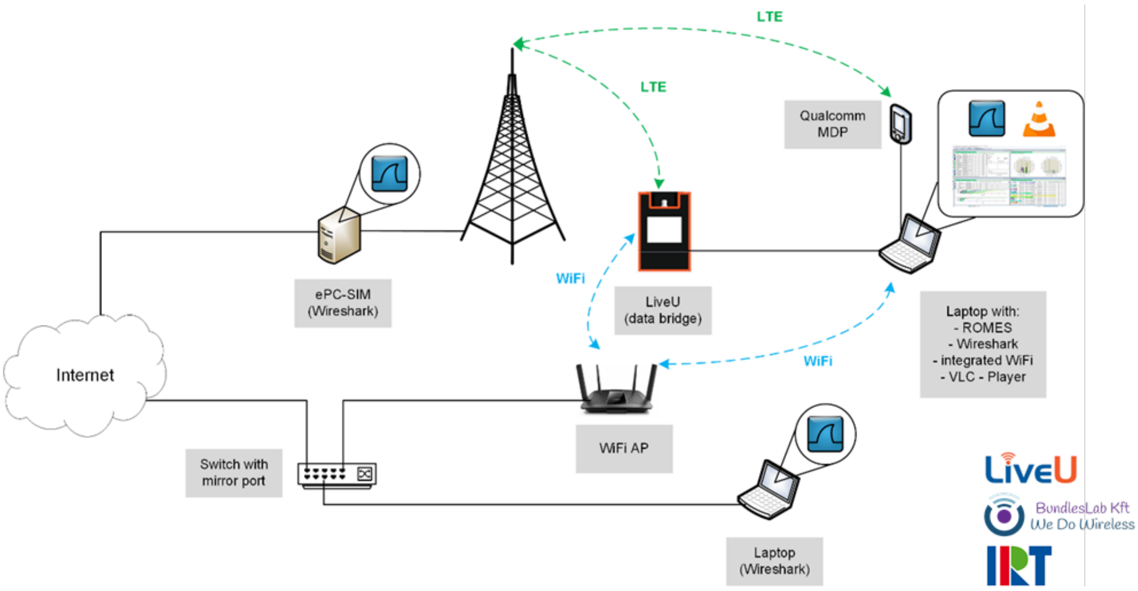

Figure 10: Integration of MultiLink features in the Munich Test-bed

Multi-connectivity supports simultaneous connectivity and aggregation across different technologies such as 5G, LTE, and unlicensed technologies such as IEEE 802.11 (Wi-Fi) [7]. In heterogeneous networks, multi-connectivity helps to provide an optimal user experience (e.g. high bandwidth, network coverage, reliable mobility etc.). One subcase of multi-connectivity is multilink is the exploitation of different heterogeneous wireless link for improving service delivery. In the scenarios that require high bandwidth or assured service continuity, a user may need multiple concurrent connections. For example, data aggregation from multiple subscriptions to LTE, 3G and Wi-Fi (and even fixed networks) increases available bandwidth. A cellular (e.g. 5G or LTE) network access is required to maintain the service continuity after a UE has access to Wi-Fi coverage. Multi-link is tested by means of an external unit (provided by LiveU) that is able to bond the traffic from different interfaces. The unit is connected to an entity in the cloud in charge of splitting the original source and route the traffic to the client. At the client side, the unit is connected via ethernet to a laptop that will request the reception of traffic. The setup is depicted in Figure 10.

2.4.1 Measurements, Evaluation and Results

The performance of multi-link with unicast traffic over the LTE (700 MHz) and WiFi (2.4 GHz) networks is analysed by means of monitoring different network interfaces (i.e. the upcoming traffic to the PDN Gateway from the internet, the ethernet link between the LiveU unit and a laptop, and the interface of a WiFi AP where the unit is attached). An H.264 test video stored in a CDN server is used as the source for monitoring IP traffic. The video is a constant bit rate clip with an data rate of 3.77 Mbps. The playback is triggered by a video player at the client laptop.

A set of test measurements are taken at the premises of the IRT [8]. A transition scenario between an indoor area with WiFi but poor LTE coverage and an outdoor location without WiFi but good LTE coverage is selected. The AP is mounted close to a window in order to obtain a smooth WiFi coverage decrease when transiting to the outdoor location. It should be noted that it is desirable that the network details are stored in advanced in the ML unit and the interfaces active so that in the presence of signal coverage the connection can be established immediately. An overview of the scenario and the route followed in the measurements can be seen in Figure 11.

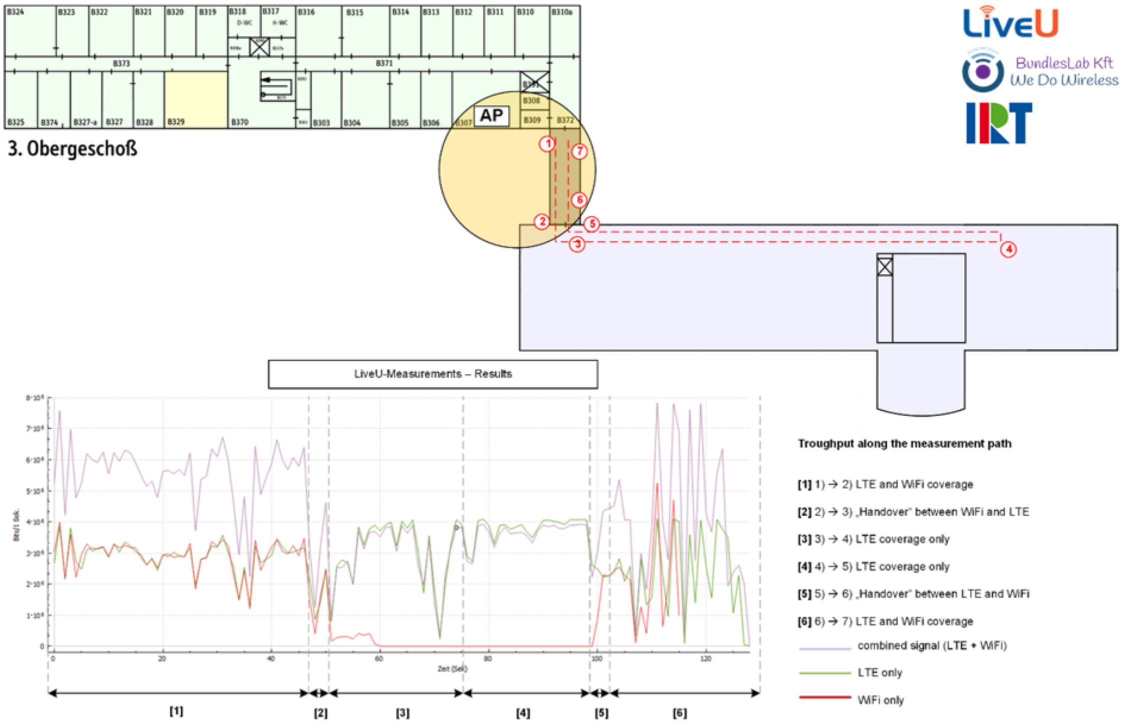

Figure 11: Multilink measurement scenario

Figure 11 shows the taken route and results of measurements. The instantaneous throughput (bps) as a function of time is represented for the three monitored interfaces. The line in violet is the IP traffic between the LiveU unit and the client laptop. The red and green lines represent the traffic at the WiFi AP and the LTE ePC, respectively.

It can be seen that the traffic sent to the laptop when both the WiFi and LTE network provide good coverage is the aggregated throughout by the LiveU unit. In the transition area where WiFi coverage is lost (see the decay of the red line) only traffic from the LTE network is received, with the same bitrate as the original video source what translates into no disruption at the client. When the WiFi connection is restored, the traffic is, again bonded.

It should be noted that during the experimental testing, the video was presented at the laptop without any disruption. A closer look into the TCP traffic at the LiveU unit to laptop connection it is possible to detect the reception of several TCP Retransmissions, TCP DupACK´s, TCP Fast Retransmissions and TCP Spurious Retransmissions that indicates the presence of an error-free mechanism to prevent packet losses.

3 Hybrid Broadcast Service: Demonstrators

3.1 Showcase and Demonstrator: European Championships 2018

The European Championships 2018 provided an opportunity for the IRT in collaboration with the EBU to show how audiovisual content produced in the state-of-the-art formats both live and on-demand can be distributed to large audiences in the 5G environment. The demonstration highlighted the following aspects:

- fixed/mobile convergence
- combined use of unicast and broadcast capabilities
- use of standardized 3GPP interfaces to deliver MPEG-2 Transport Stream including live TV programmes and HbbTV service information
- free-to-air reception
- reception on both mobile/portable user devices and stationary TV-sets

This demonstration shows the value of point-to-multipoint capabilities in 5G, especially for a large-scale distribution of the popular content such as premium sports. The 5G-Xcast project is defining the solutions that will help to ensure that such capabilities are available in the future 5G networks.

The demo presents the following two concepts:

- Live TV content and the signalling for add-on services based on the HbbTV standard were both included in an MPEG-2 Transport Stream and transmitted over the LTE eMBMS broadcast system. The broadcast signal is received by stationary eMBMS-enabled TV receivers and by smartphones simultaneously and without the need of unicast connectivity.

- Users can access additional on-demand content either via an HbbTV application on TV sets or an HTML-based application on mobile phones. The on-demand content is delivered over the LTE unicast link in the mobile network. This gives an outlook on the coming technology convergence and future capabilities of 5G.

Figure 1 illustrates the overall picture of the showcase depicting the transmitter and receiver sides, from signal acquisition to display in user equipment. The following steps are identified in the chain:

1. Content is provided by the EBU from the European Championships venues via satellite.
2. The European Championships stream is encapsulated in a MPEG-2 Transport Stream alongside other live TV programmes. HbbTV signalling is inserted pointing to additional on-demand content offered by the broadcaster (stored on a dedicated web-server).
3. The MPEG-TS over RTP is streamed to the BM-SC in the Munich Test-Bed. The Test-Bed is also provisioned with an internet connection so that both broadcast and unicast are available in the coverage area.
4. The EPC is connected to the eNodeB that serves 4 RRHs in the urban and rural areas of the city.
5. The signal is transported to the RRH which will transmit the radio signal.
6. On air, an LTE sub-frame is configured with 60% capacity dedicated for broadcast and 40% capacity for unicast traffic.
7. Smartphones with Expway’s middleware allow users to watch live TV programmes via the broadcast system and on-demand content via a mobile web application and a unicast internet connection.

8. A smartphone acting as a set-top-box forwards the original MPEG-2 TS to a TV-set that can tune to the live TV signal with the possibility to access HbbTV services.

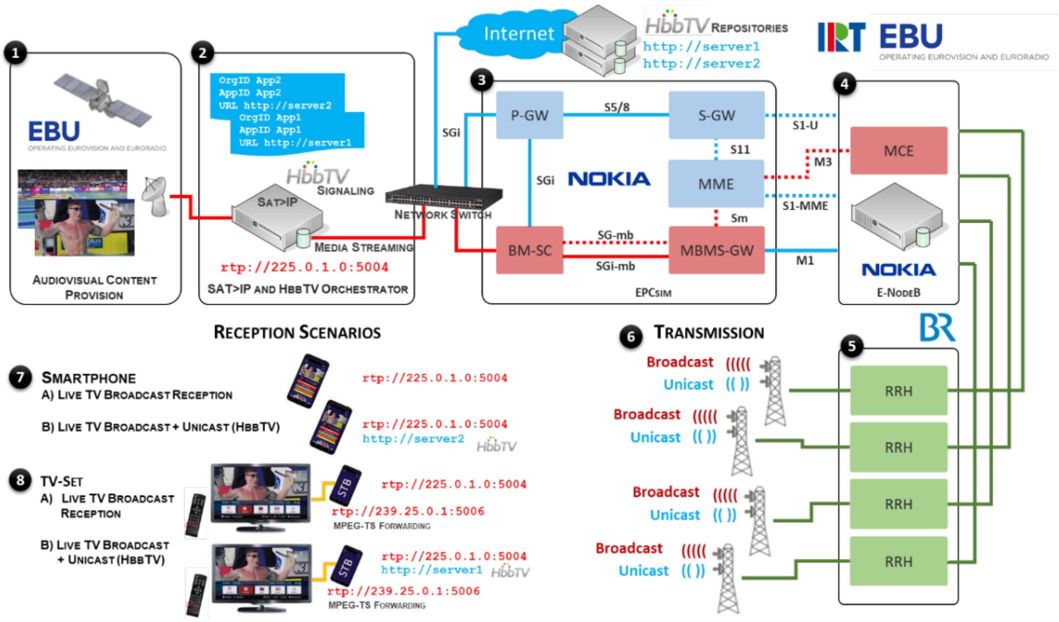

Figure 12 Illustrated use case

Figure 13 shows an overview of the trial using Munich test-bed.

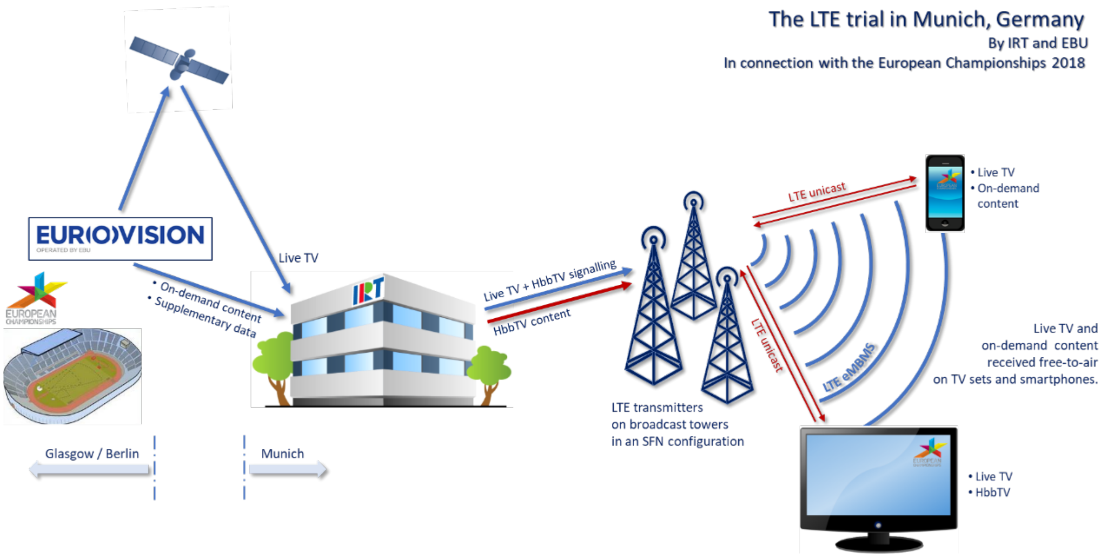

Figure 13 Scenario block diagram

One of the key points of the showcase is the development of two applications for the smartphone.

One application has been developed in order to provide hybrid services (combination of linear and non-linear content) directly in the smartphone so that different TV services (within the MPEG-TS) over eMBMS can be tuned and displayed in the screen.

The app is able to identify when HbbTV signalling is present in the stream so that access to additional content over the internet can be provided. The add-on content showed in the smartphone is retrieved from a web server where an HTML site has been developed by the service provider allocating the desired information, in this case, related to the European Championships (Statistics, information about sports, schedules…).

An additional app has been developed in order to forward the MPEG-TS to an IPTV-set able to show the live TV programme and also an HbbTV app prepared on purpose with the correct format to be displayed in the TV-set.

The overall setup can be seen in the following figure.

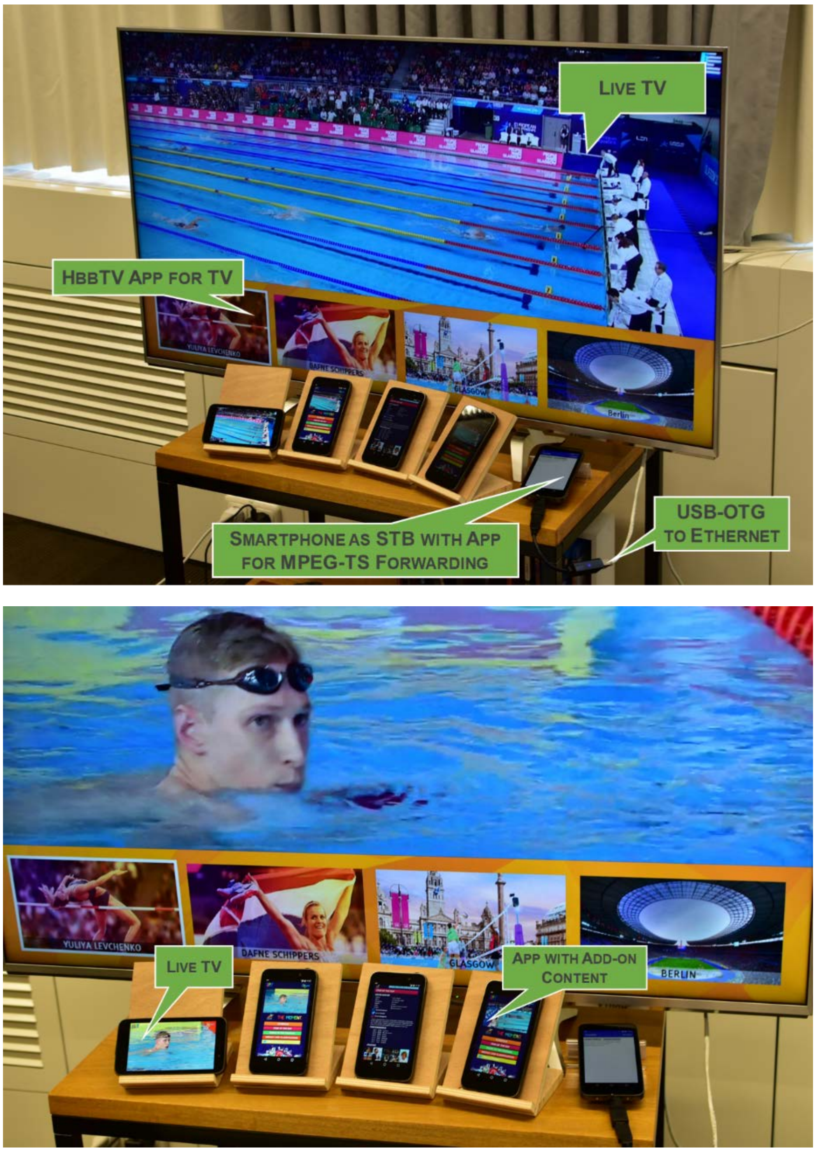

Figure 14 Setup of the Showcase

The trial conducted in Munich during the European Championship was replicated in a small-scale demonstrator based on a portable LTE base station with enabled eMBMS capabilities and EPC to conduct unicast traffic [2].

More information about this Demonstrator is contained in D6.5 [9].

3.2 Demonstrator: Optimized Resources Allocation For Live Video Content

The objective of the demonstrator is to illustrate how a service routing functionality can allow to take into account the context of each end-user to select the best route for a live video content consumed on a mobile device.

We consider several aspects that summarize the context:

- the content popularity: a popular content will be delivered in multicast mode (eMBMS or Multicast ABR) while a non-popular content will be delivered in unicast

- the user location: inside a home network, the user can benefit of multicast ABR technology whereas he will rely on unicast or eMBMS outside

- the capabilities of the device: to receive video via eMBMS, the device must be equipped with the proper chipset

- the capabilities of the base station that covers the user: to send eMBMS content, it has to be equipped with the proper transmitter

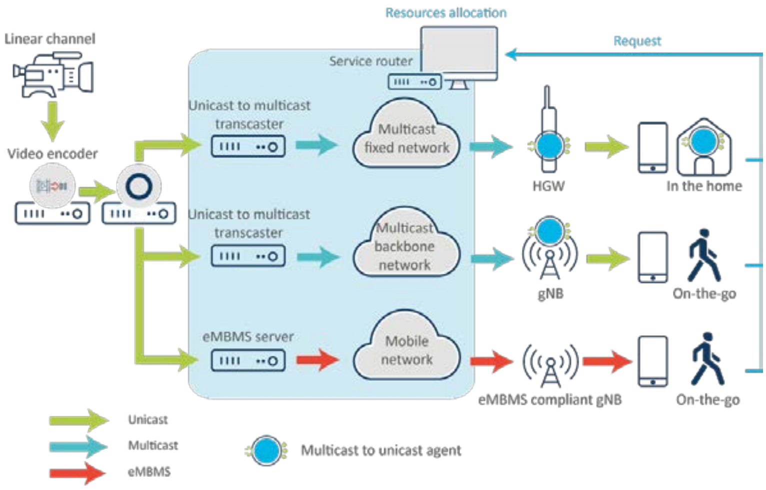

Figure 15 Illustrated use case

Figure 16 Demonstrator setup

More information about this Demonstrator is contained in D6.6 [10].

3.3 Demonstrator: Large Scale Media Delivery powered by MooD and free-to-air distribution to TVs and Smartphones

This demonstrator shows the support 5G for two different operation modes:

A) An adaptive unicast/broadcast switching mode where live TV, encoded with multiple DASH profiles, can adapt to user demand and reception conditions.

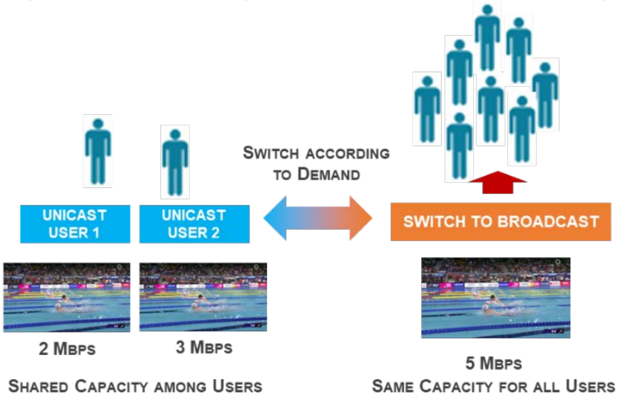

Figure 17. MooD enabling seamless transition between unicast to broadcast

A live stream is originally delivered over unicast to a few smartphones. The content then becomes popular, the MooD feature is activated and the network automatically switches to broadcast mode to optimise the overall system resource usage and to guarantee the quality of user experience (QoE). The smartphones with eMBMS middleware installed automatically switch to broadcast if they are in the coverage area of that signal. The switching is transparent to the users who do not experience any interruption while watching the content.

When the content becomes less popular, the network automatically switches back to unicast while ensuring the smooth playback experienced by the end users.

B) A broadcast mode where the live TV programme is delivered according to QoS and coverage requirements defined by the service provider.

Live TV content is transmitted over the LTE eMBMS broadcast system with a pre-defined format and quality. The broadcast signal is received by smartphones. Additionally, they can also display on-demand content via an HTML-based application for mobile phones when the unicast connection is available. This is the look and feel of state-of-the-art HbbTV applications for TVs.

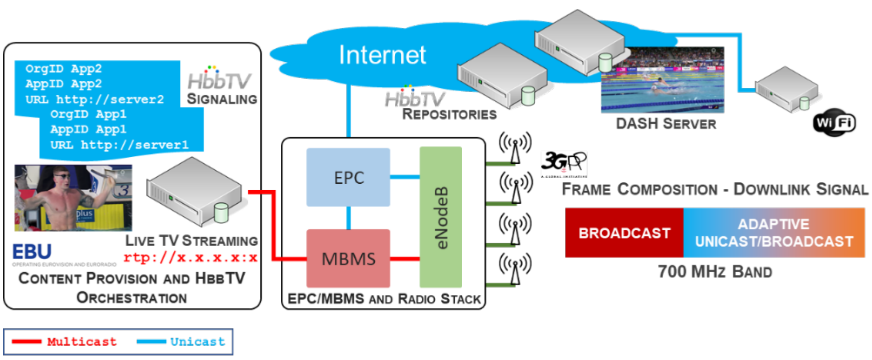

Figure 18. Transmission chain of the proposed demonstrator

The demonstration employed commercial equipments enabled with the specific middleware from Expway to realize the operations explained above. Smartphones with

Expway's middleware allow users to watch live TV programmes via the broadcast system and on-demand content via a mobile web application and a unicast internet connection. Users can select to watch the live TV programme via broadcast or chose another stream via a unicast link. When the audience consuming the unicast stream increases over a certain threshold, a MBMS session is established thanks to MooD feature so that the users transparently switch between unicast and MBMS. When the demand decreases, users can again be served via unicast. The reception of the live TV programme over broadcast is not affected by the increasing number of users.

More information about this Demonstrator is contained in D6.7 [11].

3.4 Demonstrator: Converged Autonomous MooD in Fixed/Mobile Networks

This demonstrator showcases key features of the content distribution framework proposed in WP5. In particular:

- The use of multicast/broadcast as an internal network optimisation, rather than as a service to be sold.
- The use of simple unicast interfaces with content service providers to simplify integration and facilitate adoption.
- How client applications do not require any modification to benefit from the use of multicast/broadcast.
- How the framework is applicable to both fixed and mobile networks

These features are demonstrated through the integration of the live, unmodified, BT Sport commercial service with the 5G-Xcast content distribution framework. It shows content prepared for unicast distribution with dynamic switching between multicast/broadcast and unicast delivery as the audience size changes over both fixed network with Multicast ABR and mobile network with LTE-Broadcast. This is achieved for mobile networks using MooD for MBMS.

The configuration for the mobile demonstrator is show in Figure 19. It comprises a content source in HLS format which the BMSC ingests in response to configuration information sent to it by the BPM. The BT Sport App is installed on an MBMS capable device which also includes an Adaptation Layer and Expway's MBMS middleware (shown as MSP Server in the diagram). When the BT Sport App makes a request for content, this is detected by the Request Routing component that redirects the request to the Adaptation Layer. Here, the request is inspected and the appropriate MBMS service is activated through the use of the MSP client. This causes the HLS content to start being received and is placed in the MSP Server cache where the Adaptation Layer is able to request it and forward it on to the BT Sport App. The app remains unmodified and is not aware of the use of multicast/broadcast. The Adaptation Layer allows it to operate as a simple unicast client.

MooD is implemented in the BMSC where a Consumption Reporting component monitors the demand for content and through the MCE is able to activate and deactivate MBMS services. Thus, multicast/broadcast is used as an internal network optimization leaving the content service provider and client application with simple unicast interfaces.

The mobile network aspects of the demonstrator are implemented using Amarisoft EPC components.

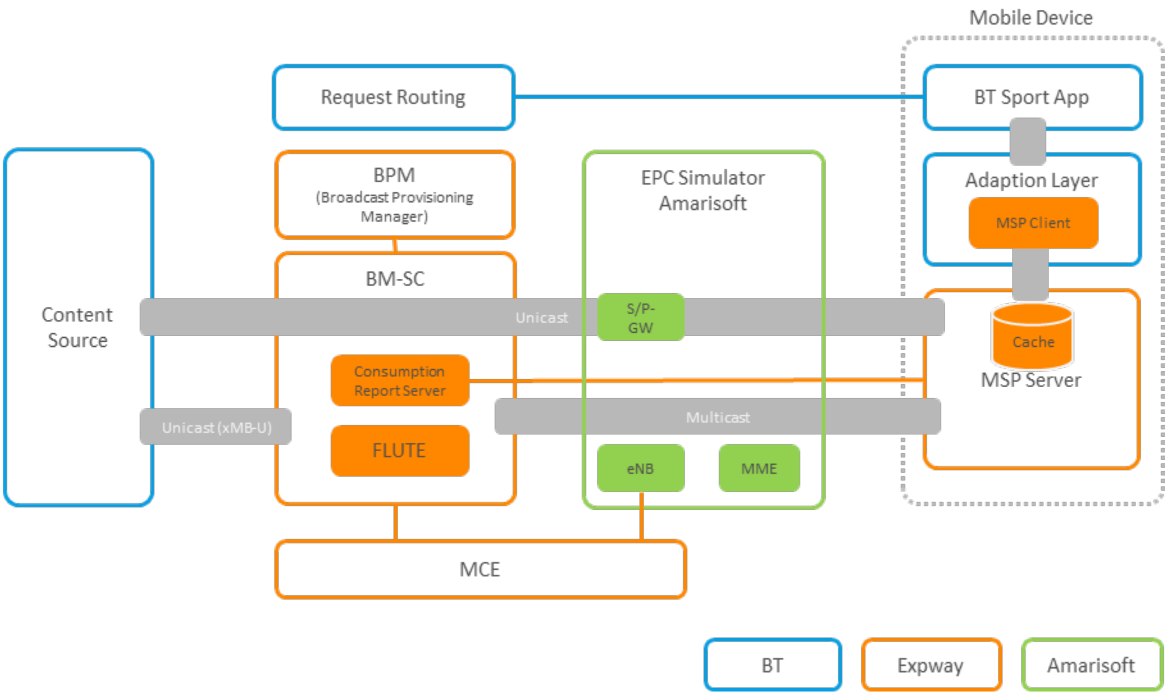

Figure 19: Demonstrator configuration for mobile case

The approach taken for the fixed network demonstrator is largely similar, although slightly simpler as shown in Figure 20.

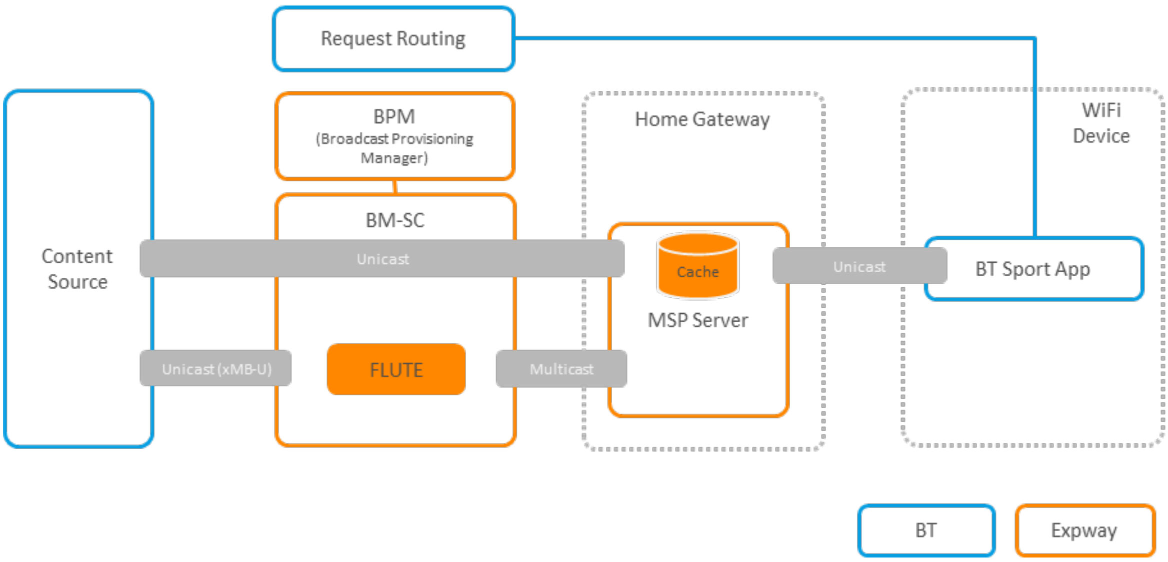

Figure 20: Configuration for fixed network

The same content source and BMSC/BPM components are present and are configured to ingest the HLS content and stream it out on a multicast address as configured through the BPM.

In the fixed network, the introduction of a Home Gateway (HGW) affects how content is received. When the app requests content, the request routing component directs the request towards the MSP server running on the HGW. An Adaptation Layer is not required as the MSP server is able to match the requested URL directly to an appropriate multicast address. When the MSP server makes the match it joins the appropriate multicast address and starts to receive media segments which are placed in the cache.

The segments are subsequently forwarded to the app as HTTP responses. Initial requests made to the MSP server may need to be satisfied by unicast prior to the cache being populated with the required content.

It can be seen that this demonstrator shows how multicast/broadcast has been used as an internal network optimization for application that are unmodified. This is an advance over current systems such as eMBMS that require MBMS-aware applications and extensive service specific configuration. The approach taken here uses the existing unicast interface with content service providers and is applicable to both fixed and mobile networks.

3.5 Demonstrator: Reliable Multicast Delivery in 5G Networks

This demonstration shows the gains achieved by reliable multicast delivery in 5G networks. This includes the gains in and trade-offs among resource consumption, spectrum efficiency, service coverage, and QoE when multicast is introduced as a radio access network optimization—against unicast delivery mode—for delivering popular content. The demonstration also highlights the effects of using application layer methods, such as DASH streaming and multilink delivery, on the efficiency and reliability of multicast delivery. Overall, the observations will contribute to a deeper understanding of the improvements achieved and to deriving the conditions under which deployment of such technologies benefits the end-to-end network. More information can be found in Section 2.9 in D6.2 [2].

In light of the described objectives, the reliable multicast delivery in 5G networks is shown through the following three demonstration scenarios:

1. *Unicast-only:* As a baseline scenario, all the content is sent via unicast delivery mode.
2. *Multicast-only:* The popular content is sent via multicast delivery mode.
3. *Multilink-enhanced multicast:* The popular content is sent via multicast delivery mode where multilink technology is automatically enabled for UEs with poor multicast reception.

Architectural framework of the demonstrator is as shown in Figure 21 and information on the components used in this setup is provided in Table 2.

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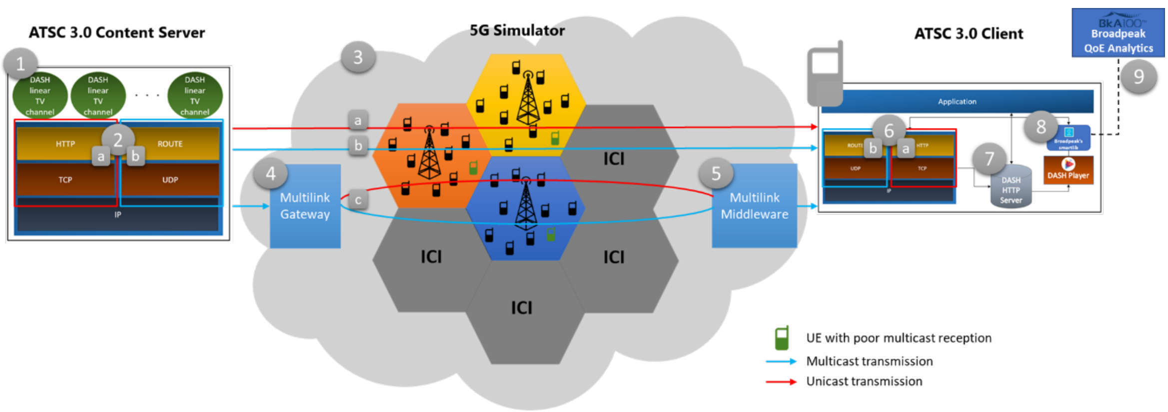

Figure 21: Architectural diagram of the demonstration.

Table 2: Demonstration setup information.

Setup Component	Subject	Information	
ATSC 3.0 Content Server	Apache server	- Version 2.4.7	
	ATSC 3.0 software	- ROUTE/UDP transmission	
	Stored content	- Wembley Cup Final 2018 - Codec: HEVC - Unicast serving: • 1Mbps@480p, 3Mbps@720p, 5Mbps@720p, 8Mbps@1080p, 12Mbps@1080p, 16 Mbps@1080p - Multicast serving: • 16Mbps@1080p - 1s DASH segmented	
5G simulator	Simulation environment	Scenario	Urban
		Carrier frequency	3.5GHz
		Total BS transmit power	51dBm
		System bandwidth	100MHz
		BS antenna configuration	[M, N, P] = [8, 4, 2]
		BS TXRU configuration	[Mp, Np, P] = [1, 4, 2]
		UE antenna / TXRU configuration	[M, N, P] = [1, 4, 2]
		UE mobility model	3kmph, randomly uniform distr.
		BS noise figure	5dB
		UE noise figure	9dB
		BS ant. element gain	5dBi
		BS ant. elevation – 3dB-BW	65°
		Multicast MCS index	{2, 4}
	Multilink	Automatic switching to multilink threshold	Multicast $SINR_{eff}$(UE) < 10dB
ATSC 3.0 Receiver box PC	Apache server	Version 2.4.39 Forward proxy	
	ATSC 3.0 software	- ROUTE/UDP reception	
Android tablet	Model	- Samsung Galaxy S4	
	Player	- ExoPlayer 2.8.4	
	Smartlib QoE Library	- Library for ExoPlayer 2.8.4	
BPK QoE Analytics Server	Location	- Cloud server reached from URL	
Router	Model information	- Linksys 2.4GHz, 54Mbps - For Internet connection	

In this regard, ATSC 3.0 Content Server (1) is the content and service provider, responsible for starting the service transmission. The content (Wembley Cup Final 2018) provided by BT is pre-encoded with the parameters shown in Table 2. It is served either upon request via HTTP/TCP (2a) or linear via ROUTE/UDP (2b). The former is for unicast-only demonstration scenario whereas the latter corresponds to multicast-only and multilink-enhanced multicast demonstration scenarios.

5G simulator (3) emulates the cell environment with the parameters as provided in Table 2. It initiates the point-to-point and/or point-to-multipoint communication for the Android tablet and the content server (3a, 3b, 3c). In this regard, it acts as a forwarding entity of the incoming media service and serves it to the Android tablet for consumption. Also, to better demonstrate the scenarios remaining UEs in the cells are emulated to receive the similar traffic generated by the simulator. Additionally, the simulator handles the multilink functionality when enabled, relevant for multilink-enhanced multicast demonstration case. This solution provided by BLB includes 1) Multilink GW (4), where the multicast stream packets are duplicated onto a newly-instantiated unicast session and 2) Multilink MW (5), where packets received from unicast and multicast are ordered and merged into one stream. It also provides real-time monitoring of network-related KPIs through its GUI.

ATSC 3.0 receiver box PC (6) is configured as a forward proxy which first checks if the requested media segment already exists locally in its cache (7) before raising the request to the origin server for fetching (6a). This component also hosts the ATSC 3.0 service layer software for ROUTE/UDP reception (6b), relevant for multicast-only and multilink-enhanced multicast demonstration scenarios.

Android tablet represents the UE through which the content playback is shown. For this purpose, it contains a media application that uses ExoPlayer (8), a DASH-compatible player developed for Android devices. ExoPlayer is integrated with BPK's Smartlib QoE Library to collect QoE-related metrics, such as playback freezes, losses, initial playout delay, etc.

BPK's QoE Analytics Server (9) is a cloud-based server that periodically fetches the metrics collected by BPK's Smartlib QoE Library and generates real-time QoE reports and more.

Each demonstration scenario is initiated by pressing "Play" button on the Android tablet and consequently the setup components perform according to their described roles. Corresponding QoE monitoring and network-related KPIs are observed through 5G simulator GUI and QoE Analytics Server. These measurements are accompanied by changing the UE position within the cell to vary its reception quality for broader analysis on the objectives.

More information about this Demonstrator is contained in D6.9 [12].

3.5.1 Measurements, Evaluation and Results

3.5.1.1 *KPI Definitions*

Measured KPIs for performance comparison are resource consumption, spectral efficiency and QoE. In this section, the definition of each KPI in the scope of this demonstrator and how each of them is computed is provided.

3.5.1.1.1 Average Resource consumption

It measures the average percentage of the resources used up for the service delivery. It is calculated as a ratio of the number of radio resources used on average and the number of available radio resources.

3.5.1.1.2 Average User Application Layer Spectral Efficiency

It measures the average user spectral efficiency from the application layer. It is calculated as the total number of bits generated by the content source divided by the average bandwidth usage which is system bandwidth multiplied by the average resource consumption ratio.

We emphasize that this does not take into account the packet losses due to transmission errors or congestion. As such, this KPI must always be considered in conjunction with the QoE KPI defined below, as packet losses reflect in a degradation of the QoE. This spectral efficiency KPI is defined as is to be able to compare multicast and multilink investigation scenarios and find out the limit (UE density in the cell, multilink switching threshold, etc.) at which one performs better than the other.

3.5.1.1.3 QoE

It is the quantitative estimation of the subjective user experience (MOS) calculated for each UE. It incorporates objective factors of initial delay, stall duration, number of stalls, level variation in DASH adaptive streaming and subjective factors of spatial quality and temporal quality. This estimation algorithm is taken from the study presented in [9][14]. For more information on the algorithm and its integration details, please refer to D5.4 Section 4.1.3 and 4.1.4 [15].

3.5.1.2 *Results*

The evaluation results for the mentioned KPIs are provided and explained in this section.

3.5.1.2.1 Average Resource Consumption

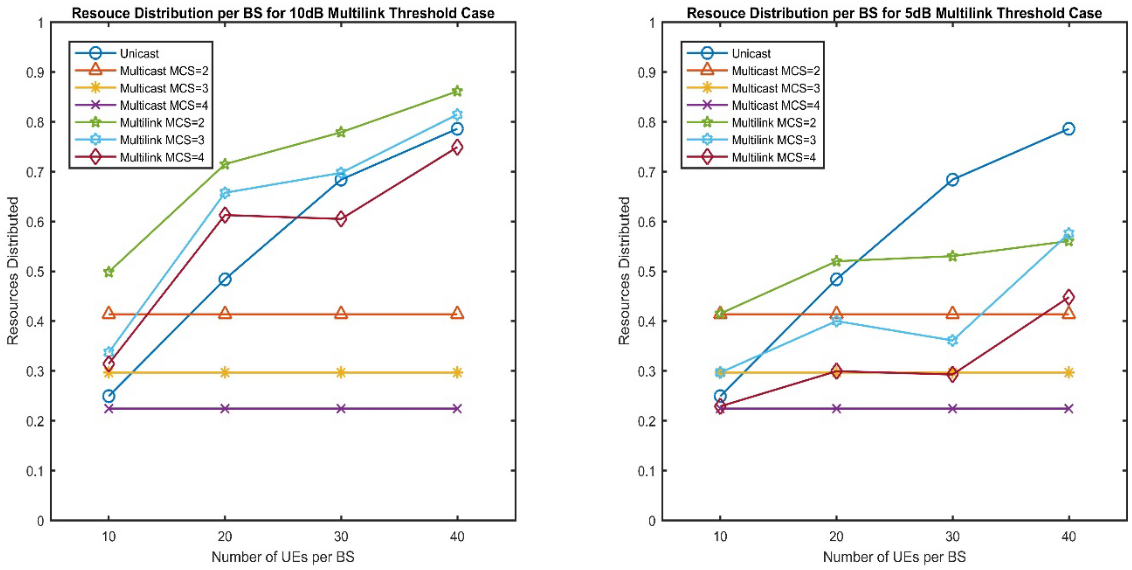

Figure 22: Average resource consumption of unicast, multicast and multilink.

Resource consumption plots for each demonstration scenario is as shown in Figure 22. At the UE density of 20 per cell, unicast-only case uses more resources compared to multicast-only cases for all investigated MCS indexes. When compared with multilink, due to the MCS indexes and the additional PTP links that multilink provides, the resource consumption with multilink is higher than unicast-only for most of the combinations of UE density and MCS index when the multilink switching threshold is set higher (e.g. 10dB). For 5dB threshold case, since there are less UEs per cell leveraging from multilink reducing the total number of PTP links and operating closer to multicast-only case, the resource consumption is less than the unicast case from the UE density of 20 per cell on. Furthermore, as expected, the resource consumption is higher in multilink case compared to multicast case at the same MCS indexes, since there is additional PTP links in multilink case. Therefore, for multilink to be favourable against multicast in terms of resource consumption and not to cause network congestion, in multilink case, higher MCS index and possibly lower multilink switching threshold need to be chosen.

When comparing between the different multilink switching thresholds, higher threshold leads to higher resource consumption in the respective multilink case. This is because the higher the threshold, the more the number of UEs that get provided with a second PTP link and hence the more resources allocated in total.

3.5.1.2.2 Average User Application Layer Spectral Efficiency

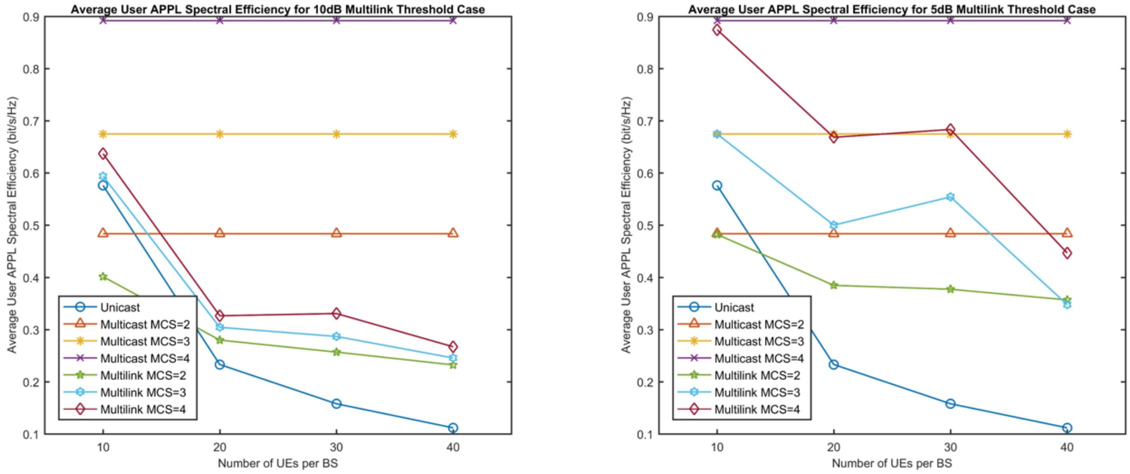

Figure 23: Average user application layer spectral efficiency for unicast, multicast and multilink.

The objective of this measurement is to find in which case multilink provides better average user application layer spectral efficiency than the multicast and unicast. In Figure 23, the spectral efficiency depends on the number of users in the presence of PTP links. The higher the number of UEs, the higher the number of PTP links and the higher the resource consumption which is inversely proportional to the defined spectral efficiency. In multicast-only case however, since the service delivery does not depend on the number of UEs receiving the service, the spectral efficiency is constant for all the tested UE densities.

When comparing different multilink switching thresholds, the spectral efficiency increases for the multilink case as there are less UEs being assigned an additional PTP link.

Additionally, from this figure, the points where multicast and multilink could be beneficial in the system can be determined. As can be seen, multicast mode of delivery proves to be favourable when compared with unicast for each MCS and UE density combinations – apart from multicast with MCS index 2 and 10 UE – as the computed spectral efficiency is higher. In the same way, it can be observed that multilink with MCS index of 3 and multilink with MCS index of 4 can be beneficial in case of UE density of 10 per cell when compared with unicast and multicast with MCS index of 2. From here on, we have selected unicast, multilink with MCS index 4 and multicast with MCS index 2 to compare the performance of each scenario in terms of QoE results.

It can be concluded that in terms of spectral efficiency, multicast scales better than multilink and multilink can potentially bring benefits for low density of UEs.

3.5.1.2.3 QoE

QoE CDF plots for each investigation scenario is as shown in Figure 24 and Figure 25. From these figures, we see that the unicast-only scenario provides the high QoE results with the highest probability amongst all the cases. When switching from unicast to multicast, although network efficiency is provided, we see that smaller amount of UEs have high user experience. This is largely due to the high robustness of the unicast transmission, while in multicast-only case, no error recovery mechanism is employed. Additionally, a small factor that contributes to this difference is that the DASH adaptation mechanism (see D5.4 Section 4.1.1.2 [15]) has been applied only in unicast case and not in the other cases as multicast ABR is out of the scope of this PoC. This means that while the UEs in unicast case could choose from a catalogue of different DASH Representations, in the multicast and multilink cases these UEs are served the highest quality DASH representation. Another small factor is that the segment download cancellation and session quitting mechanisms – see D5.4 Section 4.1.1.3 and Section 4.1.1.3 [15], respectively – also were employed only in the unicast case, further increasing the robustness of the player.

As the UE density increases, we see that more and more UEs in unicast case are dropping session (indicated by the increase in the probability of MOS values of 1.0) due to network congestion. This is largely due to that each UE starts at the lowest quality DASH Representation and having these initial segments received quite quickly each UE individually decides on switching to higher DASH representations aggressively. This causes resource outage and consequently some UEs quitting the session. The UE density increase however does not have a considerable impact on the QoE results in the multicast-only case. The only factor that could be caused by the UE number increase would be the probable increased probability that more UEs will have poor multicast channel conditions.

When assessing the multilink case, the expected benefit of using multilink can be observed when the UE density per cell is 10. The reliability of the service provided by the second PTP link directly reflects in the user experience and the highest MOS values are obtained for almost all the UEs. As the number of UEs increases, however, more UEs are served with in multilink with an additional PTP link. Because of the large number of duplications, the available radio resources may at times be insufficient to accommodate all data, hence ultimately affecting the service reception and user experience.

Consequently, another observation regarding multilink is that lowering the multilink switching threshold reduces the number of UEs with excellent service reception. Although still not sufficient for UE densities of 20 and more per cell, due to a smaller number of duplicate PTP links, the available network resources accommodate the UEs better. This means that with a density of 10 UE per cell and 5dB multilink switching threshold, perfect service quality – MOS of 4.5 – can only be achieved for approximately 70% of UEs as compared to unicast, where approximately 95% coverage is achieved. However, multilink achieves a user application layer spectral efficiency that is approximately 50% higher than that of the unicast configuration.

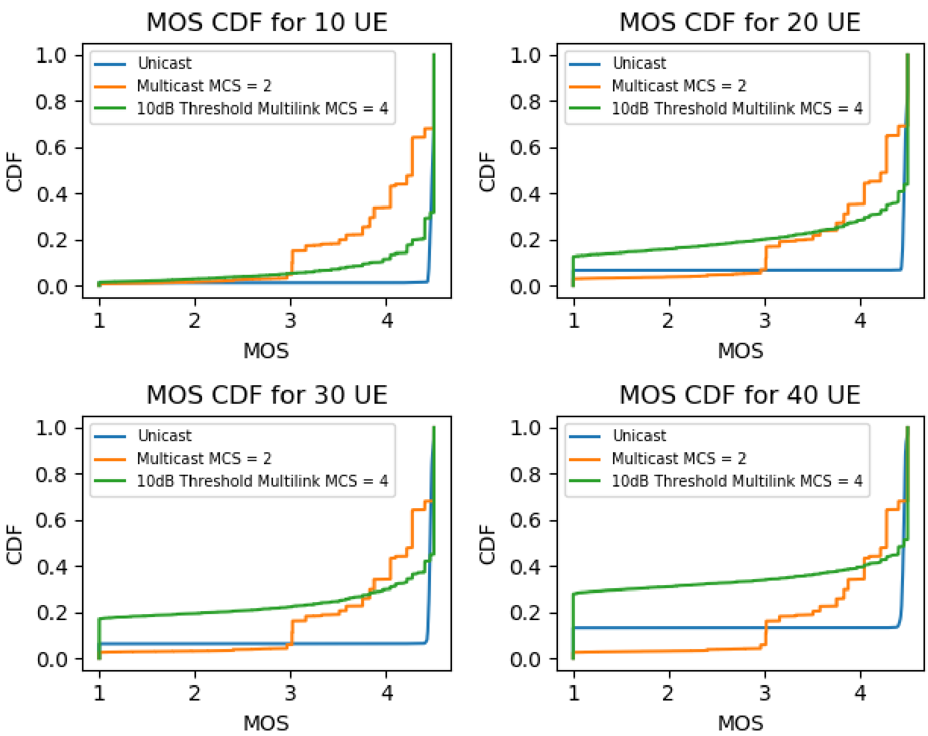

Figure 24: CDF plot of measured QoE with multilink switching threshold of multicast $SINR_{eff}$ of 10dB.

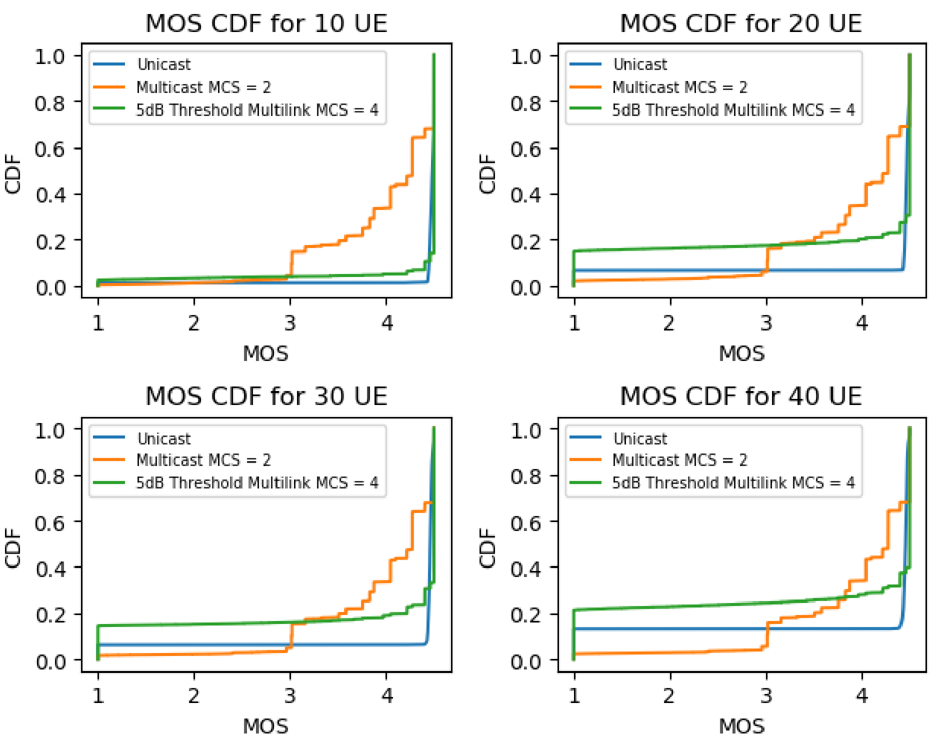

Figure 25: CDF plot of measured QoE values with multilink switching threshold of multicast $SINR_{eff}$ of 5dB.

From all the results presented above, the QoE results from the demonstration scenarios have been collected for unicast, multicast with MCS index 2 and multilink with MCS index 4. The QoE results of the emulated UEs obtained from the 5G simulator are as shown in Figure 26. Similar to the above results, in unicast mode the highest MOS score is achieved for almost all the UEs. In pure multicast mode, we can see also here that the provided network efficiency comes with the drawback of more UEs not being able to receive the excellent service. When multilink is enabled for service reliability, we can see that almost all the UEs achieved the highest MOS score just as in unicast mode.

The QoE results of the live UE obtained from BPK's Analytics Server for each demonstration scenario are as provided in Figure 27. The plots here show the playback information on the end device, such as the duration of playback start-up, freezes, pauses, buffering, and uninterrupted play. This information then generates an MOS value out of 10. As in the emulated case, same observations can be done for this live UE as well, where the excellent service is achieved in unicast case (MOS of 10.0/10.0), interrupted service in multicast case (MOS of 4.0/10.0) due to high segment losses when the UE is moved to the cell edge, and the perfect service of this UE being established with multilink (MOS of 9.9/10.0).

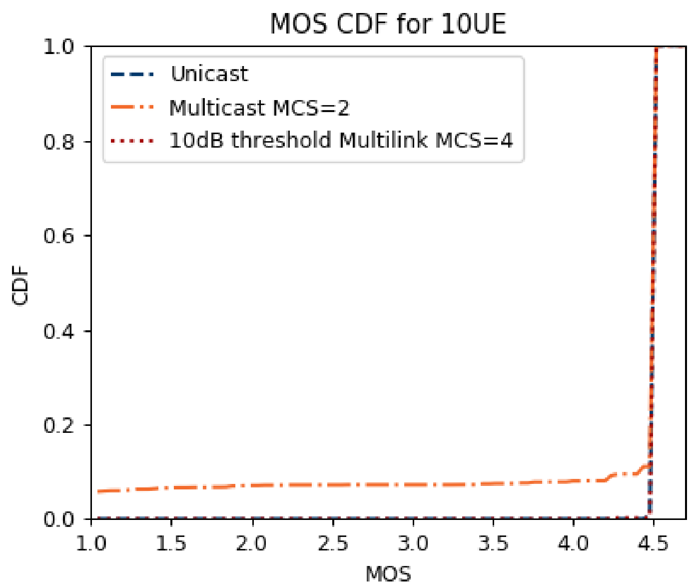

Figure 26: CDF plot of measured QoE of the simulated UEs from the demonstrator.

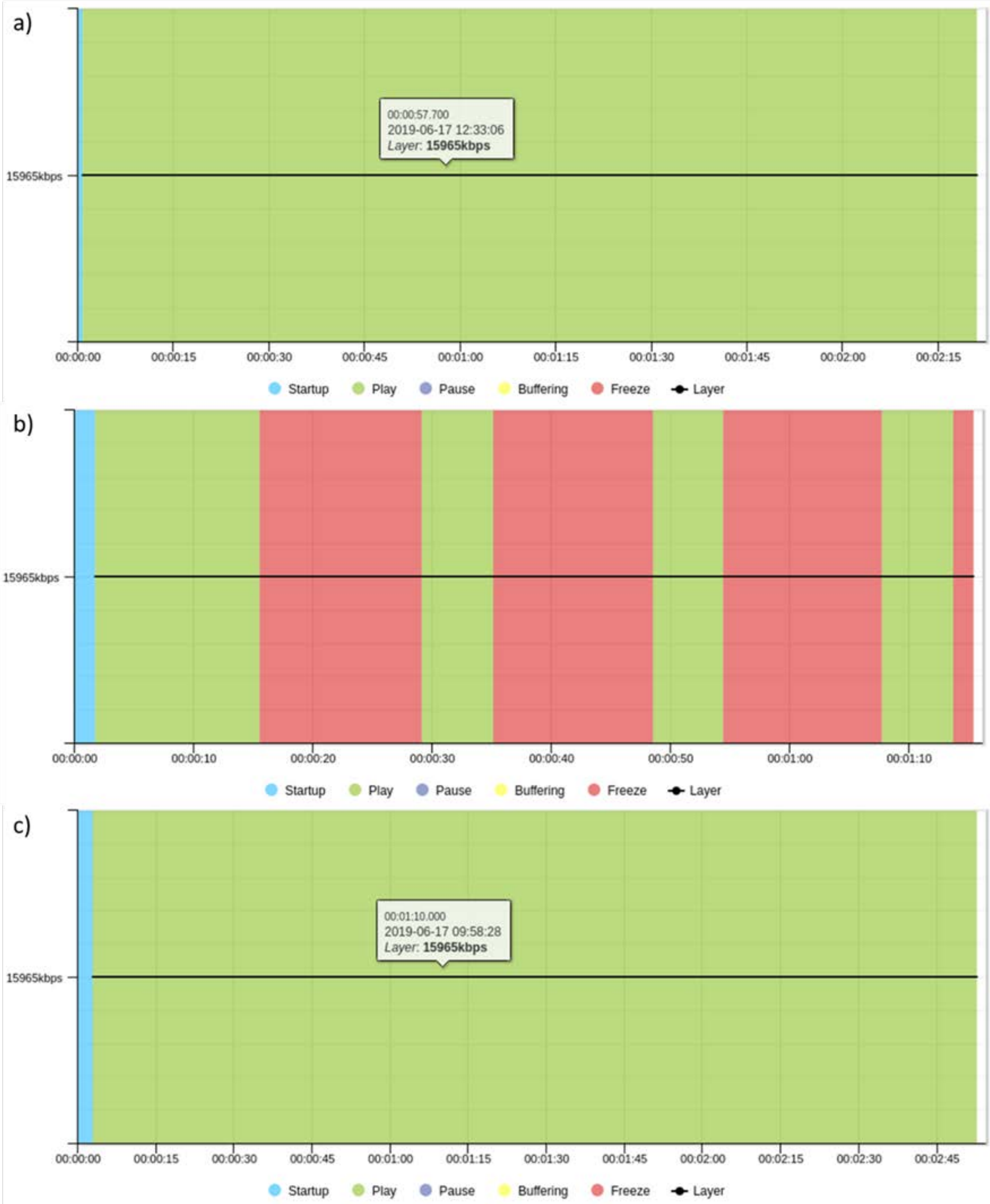

Figure 27: QoE results of the live UE from the demonstrator via BPK's Analytics Server for a) unicast, b) multicast when at the cell edge, c) multilink.

3.6 Demonstrator: Hybrid Broadcast Service with Multi-Link

The demonstrator involves several technical features to show the potential of 5G for media delivery in a hybrid fashion combining the ability of seamless switching from multicast to unicast using multiple links under different radio access technologies.

Live TV content is encapsulated in HLS (HTTP Live Streaming) format. With this, an original source in an MPEG-2 Transport Stream is divided into a series of smaller packets and referenced in a .M3U8 playlist file.

The packets, stored in the Multilink server are launched in a sequential manner using eMBMS (broadcast). The client can request packets which have been received corrupted via unicast, reorder them and deliver to the video player.

The approach to Multilink with WiFi and LTE is depicted in the following figure. A Bittium Tough smartphone, with eMBMS capabilities is attached to a client which also integrates a WiFi module. The phone is attached via an USB-OTG to Ethernet cable. When the client requests a video stream (1), the initiation request is done over the WiFi connection.

The server starts a multicast stream on the LAN side and streams the video to the BMSC of the LTE ePC + eNB (2). The phone is able to receive the eMBMS stream and forward the multicast stream to the client (3). In the case that packet drops and errors occur in the eMBMS multicast stream, a repair mechanism starts and the client will request the missing packets/chunks via unicast, using in this case the WiFi unicast connection (4).

In this setup, that is prepared for the EUCNC, only one client is involved to demonstrate the repair mechanism and the transmission over different physical interfaces. In further developments, more clients can receive a live stream in a synchronized manner. The analysis of the captured traffic on the three sites (Server, Client and eNB) shows that the repair mechanism works is active when the video stream over LTE eMBMS has problems and therefore packets can be requested using unicast even over another interface. Note that enough buffering is necessary at the receiver side in order to prevent disruption in the visualization of the content.

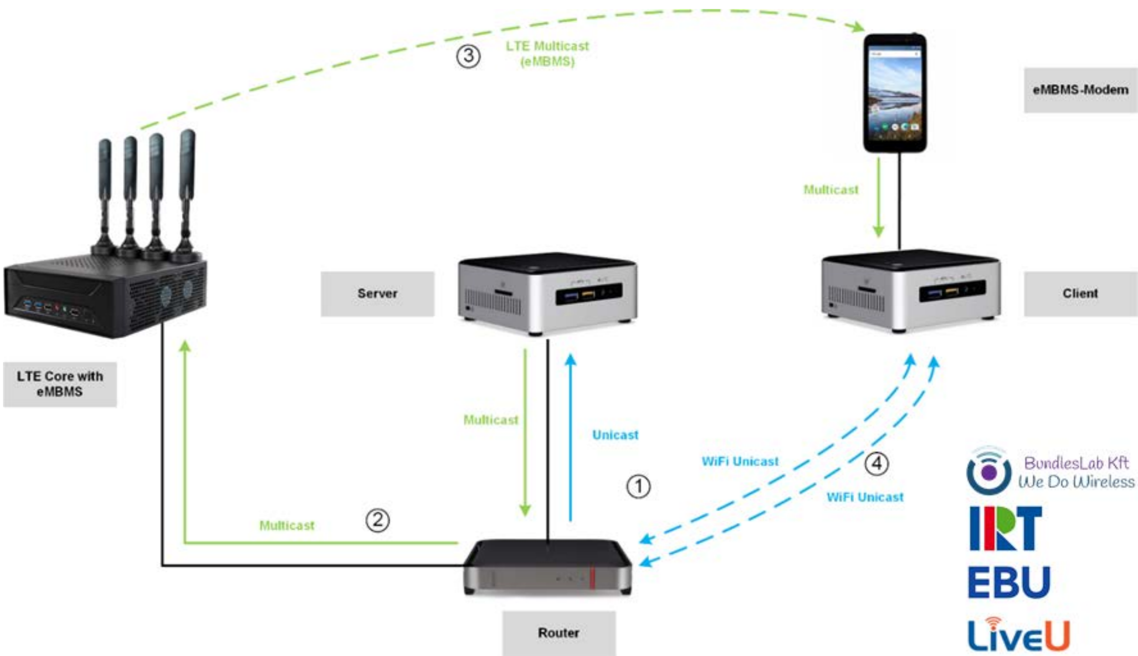

Figure 28: Configuration for fixed network

More information about this Demonstrator is contained in D6.9 [12].

3.7 Joint 5G-Xcast/Sat5G Demonstrator: mABR

This demonstrator is a joint partnership between 5G-Xcast & SaT5G 5G-PPP projects focusing the use of satellite multicast capabilities to deliver live channels to a 5G Edge mobile network.

The main objectives of the demonstrator are:

- To improve video distribution efficiency using mABR over Satellite as contribution link
- To Minimize end-to-end latency using CMAF-CTE Dash over mABR link
- To Address all screens thanks to transparent use of local cache servers
- To Provide synchronized video delivery on any screen

3.7.1 Concept

The concept of this demonstrator is to showcase over-the-air satellite multicast technology for the delivery of live channels using a MEC platform for Content Delivery Network (CDN) integration with efficient edge content delivery. This Demonstrator highlights the benefits in terms of bandwidth efficiency and delivery cost of using a satellite-enabled link for provisioning live content in a 5G system.

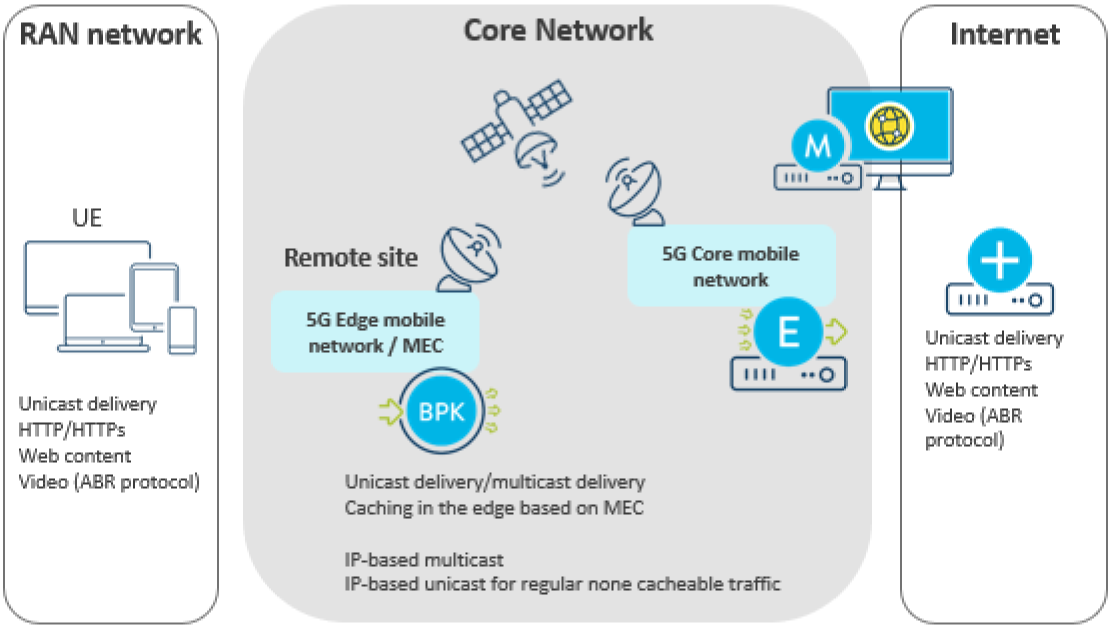

Figure 29 Demonstrator concept

More information about this Demonstrator is contained in D6.9 [12].

4 Object-based Broadcasting: Trials in the Surrey Testbed

4.1 Description of Object-based Broadcasting Trials

The trial of object-based broadcasting (OBB) in the Surrey testbed, developed by the BBC and University of Surrey (UNIS), addresses the Media and Entertainment Hybrid Broadcast Service use case, see Section 2.3.1 in [1]. In this use case users have access to a diverse set of linear and non-linear video, audio and text media coming from various sources, which are personalized and combined with social media, location-based features and interactivity. This could include linear and on-demand video and audio, social media, and interactive advertising being consumed on user equipment (UE) that ranges from fixed TV sets, mobile devices, and vehicle mounted devices. The access to this content and these services is enabled for a possible population of millions of concurrent viewers over a wide variety of environments and contexts such as indoors, over large geographic areas, and at venues (for example live sporting events).

Object-based broadcasting is an attractive proposition as it gives the user an optimised experience, by which it is meant that the content would be displayed in a manner that takes into account the user's environment, preferences, and the capabilities of the UE. This is achieved by splitting a traditional piece of linear media into multiple objects, in our case the objects include an MPEG-DASH video of the presenter, an MPEG-DASH video of a sign language presenter, audio, subtitles, and image assets (which include some personalisation).

Compared to the traditional delivery of a single broadcast stream to all users, the improved user experience due to OBB has a number of potential costs associated with it, of which a significant one is that of an increased network load to deliver multiple unicast streams. Since the object-based approach could require (as in this testbed) multiple videos and assets to be delivered to a single UE, there is a concern that networks may not be able to deliver this experience for large scale events using traditional unicast (UC) – for example 10 million people tuned in to watch the BBC's coverage of the 2018 world cup final [reference: https://www.bbc.co.uk/sport/football/44850988]. There is also a concern about the cost of delivery. Since content providers pay a CDN provider for every bit delivered, a linear growth in the number of streams causes a linear growth in the cost of the delivery. The work done in this test bed aims to combat these two concerns by exploring a more efficient delivery of content over multicast (MC), thereby helping with the capacity constraints and flattening the delivery costs.

In order for this to work in an object-based paradigm, we need MC and UC objects to be seamlessly combined into a single experience on the UE. To achieve this (and with the added benefit of keeping the coding complexity of the app low) we insured that the delivery method (MC or UC) of the objects was transparent to the app. This is achieved by allowing the Dynamic Adaptive Streaming Over IP Multicast (DASM) system to handle the MC through the use of a proxy, while the app concentrates solely on delivering an object-based experience.

The BBC has developed the Forecaster5G app to test both the assumption that delivering common and bandwidth-heavy objects over MC will reduce the network load, and the assumption that an object-based approach will be feasible to deliver whilst improving the user's experience.

4.2 Integration of Object-based Broadcasting in Surrey Test-bed

The OBB solution focusses on delivering content reliably over MC and on composing objects from MC and UC sources into a single experience within an app on a UE, in order to provide an optimised user experience. In order to achieve this optimised experience the UE renders the objects itself, taking into account the user's preferences and including personalisation. The experience provided by the app is an OBB weather forecast; see Figure 30, which highlights the object-based nature of the app - see [Section 2.7 of D6.2 [2]] for more details. In order that the MC content be delivered reliably we are using the DASM system, developed by BBC R&D – see [Section 2.7.2 of D6.2] for more details, and the schematic in Figure 31. The DASM system consists of a *DASM Head-end*, which resides at the BBC and packages the MC content, and a *DASM Client Proxy*, which is integrated into the 5G core at the Surrey testbed [3]. The *DASM Client Proxy* converts the MC traffic into UC traffic for the UEs to consume, and uses UC to patch any errors in the content delivered over MC. The UEs are connected to the 5G core over Wi-Fi, via a 5G NR CPE. This set up can be seen in Figure 31.

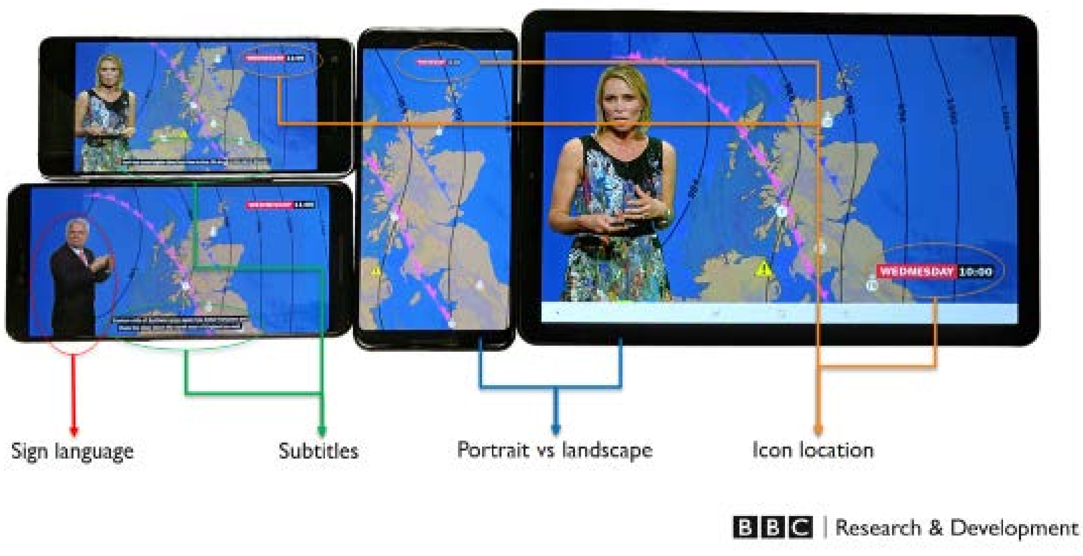

Figure 30: OBB weather forecast.

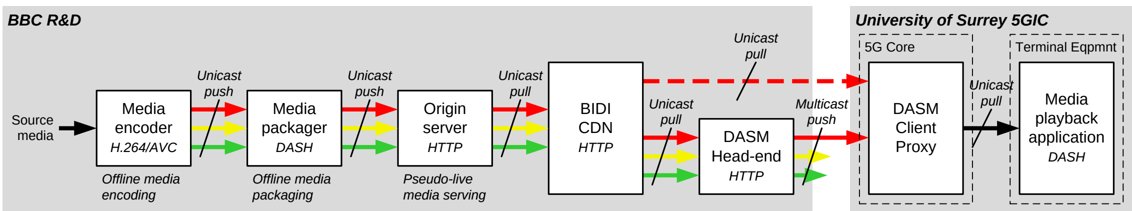

Figure 31: Schematic of the DASM system.

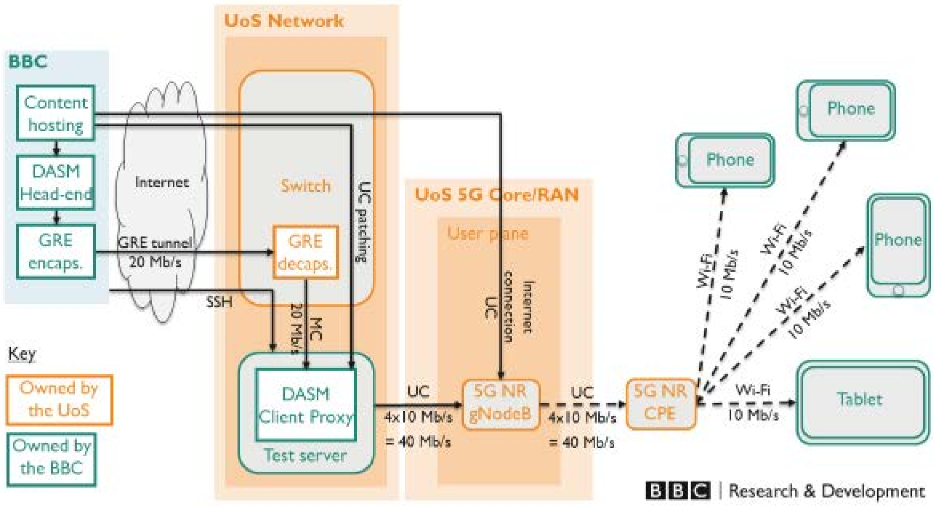

Figure 32: The architecture of the OBB solution in the Surrey testbed.

In Figure 32 we see the delivery method (MC or UC) of the objects consumed by the UEs. As discussed in [Section 2.7 of D6.2 [2]], the objects that are common to many users or are bandwidth-heavy, for example the pseudo-live MPEG-DASH presenter and sign language videos, are delivered over MC, while the objects that are used for personalisation or are less bandwidth-heavy, for example thumbnail images of the user's friends, are delivered over UC. The UC assets are either fetched on the application start up (e.g. the background tiles), or as and when they are needed (e.g. the weather icons). Since the timing and layout of the weather map, icons and subtitles are of a pseudo-live nature (in order to be synchronous with the MPEG-DASH video), these are encapsulated in a collection of MPEG-DASH events, and are thus delivered over MC.

In Figure 33 we can see that ultimately all content is delivered over UC to the UEs. A future goal would be to install the *DASM Client Proxy* directly on the UE in order to receive MC direct to the device over the radio layer. This was not, however, possible in the current setup of the demonstration. Looking back from the UEs, we can see that the MC and UC sources bifurcate at the 5G NR gNodeB. Here there is a UC link over the 5G core to the internet, which originates at the content hosted at the BBC. The 5G NR gNodeB also has a link to the *DASM Client Proxy*, which consumes the MC content, and converts it into UC. The *DASM Client Proxy* also has a UC link directly over the internet to the content hosted at the BBC, which it uses to patch any errors in the MPEG-DASH segments received over MC. The MC is encapsulated within a GRE tunnel at the BBC, where it travels over the internet and is delivered to the University of Surrey network. Here the MC is decapsulated from within the GRE tunnel, and the MC then travels to the *DASM Client Proxy*.

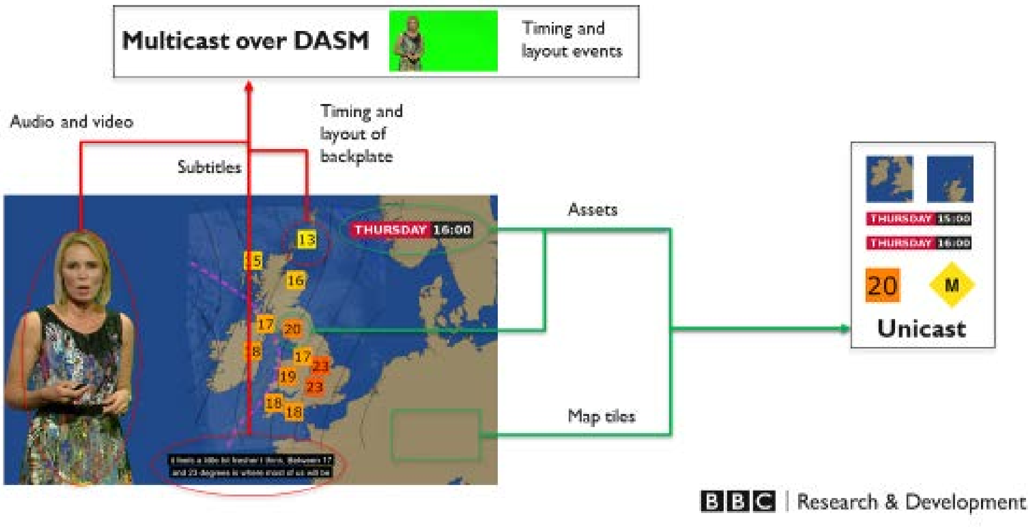

Figure 33: Origin of the objects.

4.3 Measurements, Evaluation and Results

The testbed with the architecture illustrated in Figure 32 was implemented. In Figure 34 shows the Forecaster5G OBB app running on four devices, which are connected as in Figure 32. Here we can see the app seamlessly combining content delivered over UC with content delivered over MC, both content sources going via the 5G core.

Figure 34: The app running on devices over the 5G core with integrated DASM Client Proxy.

In order to gauge the savings afforded by using MC to deliver the bandwidth-heavy and/or common objects, the throughput (or bit rate, in bits per second) was measured on the 5G core. This was done in two cases; the first is using a hybrid of MC and UC to deliver the content, the second is using only UC to deliver the content. Thus, the throughput across the blue line in Figure 35 (using MC and UC) and Figure 36 (using only UC) was measured. Each of these measurements was performed with 1 through 5 devices, with the hypothesis that the throughput would increase in a linear fashion as devices were added when only using UC, but that the throughput would remain relatively constant as devices where added when using a hybrid of MC and UC.

When a given device first starts the Forecaster5G app a number of assets are fetched over UC. These are then cached and subsequently used the display the background weather map. The result of this is that there is a spike in the throughput for approximately 5 seconds when the app is first started. The throughput then becomes more stable, as it fetches each segment of the video and additional assets over UC as and when it needs them. This effect can be seen in Figure 37. We excluded this start up period from the results for a number of reasons:

1. The first reason is that if the app runs for a significant amount of time then the impact of the initial spike is negligible – it will be overshadowed by the following stable period.
2. The second reason is that it may artificially inflate the throughput. If the initial spike is included in the calculation of the average throughput, then the length of time over which the measurements are taken will impact the average throughput for a given number of devices.
3. The third reason is that when the first device starts the Forecaster5G app using a combination of MC and UC, the initial DASH representation for the video will be at the lowest setting (i.e. the one with the smallest bit rate). This is due to the *DASM Client Proxy* requiring some time to settle at the optimal DASH representation (in this case, a higher bit rate). Thus, in order to take the measurements combining MC and UC, the app must be started on the first device and then a period of a few minutes must elapse for the DASH representation to be steady. Only then can additional devices be added and measured. For this reason, the initial spike for the first device in the case of combined MC and UC is not representative. Thus, the initial spike has been removed from the results.
4. Additionally, note that the initial assets that are fetched by the Forecaster5G app constitute the background weather map. Since the background weather map would be constant across every instance of the app (even if the app was displaying different weather on different days), there is an argument for saving/caching these assets on the device (or near to the device in the network), thus removing this initial spike on app startup.

The results can be seen in Table 3 and Figure 38, where the measurements UC and MC with UC are carried out twice each. It is particularly clear in Figure 38 that when MC and UC are being used (labeled MC 1 and MC 2 on the graph) the bitrate remains relatively constant, whilst when only UC is used (labeled UC 1 and UC 2 on the graph) the bit rate increases at a linear rate. This supports the hypothesis that delivering some carefully chosen content over MC can offer substantial savings with regard to network load.

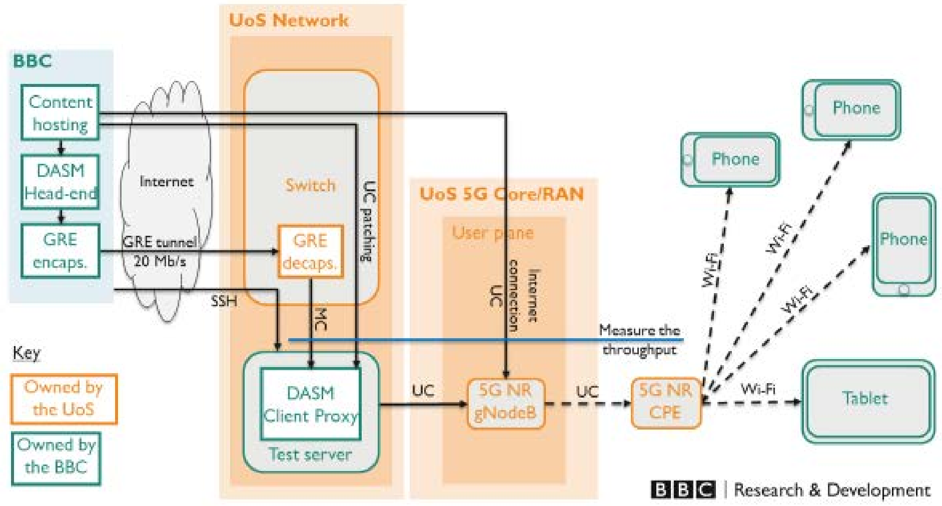

Figure 35: Measure the throughput across the blue line in the case of MC and UC.

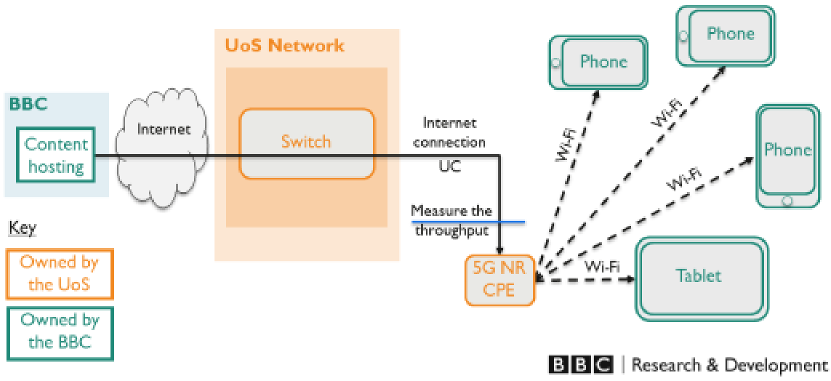

Figure 36: Measure the throughput across the blue line in the case of UC only.

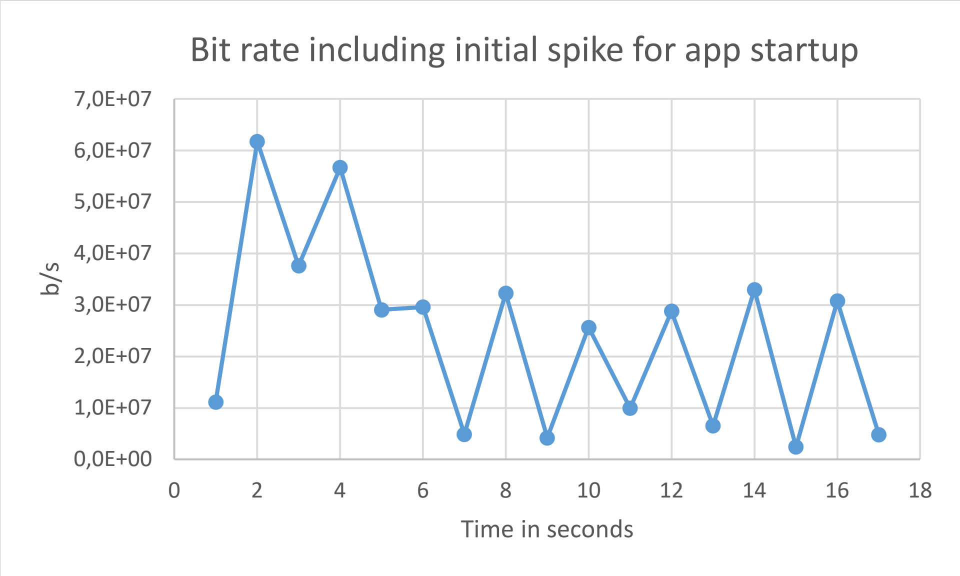

Figure 37: Bit rate for a single instance of the app on startup, including the intial spike in bit rate.

Table 3: MC and UC bitrate against number of devices.

Bit rate in b/s				
Devices	MC 1	MC 2	UC 1	UC 2
1	1.12E+07	1.13E+07	1.15E+07	1.05E+07
2	1.12E+07	1.50E+07	2.24E+07	2.14E+07
3	1.28E+07	1.23E+07	3.21E+07	3.05E+07
4	1.24E+07	1.67E+07	4.18E+07	4.36E+07
5	1.45E+07	1.58E+07	5.10E+07	5.39E+07

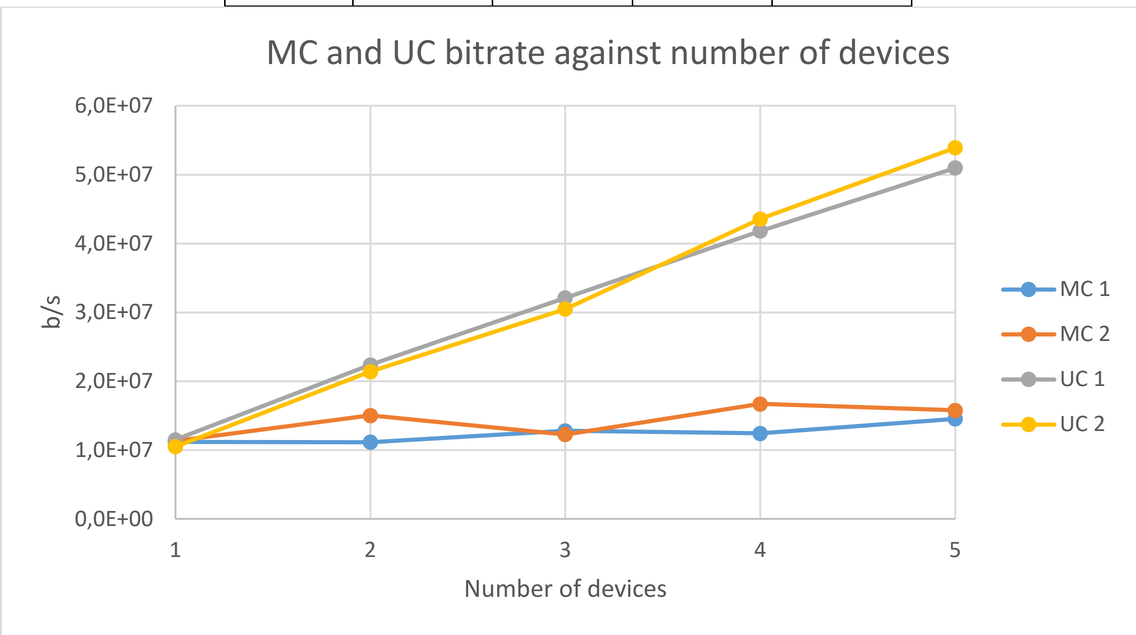

Figure 38: MC and UC bitrate against number of devices.

5 Object-based Broadcasting: Demonstrator

5.1 Demonstrator: Forecaster5G. Object-based broadcasting over Multicast and Unicast

This demonstrator is related to the integration in the Surrey testbed. The architecture of the demonstrator can be seen in Figure 39. It has some similarity to the architecture of the testbed, see Figure 32. The main similarities are firstly that the same Forecaster5G application, developed by the BBC, runs on the UEs (see Section 0 for a description), and secondly that the DASM system is used to ensure reliable MC delivery (again, see Section 0 for a description). There are some important differences between the architecture of the testbed and the demonstrator. Most notably the GRE tunnel, which originates at the BBC, does not terminate in the University of Surrey network, but instead terminates on the test server which houses the DASM Client Proxy. This is situated at the EuCNC venue. Additionally, the devices are connected to a Wi-Fi access point, as opposed to a 5G NR CPE.

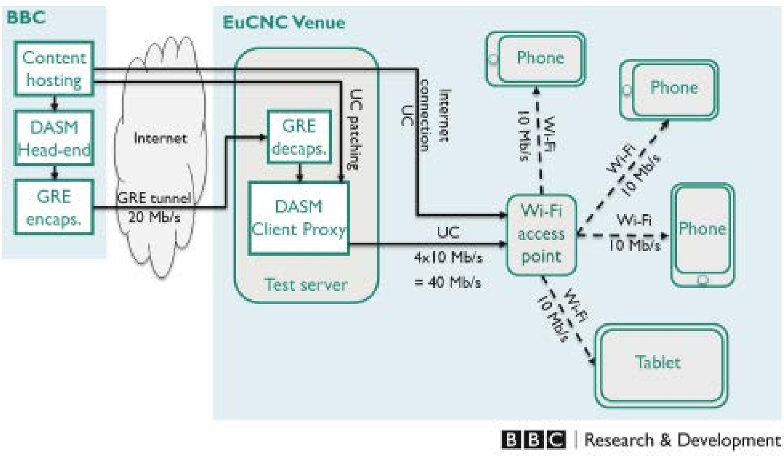

Figure 39: OBB demonstrator architecture.

More information about this Demonstrator is contained in D6.9 [12].

6 Public Warning Service: Trials in the Turku Testbed

6.1 Description of Public Warning Service Trials

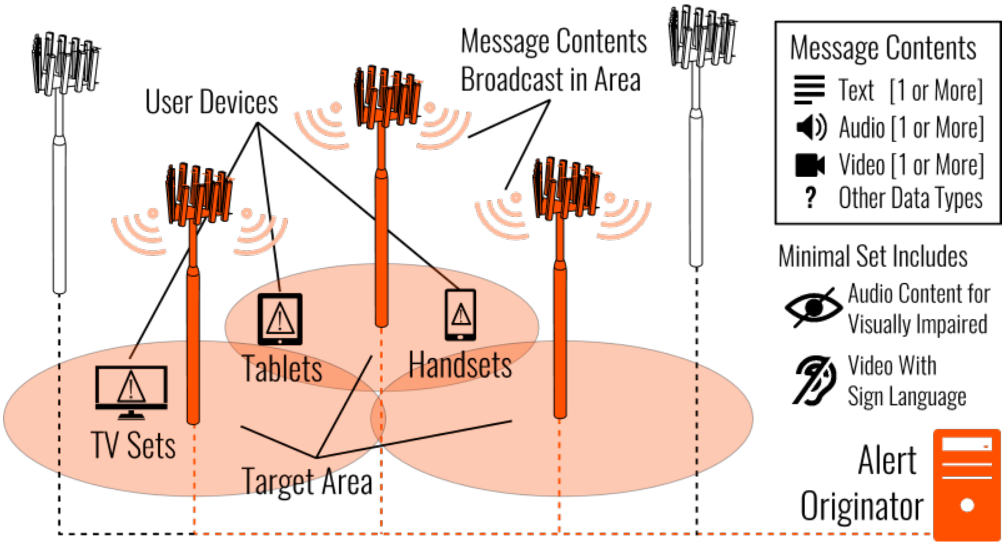

Figure 40: Public warning use case description

The trials for public warning use case (as illustrated in Figure 40) aimed at studying the multimedia public warning alert use case. The trials were performed in the Turku test-bed. The novelty of the demonstration is the ability to send multimedia information for public warning as a broadcast, something that the existing cell broadcast is not capable of. Cell broadcast is true broadcast but it is limited to text only. Unicast transmission of the public warning information would not have the resource efficiency of broadcast, which is needed at the time of an emergency.

The technologies enabling the public warning message broadcast transmission are eMBMS and components for both network and UE sides created by One2Many.The trialed features are:

- Delivery of alert messages with multimedia content such as:
  - map of affected area
  - a picture describing the incident
  - audio
  - instructions on things to do during a disaster
- Successful delivery of alert in various reception conditions
- Combination of public warning with multilink and spectrum sharing (proof-of-concept described in D6.2)

The architecture of the validated system is illustrated in Figure 41. The public warning messages are generated by special software and transmitted to several users with eMBMS broadcasting. Mobile phones with eMBMS support and an appropriate user App for the alerts are used in the setup.

The steps for the delivery of the alert together with the user interface visible in the alert App is illustrated in Figure 42. The reception of the alert is triggered by HTTP push message using 4G radio. When the alert is triggered the content is received via eMBMS file download. Finally, the content of the alert message is displayed to the user by the alert APP.

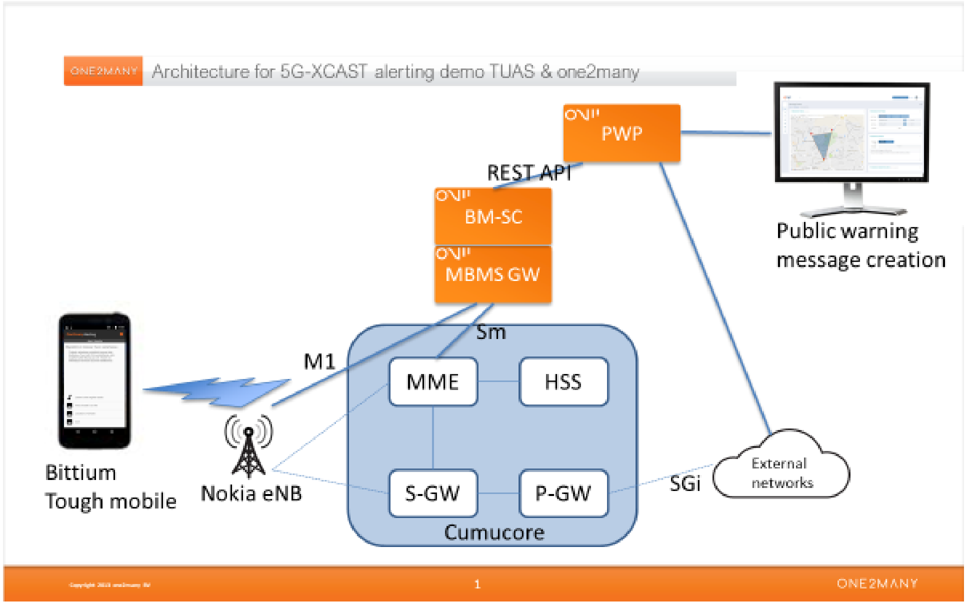

Figure 41: Architecture for transmission of public warning alerts

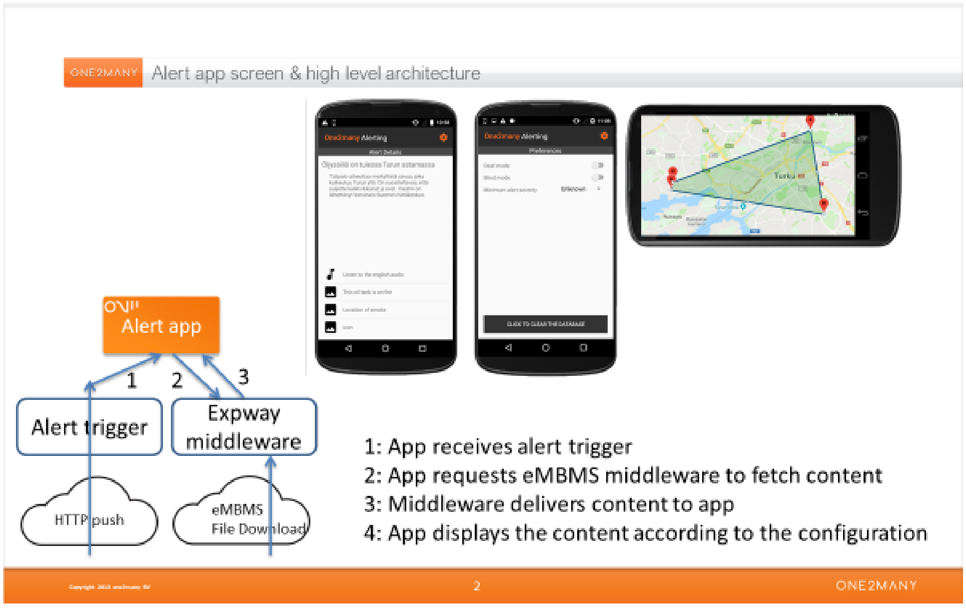

Figure 42: Alert screen shots and high-level architecture of the system

The setup was verified using Bittium Tough mobile phones with Expway middleware and One2Many app. The correct functioning was verified using Android and Expway middleware logs stored on the phones.

Content used in trials

The content developed for the demonstration animates an oil tank fire in Turku harbor. The content contains images such as map of the affected area, a picture of oil tank in fire and figures illustrating the required actions (close the windows etc.). Further, audio is available for visually impaired persons in both English and Finnish language. The multilingual implementation was trialed with Finnish language (with special characters such as "ä" and "ö") to show the operation of the application developed by One2Many. Screenshots of the multimedia warning messages are shown in Figure 43. The total size of data in the alert is roughly 300 kilobytes.

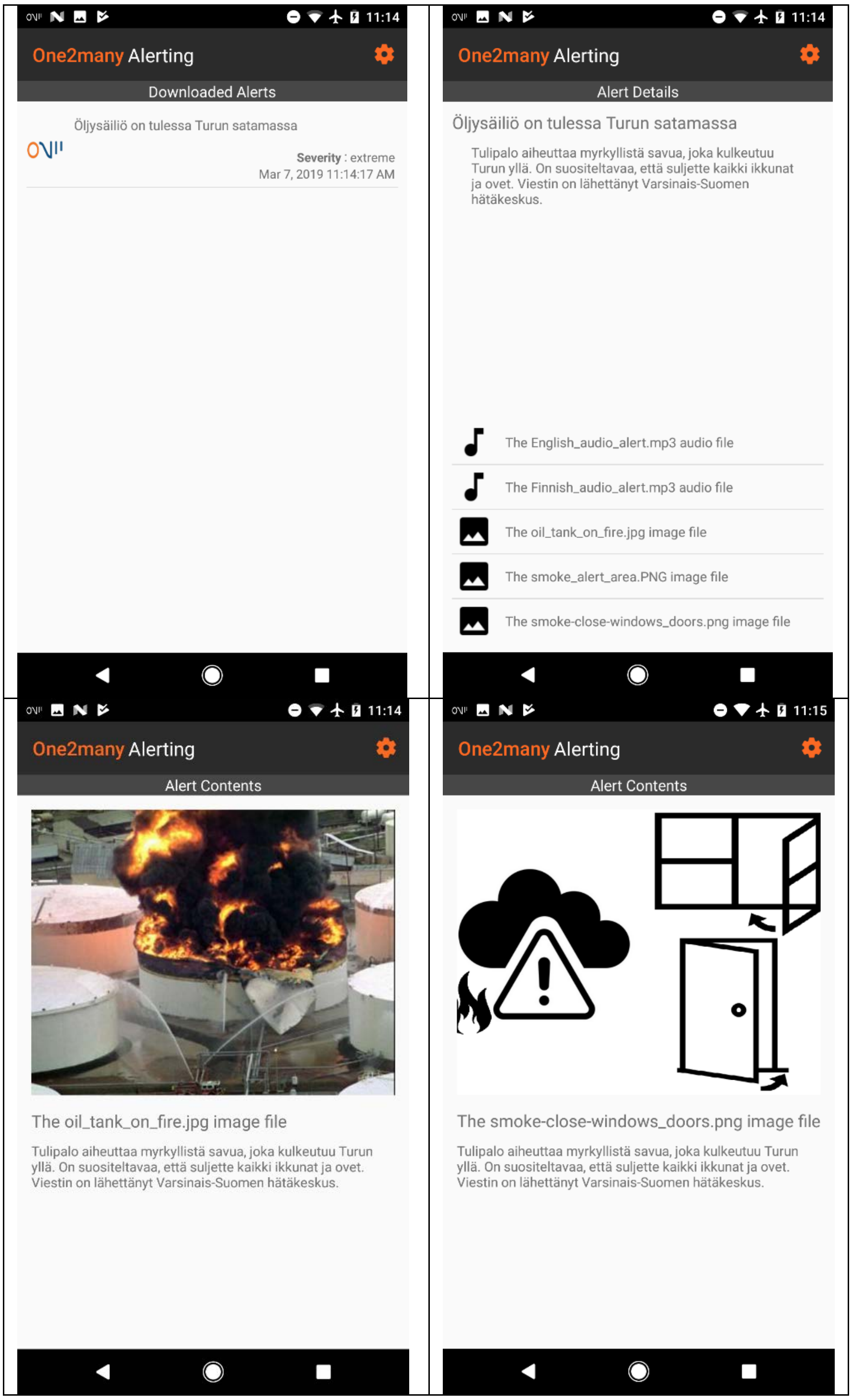

Figure 43: Screenshots of the alert contents

6.2 Integration of Public Warning Service in Turku Test-bed

6.2.1.1 *Public Warning alert creation with multimedia content*

The PW alert content is created by using the GUI of the Public Warning Platform (PWP) developed by one2many. For the 5G-XCAST project the multimedia capability was added to the PWP. To create the alert the user has to enter various information such as:

- Select the geographical area of the alert on the map
- Set start time, end time, severity
- Provide high level description and detailed text

This can be seen in the Figure 44.

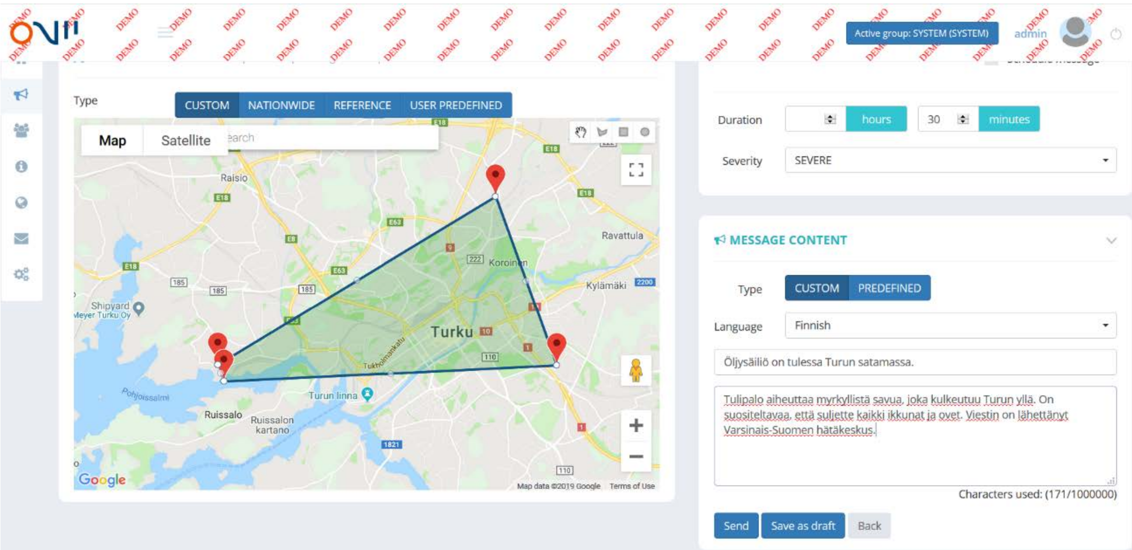

Figure 44: Screenshots of the PW alert creation

The addition of multimedia content requires the user to enter the URL of the content into the system and provide a description. The content will then be listed, and the user can view or play the content (for verification) as shown in Figure 45:

This oil tank is on fire

Description	This oil tank is on fire
MIME type	image/jpeg
File size	25635 B
URI	https://storage.googleapis.com/5gxcast_alerts/httpPost.128/oil_tank_on_fire.jpg

Download

Figure 45: Screenshot of multimedia content details

When the user is ready with the alert creation, the user presses “Send” and the alert is sent via suitable adapters (interfaces) to systems for alert dissemination. For 5G-XCAST the Common Alerting Protocol (CAP) was used. The CAP protocol specifies the alert as an XML message. To deliver the XML message HTTP was used.

6.2.1.2 *Linked and embedded content*

The CAP protocol allows for multimedia content to be delivered with the (textual) alert in two ways:

- Embedded – the content is base-64 encoded and put into the alert message
- Linked - the content is specified by links (URL). The receiver must download the content separately using the links.

The PWP system supports both methods. In the 5G-XCAST project both methods were tested.

The first solution used embedded alerts resulting in a single large file (several Megabytes) that was broadcasted using eMBMS. This worked well for receivers which are eMBMS capable but in case of unicast delivery, requires a very large file to be downloaded by each phone (causing strain on the network). The fact that the content is base-64 encoded also further increases the size of the message.

For the PoC it was also required deliver the alert using bonded channels which can only benefit if the content is downloaded in parallel as individual files. In case of eMBMS this requires broadcasting multiple content files (using a carousel, repeatedly).

The linked alert does require the content to be publicly accessible for the phones using unicast. For this purpose the multimedia content was stored at the Google Cloud Content Delivery Network (CDN), as shown in following screenshot Figure 46:

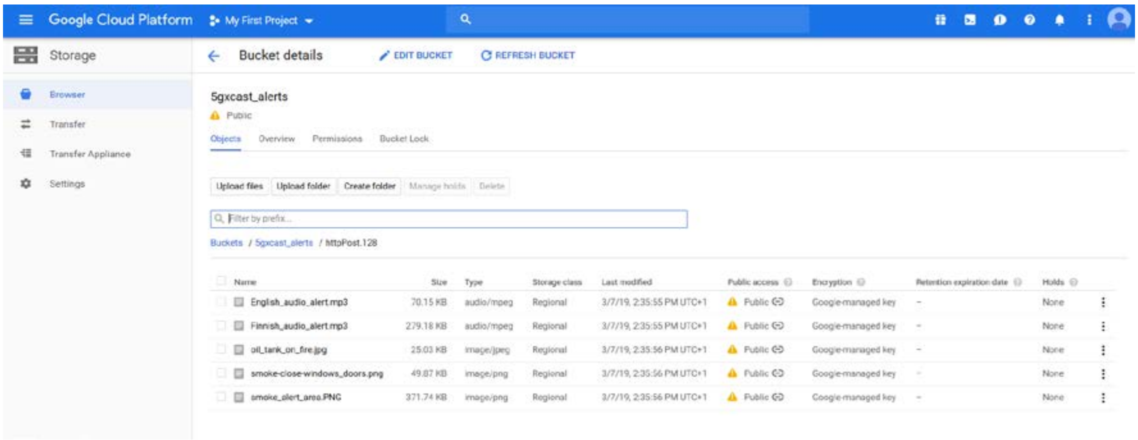

Figure 46: Screenshot of multimedia stored at Google Cloud CDN

Instead of a public cloud storage, a possibility would be to provide the multimedia content to the edge of the network using Multi-access Edge Computing (MEC) but this was not available in TUAS [3]. This would likely increase performance of the download and thus faster content delivery to the phone.

6.2.1.3 *Middleware to facilitate multimedia alert delivery*

Alert delivery to the phones using eMBMS and/or unicast, linked or embedded requires several steps to be completed. These steps were developed in separate software called here middleware. Following steps were performed:

1. Receipt of the CAP message through HTTP and positive response to PWP;
2. Storage of the multimedia content into the Google Cloud CDN (optional);
3. In case dynamic spectrum management (Fairspectrum) is used:
    a. Define area (using polygon of the alert) and start spectrum;
    b. Wait for spectrum management to have setup the spectrum;
4. In case of delivery using eMBMS:
    a. Copy the multimedia content onto the BM-SC (assumes BM-SC has no internet connectivity);
    b. Login the BM-SC REST API;
    c. Define the content;
    d. Schedule the content for broadcast in defined time window (from the alert) on eMBMS bearer with defined characteristics (area, bitrate, QCI, Forward Error Correction (FEC) etc.etc.);
5. Notify the phones using Google Firebase Cloud Messaging (GFCM). 2 different methods were tested:
    a. When embedded alerts are sent, the notification is only a trigger containing a message containing the filename of the alert;
    b. In case of linked alert, the actual alert is sent;

It should be noted that the benefit of linked alert here is that when the alert is delivered to the phone (by GCCM), the textual contents are immediately available regardless of the multimedia delivery (using eMBMS or unicast). This facilitates robustness.

The middleware was developed using node-red. This is a graphical development platform which lead itself well for implementing PoCs.

6.2.1.4 *Google Firebase Cloud Messaging fo push notifications*

GFCM was used to deliver the alert as a notification to the phones. GFCM supports both Android and Apple phones. When creating the notification, the duration for which GFCM system should try to send the notification is set to several minutes to avoid sending notifications *after* the alert has expired.

The performance of delivering the notification determines for a large part also the end-to-end performance for when the alert becomes available on the phone. When the phone has an active PDP context, the delivery is typically within 10 seconds. However, when no PDP context is available this can take up to a minute, requiring the PDP context to be created by the network due to the receipt of the incoming notification.

Possibly the network could be tuned (on the eNB) to improve the notification performance. Another option would be to install a real-time App on the phone that likes to keep the connection open such as facebook or whatsapp.

In case of dynamic spectrum, the notification was delivered as soon as the phone re-attaches itself to the network.

The GFCM console doesn't provide much information when the notification is requested using the API versus using the dashboard (manual method). It shows only an aggregate of how many messages were sent in week. A detailed delivery report of each notification send would be very useful.

6.2.1.5 *eMBMS delivery of multimedia alerts*

The one2many eMBMS was used to deliver the multimedia alert to eNB. The eMBMS consists of BM-SC and MBMS GW.

The middleware schedules the delivery of the eMBMS session. This can be verified in the dashboard of the BM-SC GUI, as shown in Figure 47:

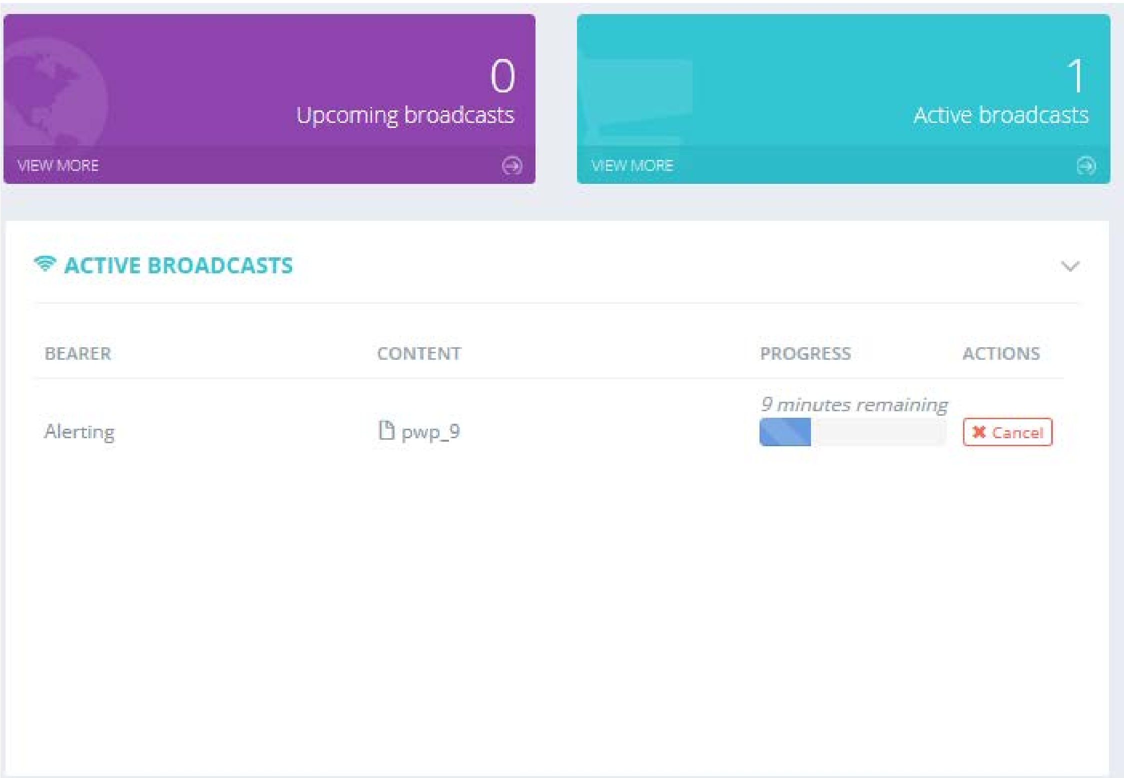

Figure 47: Screenshot of scheduled eMBMS session in BM-SC

The content derives the unique identifier from the PWP alert, allowing the eMBMS session to be correlated with the actual alert in PWP.

The eMBMS session has the following characteristics:

- bitrate 700 Kilobits per second (500 and 250 Kbps were also tested);
- FEC Raptor 10 applied allowing repair up to 25% of packet loss;
- QCI = 2, allowing the bearer to be treated separately from announcement in eNB

6.2.1.6 *eMBMS in the eNB*

The trialed PW broadcast transmission consists of two multicast streams, one for the announcement of the payload data session and the payload transmission itself. The multicast groups can be seen from the site manager snapshot in Figure 48.

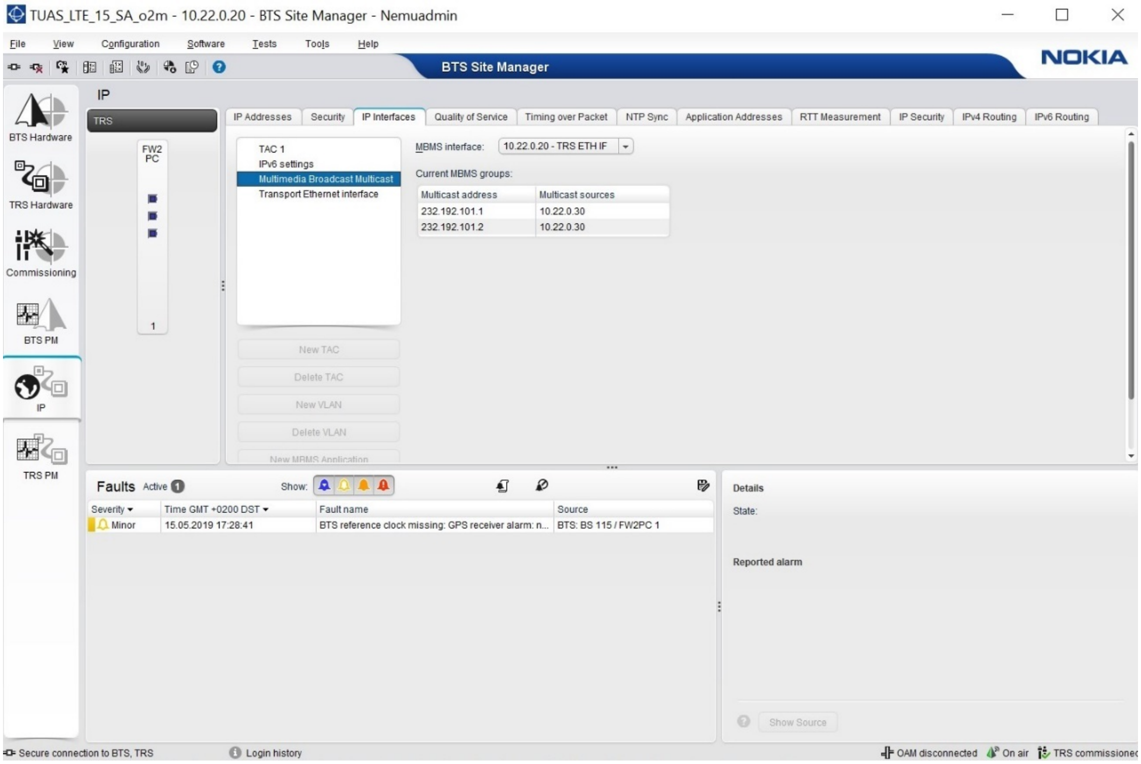

Figure 48: Multicast groups

The eMBMS signaling modulation and coding scheme was set very robust (n2) to allow reliable detection of the eMBMS service at the UEs. Both announcement and payload were transmitted with similar modulation and coding schemes (MCS number 18, 64-QAM). 10% of the capacity was allocated for eMBMS. Synchronization period length of 60 seconds was used in the trials and the UEs were using NTP from the core network for synchronization. The selection of synchronization period and time reference were observed to be important to have correctly set, as the eNB will drop packets with timestamp outside the buffering range. The eMBMS parameters and the configuration of multicast channels used in the trial are shown below in Figure 49, Figure 50, and Figure 51.

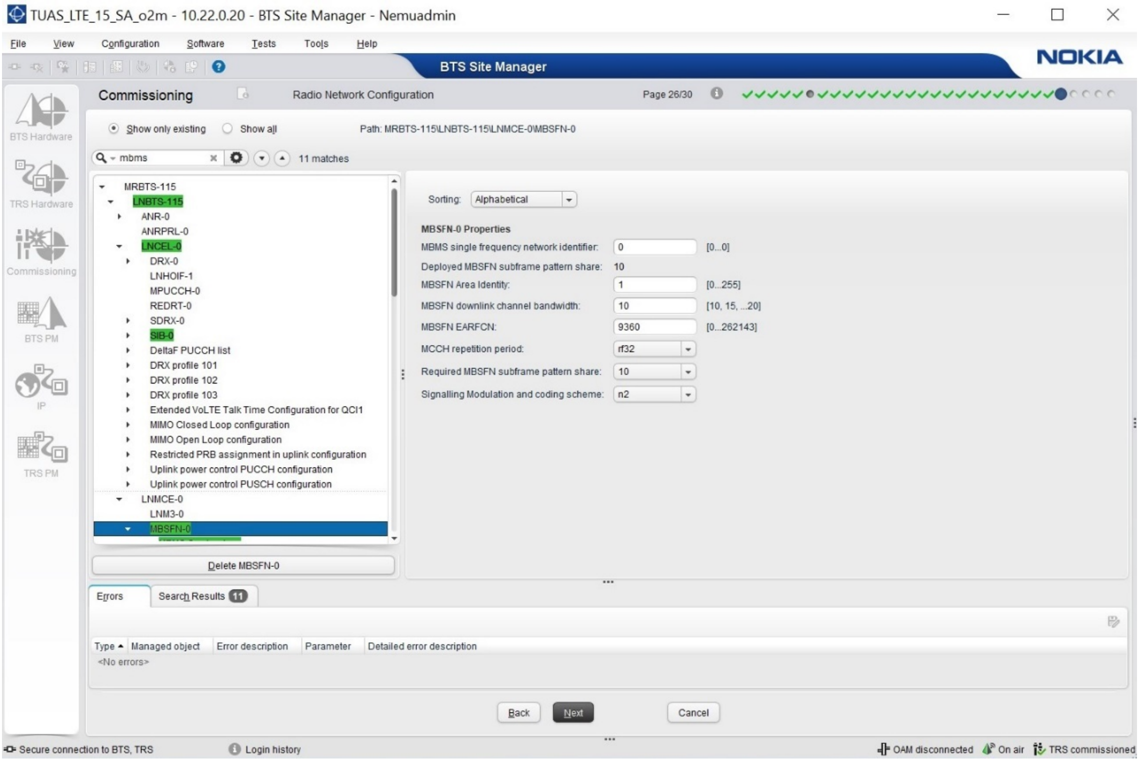

Figure 49: MBSFN-0 properties

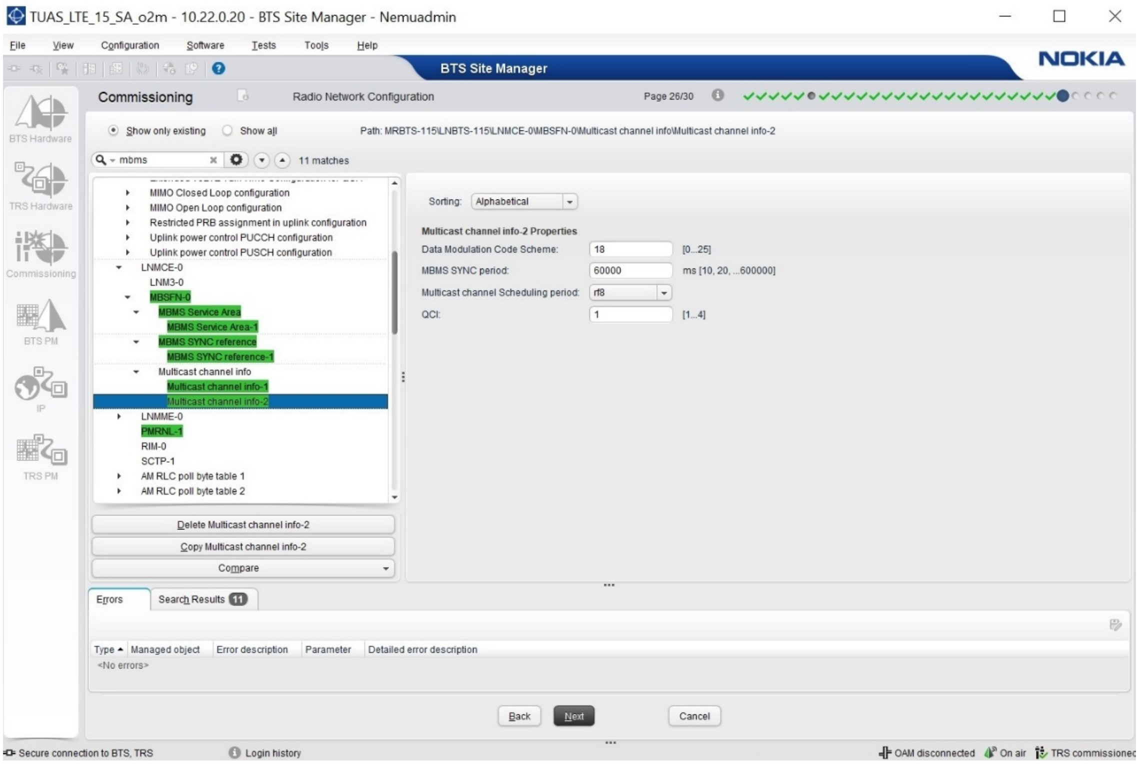

Figure 50: Multicast channel configuration for the announcement

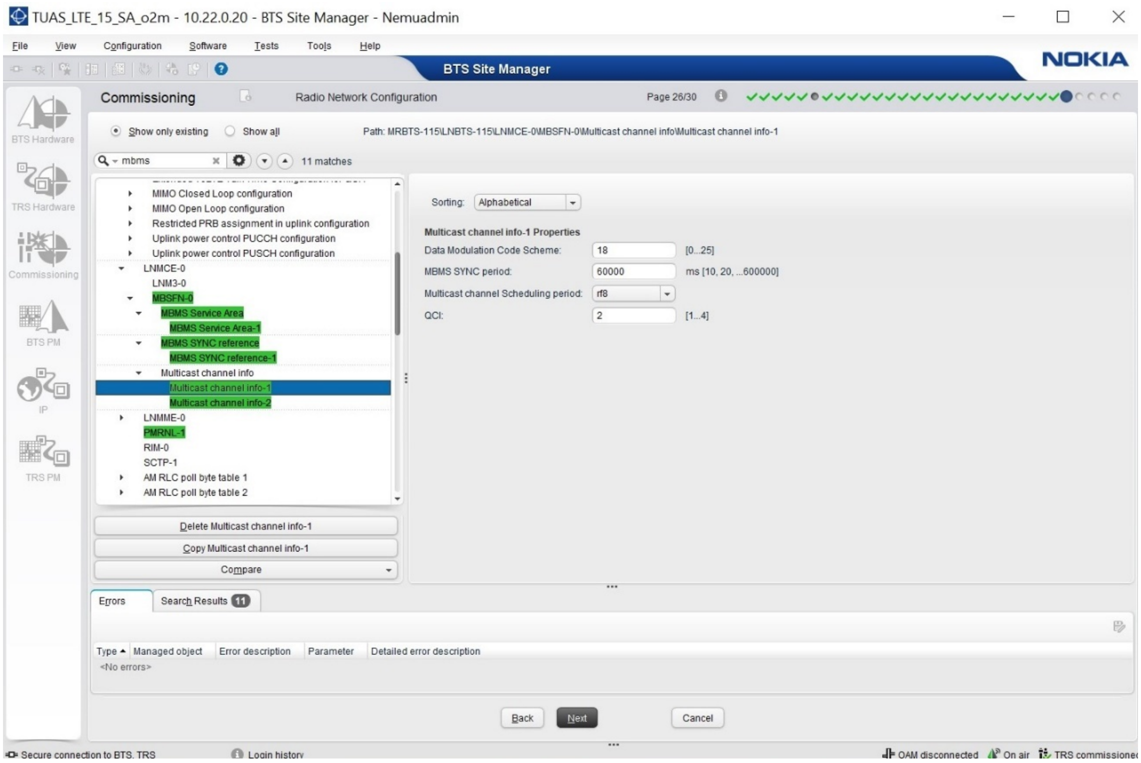

Figure 51: Multicast channel configuration for the payload

The public warning reception application developed by one2many receives trigger from Google Firebase Cloud Messaging utilizing unicast capacity of the carrier. Once the trigger is received, application fetches the content using eMBMS. If the reception over the eMBMS fails due to for example poor channel conditions, the app fetches the content over unicast after a certain timeout.

6.2.1.7 *Equipment used in the trials*

The details of the equipment used in the trials is listed below.

- 1 x Nokia FW2PC BC28 Flexi Zone G2 Outdoor Micro FDD LTE 700 MHz High Power
    - Operation frequency on B28 (Downlink 758-803 MHz, Uplink 703-748 MHz)
    - Bandwidth: 10 MHz
- 2 x Inmet 30 dB attenuators
- Low gain antennas (2 dBi)
- Terminals (4 x Bittium TM)
- One2Many BM-SC, MBMS GW & PWP
- Cumucore EPC
- Tektronics spectrum analyzer

6.2.2 Public Warning Trials: Measurements, Evaluation and Results

The primary target of the trials was to study the behavior of the end-to-end public warning message transmission. For this purpose the performance indicators at the UE side were studied:

- Time to receive the alert
- Robustness of the transmission

Measurements were performed to study the behaviour of the public warning message transmission using eMBMS. Timeliness of the transmission is an important factor for the public warning. In good conditions the download time of the broadcast content from the reception of the announcement until the receiving the payload roughly 3 to 4 seconds was observed with the selected configuration.

6.2.2.1 *Signal strength measurements*

To study the effect of the signal strength on the performance of eMBMS transmission of the public warning messages in the laboratory, step attenuators (shown in

) were attached to the RF outputs of the eNB. Same amount of attenuation on both RF outputs was used each measurement. The amount of attenuation was confirmed form the spectrum view.

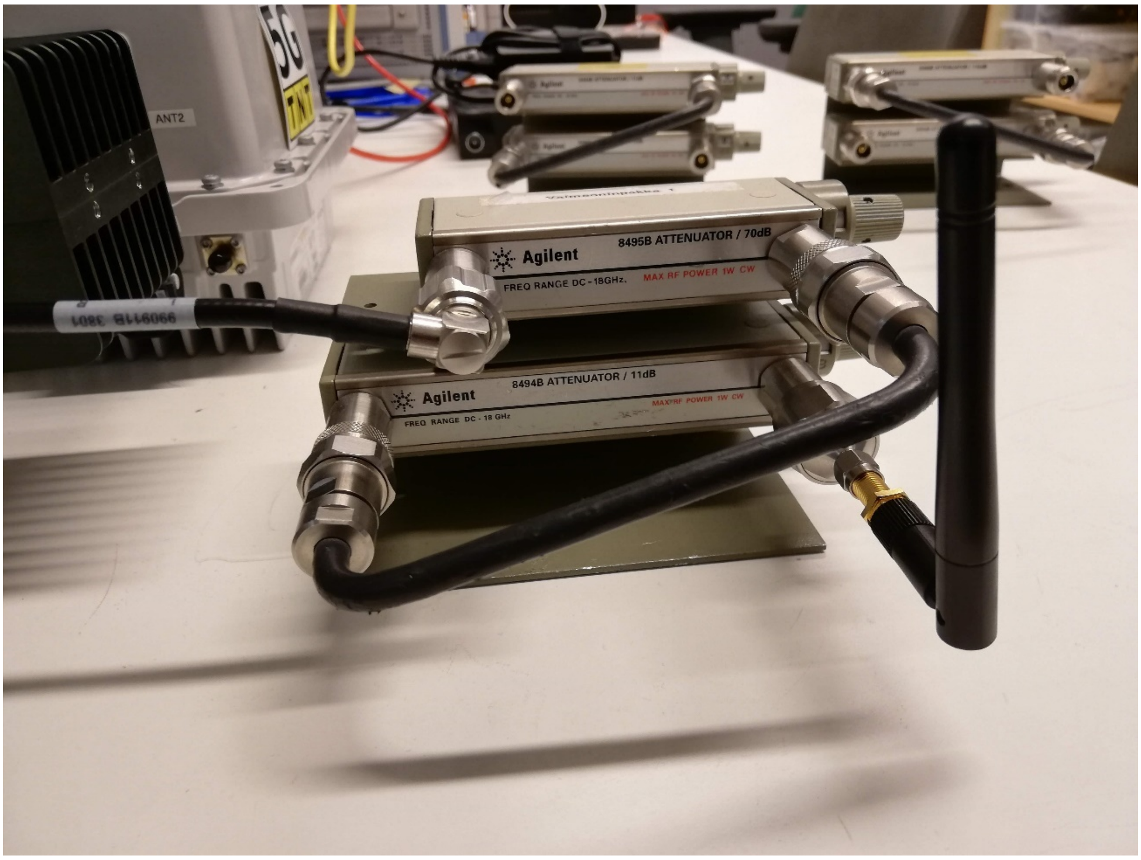

Figure 52: Step attenuator

The point where the reception of alerts on UEs is not always 100% successful was sought to study different ways the transmission of the PW transmission can fail and how this could be taken into account in the configuration of the transmission parameters.

Further, the performance of the FEC with 25% additional redundancy incorporated in the FLUTE transmission of the packets was studied. Packet loss was observed in some scenarios and the applied FEC allowed the files to be re-constructed.

The results are shown in Table 4. The 0dB attenuation represents the starting situation where the signal level is good enough for successful reception of the alert over eMBMS with all UEs every time. Increasing the attenuation in general increases the packet loss and makes the download time longer. Furher, one of the UEs was unable to receive eMBMS signal at any attenuation beyond starting situation, thus it received the alert over unicast (- sign in the table). This suggests that there may be quality variations in the RF parts of the tested UEs. It should be noted that the measurement shown on the Table contains only four UEs, meaning that the results are not statistically reliable but serve rather as an indication of the performance.

Table 4: Measured download time for the alert and respective packet losses

	UE1		UE2		UE3		UE4	
Attenuation	download time (ms)	packet loss	download time (ms)	packet loss	download time (ms)	packet loss	download time (ms)	packet loss
0 dB (MCS 18, 18)	3863	159	4264	0	3920	99	4540	0
10 dB (MCS 18, 18)	4329	0	3883	159	6004	0	-	-
20 dB (MCS 18, 18)	12805	173	17418	359	4725	0	-	-
25 dB (MCS 18, 18)	-	-	-	-	no success	260	-	-
25 dB (MCS 9, 10)	6823	0	6881	0	6791	0	-	-

The transmission of the PW messages proved to be very robust and could be made even more robust with selecting lower order modulation and lower coding rate. The last row in Table 4 shows that at the attenuation level (25dB) where MCS 18 failed, reception was successful with three UEs using MCS 9 for the announcement and MCS 10 for the payload session. PW transmission with very robust modulation and coding scheme was possible as long as the UEs remained attached to the eNB.

6.2.2.2 *Trial on effect of in-band interference*

To further study the effect of the interference on the eMBMS transmission, an 8 MHz DVB-T signal was inserted on the same center frequency (773 MHz) as downlink of the studied 10 MHz LTE signal. The spectrum view can be seen in Figure 53.

Interfering signal level when the unicast communication was barely operational (rather low bitrate, UEs having troubles to attach to the network) was sought. The eMBMS transmission parameters were gradually changed towards lower order modulation and lower code rate. Successful eMBMS file download was found impossible with this kind of interference. The considered reason for the operability of the unicast transmission is that with the feedback channel state information, the unicast transmission can automatically avoid the interfered subcarriers, while with eMBMS this is not possible. The 8 MHz DVB-T signal doesn’t affect all the subcarriers of 10 MHz LTE downlink, thus there are unaffected subcarriers at the upper and lower frequency parts of the LTE downlink signal.

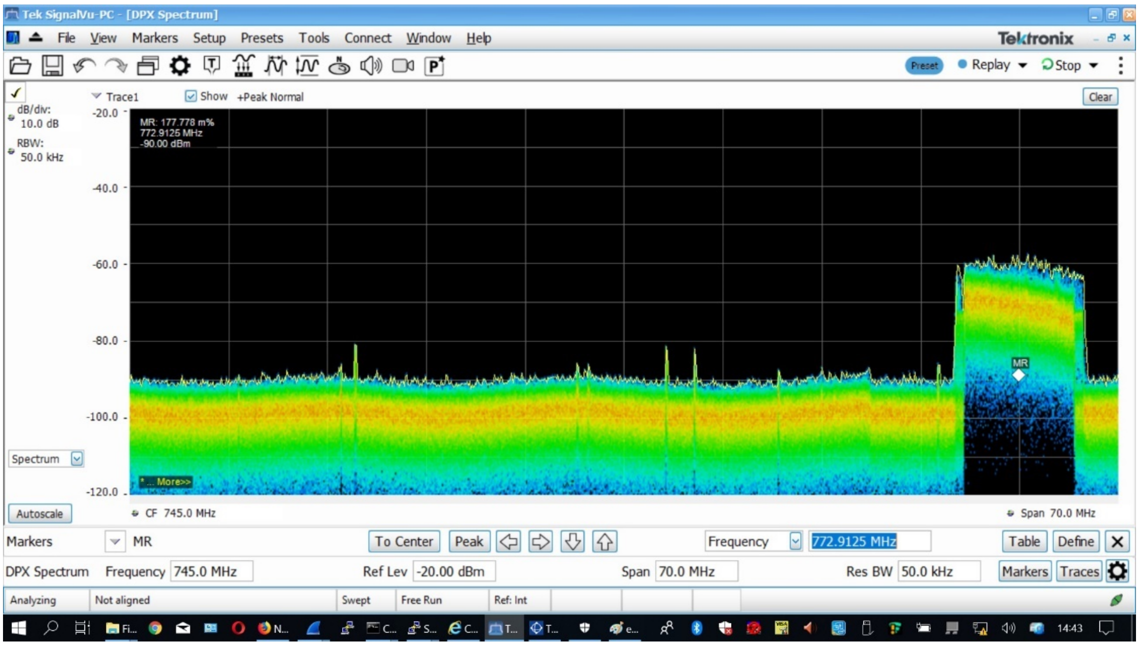

Figure 53: Interfering DVB-T signal added on top of the downlink signal

6.2.2.3 Public warning & Multilink & Spectrum sharing

The setup consists of the eMBMS public warning setup extended with spectrum management and multilink as described in section 3.6. The image of the setup in the laboratory is shown in Figure 54. The 700 MHz basestation is shown on right and the LiveU multilink device in the middle. Part of the terminals on the table are connected directly to eNB for eMBMS and unicast, and part via WiFi to multilink device operating as WiFi AP. The laptop on the left is running the software for creating an alert. Screenshot of alert creation is shown in Figure 55.

Figure 54: Laboratory setup of the demonstrator

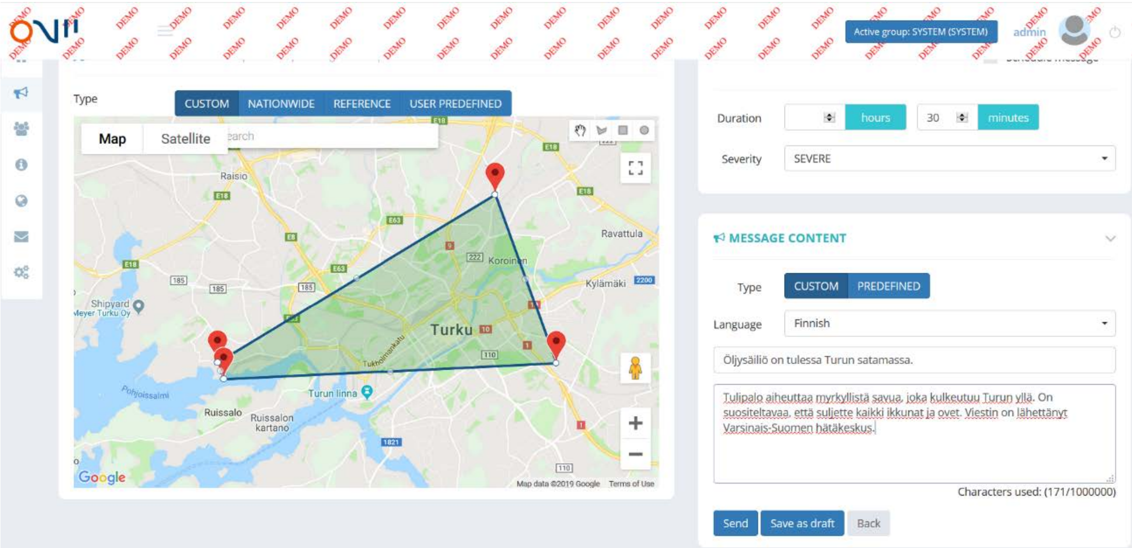

Figure 55: Screenshot of the alert creation using O2M PWP

Once an alert is set, the additional capacity is allocated for the alert transmission by spectrum manager. The correct functioning of the additional capacity allocation was confirmed by spectrum analyser, shown in Figure 56.

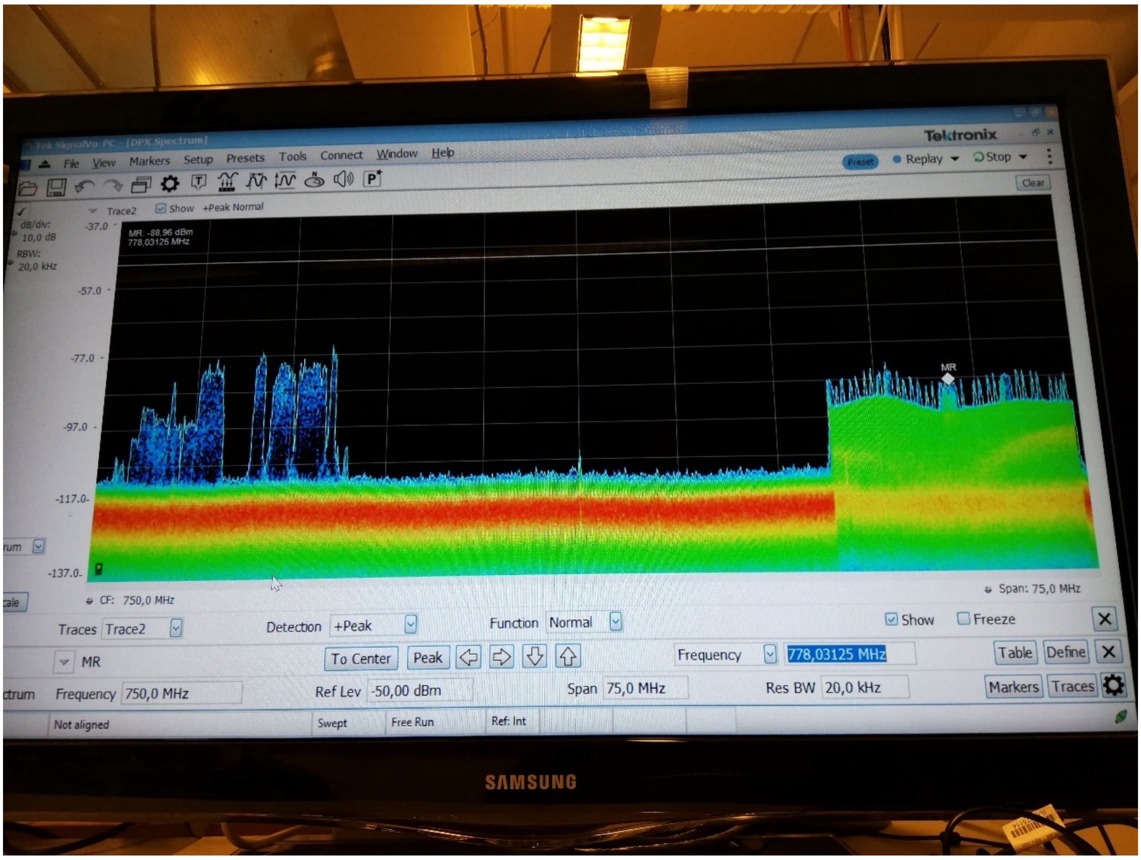

Figure 56: The spectrum view was followed to observe when the additional capacity is "online"

Further, the terminals are triggered to start the reception of the alerts. The terminals that are connected to the multilink device have access to combined capacity of different LTE networks. In all, during the setup phase three commercial Finnish 4G networks (Telia, DNA, Elisa) and TUAS network as dynamic additional capacity were used. Picture of the multilink device screen when the alerts were transmitted is shown in Figure 57. TUAS network is shown as “No Name”.

When the additional spectrum is allocated, and the 2nd network becomes available, the multilink LU600 identifies this automatically and starts using it for unicast. Rich media content can then be unicasted to connected devices, split over the two networks by the ML-GW in the cloud and reassembled at the LU600 for a coherent stream. Thus the aggregated bandwidth is used so that rich media alerts, such as containing visualization of the incident or clear evacuation or other instructions, may be delivered to these UEs. Figure 58 depicts this split content in real time transmission over the LU600 field multi-link GW.

The operation of the UEs was tracked visually and by going through the log-files to verify that the alerts were transmitted via the carriers as designed. For example, the eMBMS reception of the alert was verified by examining the middleware log-files.

Figure 57: Multilink device when the alert is being transmitted

After the alerts are received either via eMBMS, unicast or multilink, the terminals will display the alert contents.

6.3 Integration of Dynamic Spectrum Management in Turku Test-bed

The target of the performed trials is to demonstrate the LSA evolved functions that have been developed to the Fairspectrum spectrum manager to enable dynamic spectrum sharing between users with different levels of priority in 5G. The trials and demonstrations are conducted in Turku testbed.

6.3.1 Measurements, Evaluation and Results

To estimate the functionalities, a proof-of-concepts related to different usage scenarios were built. The measurable performance indicators for the spectrum sharing mechanism considered are:

- Correct operation (Suitable frequencies are allocated for networks and priority order is followed)
- Evacuation time (The time it takes for the secondary user to clear the frequency for the use by the primary user)
- Network setup time after frequency change (The time it takes for the network to set up on the allocated frequency, potentially splitted to base station and core network delays)
- Interference to other users? (Related to correct operation, regulated interference limits should be fulfilled in correctly operating system, can be observed from the spectrum analyzer)

The performance indicators such as the evacuation and setup time are implementation (and observably even base station firmware version) dependant. Thus, the measurements performed here first for LTE systems can set a ballpark reference for the 5G design and guidance what should be the targets in the future to make the dynamic spectrum use more efficient.

For the general high level KPIs, the dynamic spectrum use contributes to enabling high capacity and availability via efficient spectrum use on various bands.

The measurements focus around selected use cases. The ones measured so far are the PMSE and the dynamic priority order cases. The performed measurements, evaluation and main results obtained are presented in the following.

6.3.1.1 *First trial – PMSE on 2.3 GHz band*

For the PMSE stakeholders operating equipment in the 2.3 GHz band this concept would allow a gradual transition from older PMSE equipment towards LTE/5G based equipment.

The architecture of the trial setup shown in Figure 58 consists of PMSE equipment operating occasionally on 2.3 GHz band and MNO LTE network operating on 700 MHz and 2.3 GHz bands. The latter represents MNO employing additional capacity on 2.3 GHz band using for example supplemental downlink concept. Proprietary PMSE equipment represents an OFDM based proprietary solution for wireless cameras operating on the band. PMSE LTE in Figure 58 is a rapidly deployable LTE network that can be used for PMSE purposes. Different ePCs (evolved Packet Cores) are used for the MNO LTE and PMSE LTE networks. The ePC2 used for the private network is a limited feature core that includes only necessary components for the data transmission, thus enabling a rapid deployment.

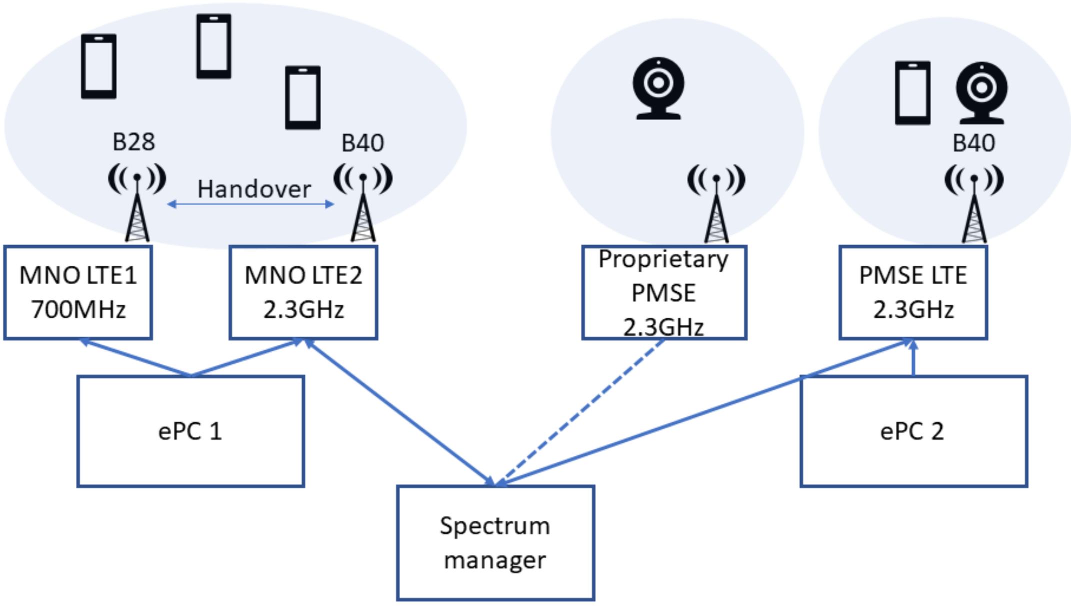

Figure 58: PMSE band spectrum trial setup

Spectrum manager orchestrates the operation of the different systems on 2.3 GHz shared band. PMSE system information is collected with a web-based reservation system. The users of the devices make reservations for their intended use. The reservation system has been piloted in the Netherlands in 2017-2018 [16]. The control of the PMSE devices also takes place through the reservation system so that the user of the devices are informed about required spectrum use changes with an email and the user has to deploy the configuration changes in the devices. Both PMSE LTE and MNO LTE systems have a direct machine-to-machine interface between the radio equipment and the spectrum manager. The priority order from highest to lowest considered in the trial is: PMSE, PMSE LTE, MNO LTE. When the priority user changes the configuration of the LTE network, a notification about the change is automatically received in the spectrum manager. Spectrum trial setup in the lab spectrum manager processes the changed spectrum situation and evaluates if the lower priority use may cause harmful interference to the higher priority use. If there is a risk of interference, the spectrum manager evaluates which changes would be required to accommodate the higher priority use and to maintain the best possible service level also for the lower priority use. On the high level, this is implemented so that if there are frequency channels available, the lower priority use is transferred to those channels. If there are no other channels available, the power level of the secondary user is lowered, or the transmission is denied. In this demonstration, the higher priority user is able to select the frequency channel to be used. An option for this could be that the higher priority user has the right to the spectrum resource in the band, but the specific frequency channel is determined by the spectrum manager.

The used equipment is listed below:

- Nokia Macro 700 MHz BTS
- 2x Nokia Pico 2.3 GHz BTS
- Samsung S8 phones
- Tektronix spectrum analyser
- DVB-T2 test transmission from R&S SFU Broadcast Test System
- Fairspectrum spectrum Manager

The spectrum manager communicates with the base stations operating at 2.3 GHz to alter their operation frequency, bandwidth and transmission power. Proprietary PMSE equipment user informs the spectrum manager that spectrum is required, but the equipment cannot be directly controlled by the spectrum manager. Commercial base stations and LTE terminals were used in the trial. The proprietary PMSE equipment was emulated in the trial with a DVB-T/T2 transmission and Samsung S8 phones streaming video served as LTE based PMSE equipment.

The steps performed in the trial were:

1) MNO LTE1 (700 MHz) and LTE2 (2.3 GHz) serving users (web surfing, video streaming)
2) PMSE LTE (2.3 GHz) turns on as a rapidly deployable network for PMSE, spectrum is available for both MNO LTE2 and PMSE LTE
3) PMSE user registers to the spectrum manager registration system, on the frequency currently in use for PMSE LTE
4) MNO LTE2 limits its transmission power (if necessary) to follow interference limits and the users remain connected to at least B28 (700 MHz) base station
5) PMSE LTE changes channel to give space to PMSE
6) Proprietary PMSE equipment turns on

Corresponding snapshots of the 2.3 GHz spectrum band are visualized in Figure 59.

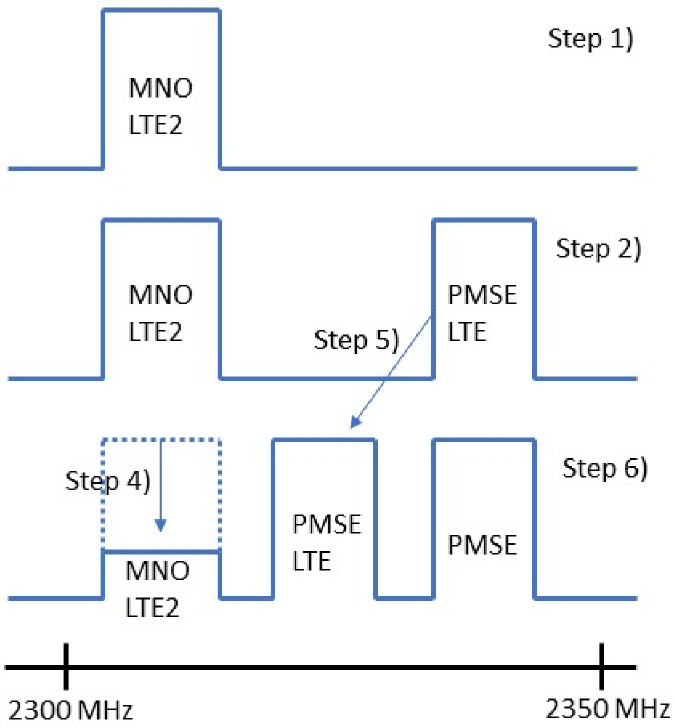

Figure 59: 2.3 GHz spectrum use corresponding to trial steps

First the lowest priority LTE service, such as supplemental downlink of MNO LTE2, operates in the band. Then PMSE using rapidly deployable LTE air interface (PMSE LTE) requests for spectrum. At the same time, there is enough free spectrum for both to operate. Then the proprietary PMSE equipment requests for spectrum and the spectrum manager allocates suitable frequencies and power levels for all users. If necessary, MNO LTE2 adjusts the transmission power according to regulated interference limits to allow for the operation of higher priority users. Also, PMSE LTE that is controlled by spectrum manager via machine-to-machine interface switches frequency (for example due to limitations of proprietary PMSE equipment tuning range). Finally, all three networks operate on the shared spectrum as shown in the spectrum view from spectrum analyser in Figure 60.

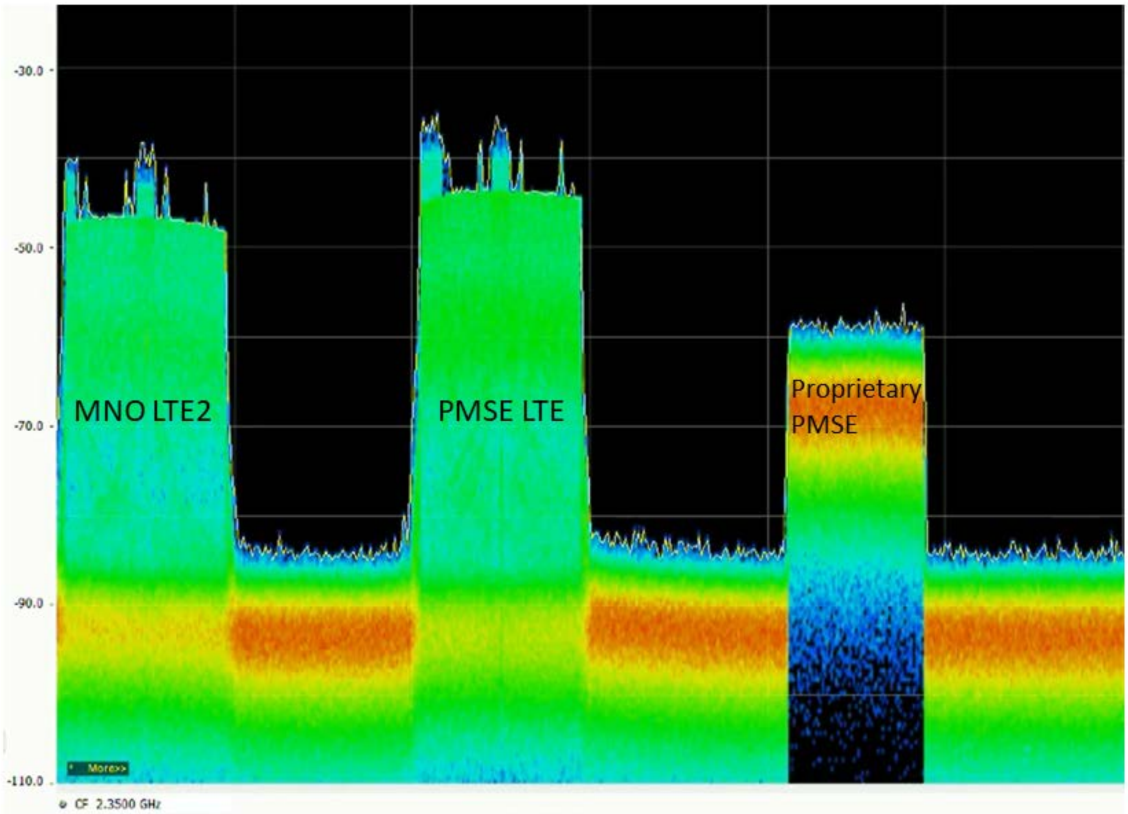

Figure 60: Spectrum view (2.3 GHz) after step 6

6.3.1.2 *Observations*

The trials indicated that the spectrum management using the tested equipment enables dynamic spectrum use in the frequency band. The spectrum manager allocates suitable frequencies for the LTE based equipment and follows the user priority order when spectrum is requested by the incumbent. In practice, there is some delay when changing the operation frequency of a base station when the RF components are restarted. During the trial, delays were in order of 10 seconds, but this value depends on the base station implementation and firmware version. Streaming live HD video over the PMSE LTE network works well, thus indicating possibility of using the network for PMSE purposes. Naturally, there is a period when video is stopped when the private LTE network is switching frequency. In real usage scenario for PMSE, however, it is not expected that the operating frequency of the systems would be constantly altered. As a conclusion, dynamic spectrum sharing between three users on the 2.3 GHz band was demonstrated illustrating a potential way for PMSE stakeholder equipment technology evolution towards LTE/5G solutions.

In the standard systems, the incumbents are heterogeneous, but the controlled devices (such as MNO LTE and PMSE LTE) are relatively unified. The demonstration shows that a dynamic spectrum management system can control simultaneously various types of devices and they may have differing capabilities and restrictions in spectrum use. MNO and PMSE LTE can technologically rather flexibly adapt to power level, center frequency, and bandwidth control. If MNO represents a geographically larger MNO network, only the power level of the base stations should be by default controlled by the Spectrum

Manager, as altering for example the center frequency of one base station would potentially require some setup in the network side as well. The effect of such operation could be a topic for further studies.

6.3.1.3 *Field proving the setup*

The trial setup was further taken to a field trial as part of larger measurement campaign. The measurements were performed in rural area of Turku archipelago. The setup consisted of 700 MHz LTE serving as a backhaul to mainland, and a local dynamic spectrum use 2.3 GHz network was set up on an island using the Fairspectrum spectrum manager. The use case for such network was considered PPDR (Public Protection and Disaster Relief) where the network will be rapidly set up for the responders in an event of an accident in a rural area with limited connectivity otherwise. The setup is illustrated in Figure 61. Measurements in action are shown in Figure 62. The setup was proven operational in realistic environment.

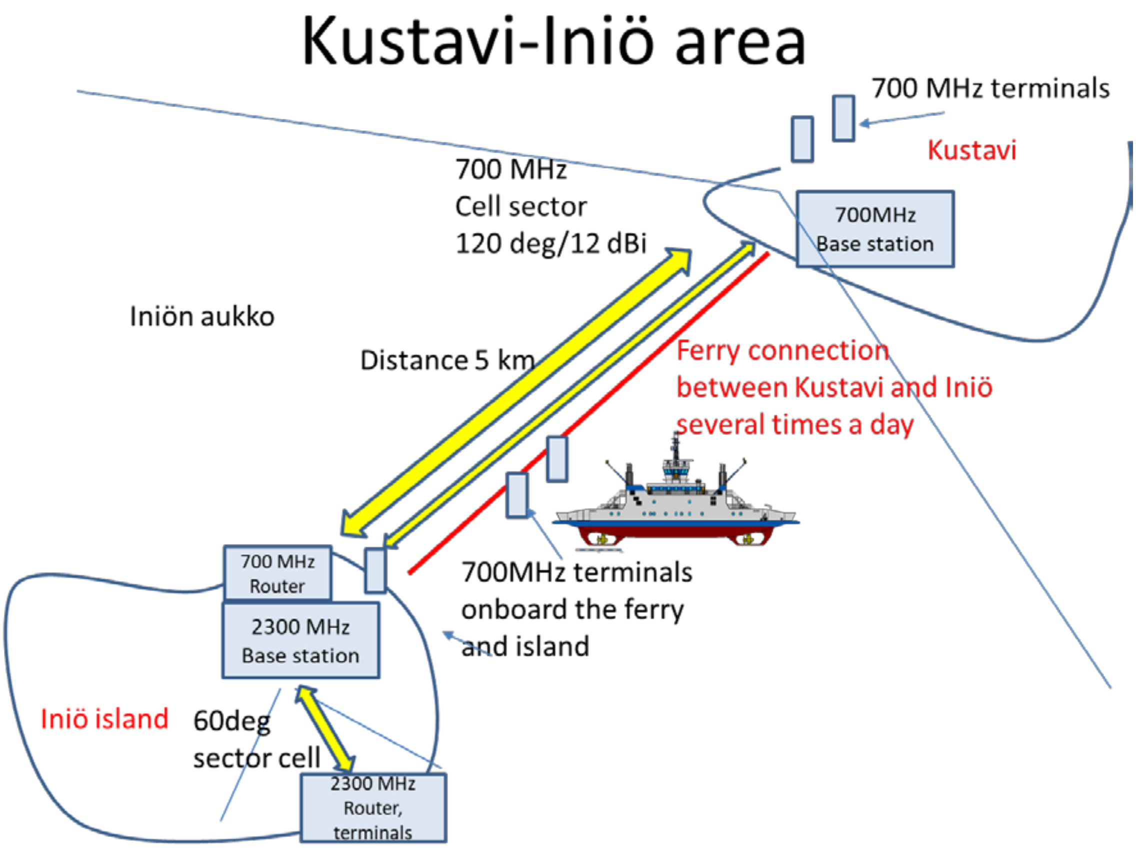

Figure 61: High level schema for the trial

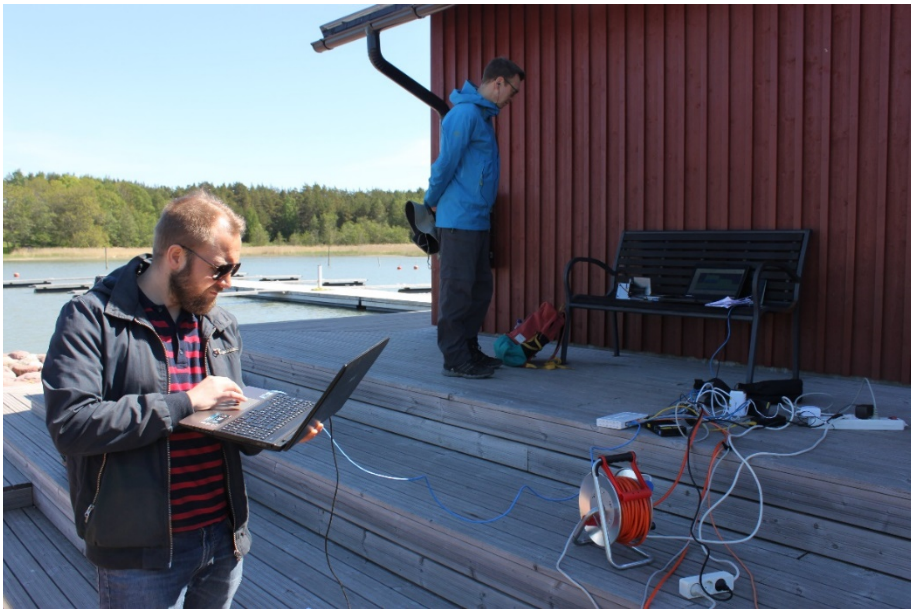

Figure 62: Controlling the basestations on the field trials

6.3.1.4 Dynamic priority order trials with 2.3 GHz band

A demonstration system was implemented to present mechanisms for implementation of a sharing agreement between different user groups [17], depicted in Figure 63. NRA (National Regulatory Authority) has a user interface to control the priority order between the user groups locally, regionally, nationally, and temporally. The setup is rather similar to the PMSE trial. MNO (Mobile Network Operator) and PPDR are demonstrated with off-the-shelf Nokia 2.3 GHz eNodeBs and MIL (Military) with Program Making and Special Events (PMSE) wireless camera using DVB-T physical layer for transmission. The PMSE camera is manually operated, and it connects to the Spectrum Manager through a similar reservation system, which is used by the Radio Administration of the Netherlands [18]. The spectrum resource in the LTE TDD 3GPP band 42 (2300-2400 MHz) is managed by a Spectrum Manager. The demonstration uses two discrete 10 MHz channels, which are 2320-2330 MHz and 2330-2340 MHz. If all three user groups want to use the spectrum simultaneously, two highest priority ones get a 10 MHz channel, and the lowest priority one does not get a permission to transmit.

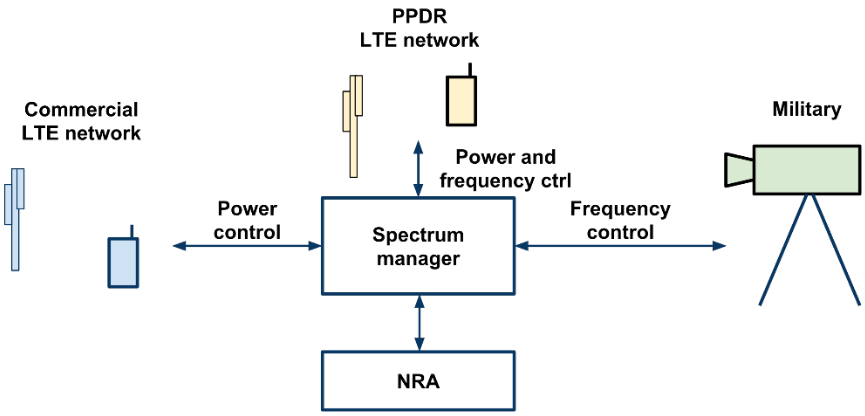

Figure 63: The demonstration setup

Analyses of scenarios above led to the notional concept of changing the roles of user groups, and that such changes could have temporal and regional variation as depicted in Figure 63. With three user groups and three priority levels there are 6 states, when all users groups have a different priority level. In case two or more user groups have the same priority level, there are further states in the system. For simplicity, Figure 64 shows only three different priority orders and the changes between them. The tested concept incorporates changing the priority order. In LSA terminology, each spectrum user can be an incumbent or a licensee[19]. The status as an incumbent or a licensee depends on the temporal and local or regional priority order, which is determined by the alert level of the society. In the shared legacy military or public safety bands, military and public safety may relinquish the protection requirements to allow commercial operations in the specified parts of spectrum in peace time. On the shared bands, which are allocated to commercial operators, the protection requirements are relinquished in times of disaster recovery or homeland defense to allow military or public safety operations in the specified parts of spectrum. Through active, trusted operations of a dynamic spectrum management system, military or public safety authorities can be assigned access to spectrum in times and in locations as the scenario requires. Commercial operators can be assigned access to spectrum in peace time. The communication between the spectrum users is dynamic and automatized as far as possible. Commercial systems can implement dynamic changes in spectrum access in operationally relevant timeframes for military and public safety use (i.e., in minutes or at maximum in hours). Military and public safety systems are allowed more time to enforce changes in spectrum access, e.g., hours or days.

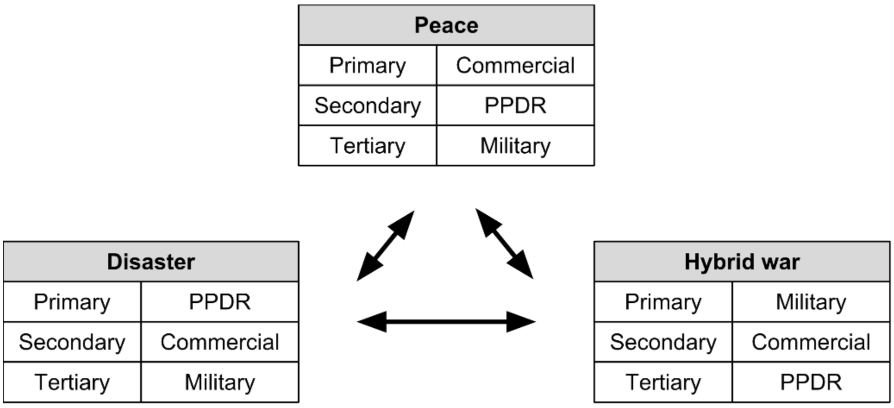

Figure 64: Concept of changing access rights of different user communities in different scenarios.

The protocols for the communication between the Spectrum Manager and spectrum users are simplified from the ETSI LSA specification [6] using https protocol. In the case that the communication is initiated by the Spectrum Manager (Notification procedures), an intermediate connectivity layer is needed, just like in email app in the mobile phone. In this study, WebSocket was used. TCP/IP is carried over the physical and Medium Access Control (MAC) layers. Between TCP/IP and HTTPS there is a WebSocket in the Notification procedure communication. The LSA-1 protocol is encapsulated in JSON messages and carried over HTTPS.

A spectrum manager can generally control the permission to transmit, transmit power, transmitter center frequency, nominal bandwidth, and in the future, antenna patterns of the devices. The control capabilities may be limited by the sharing arrangement. For example, the original TVWS geolocation database in US was able to change the center frequency but not the power nor the bandwidth. The original LSA is able to control the power level, but not to change the center frequency or bandwidth. The commercial operating environment may also limit the management choices. Considering the demonstration system here, we assume that the spectrum is shared between a MNO, PPDR, and military. The MNO has most likely been assigned the band through an auction or a beauty contest, and the MNO uses the full capacity of the band, when possible. It is not likely that the MNO would change the center frequency to a band of another MNO. The MNO network forms a large area coverage, and we assume here that the PPDR/MIL use is local or regional. Changing the bandwidth and center frequency even within the MNO assigned band, would probably cause unexpected errors at the border of LSA limited network area and unaffected parts of the MNO network. The MNO networks are wide area networks, where each basestation of a MNO has the same center frequency. If a single basestation or a small group of basestations of the MNO wide area network have a different center frequency, the mobile UEs would experience an untypical change in the traditional mobile network coverage. Due to this, at the moment we assume, that the MNO base station control is limited to permission to transmit and maximum allowed power level. PPDR and military are considered here as local networks, and they may have sharing agreements with all operators, whereby the control of PPDR/MIL networks may include also the center frequency and bandwidth changes.

We evaluated the spectrum management controls individually for each user group. Our system consisted of a mixed use of controls, and we evaluated the experiences gained during testing and demonstrations. Furthermore, applied spectrum prioritizations were verified by spectrum measurements using a spectrum analyzer. During the demonstrations, we operated the priorities through the implemented NRA UI. The possibility for local, regional, national, and temporary priority changes was incorporated to the NRA UI as well as to the Spectrum Manager. The key novelty of the system is that the changing priorities were tested with various state changes. These state changes included various arrival sequences and priority orders starting either from an unoccupied spectrum state or from a pre-occupied spectrum. During the demonstration, we monitored the radio signals with a spectrum analyzer, as illustrated in Figure 65.

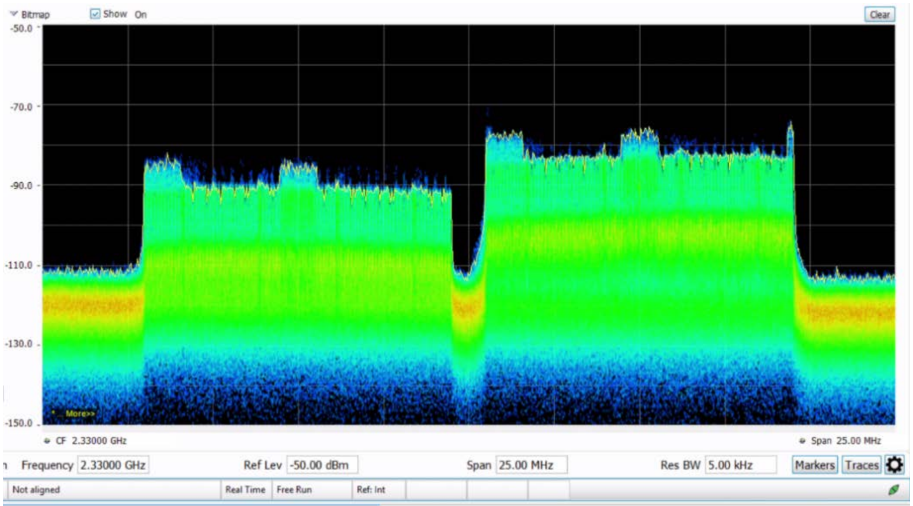

Figure 65: Spectrum analyzer view of MNO (left signal) and PPDR (right signal) transmitting

The priority order changes illustrated in Figure 64 were tested in the demonstration. The conceptual schematic depicting the demonstration is presented in Figure 66 and which is broken down to use cases, valid priority order, arrivals and spectrum occupancy. For simplicity, we present the highest priority order changes only from commercial MNO to MIL and from MIL to PPDR. In the first case the MNO arrives first, and they are allocated the lower one of the two available spectrum blocks. Next arrives PPDR, and they get the higher spectrum block. Last comes MIL, having the lowest priority. As there is no capacity available for MIL, the access to spectrum is denied. In the second case, MIL has the highest priority. The order of arrival is the same as in the previous case. MNO and PPDR get their spectrum blocks. When MIL with the highest priority arrives, MNO allocation is cleared, and MIL gets the lower spectrum block. The third case continues from the end state of the second case. MNO priority is increased to be higher than that of MIL. Consequently, MIL use is cleared, and the lower spectrum block is allocated to MNO.

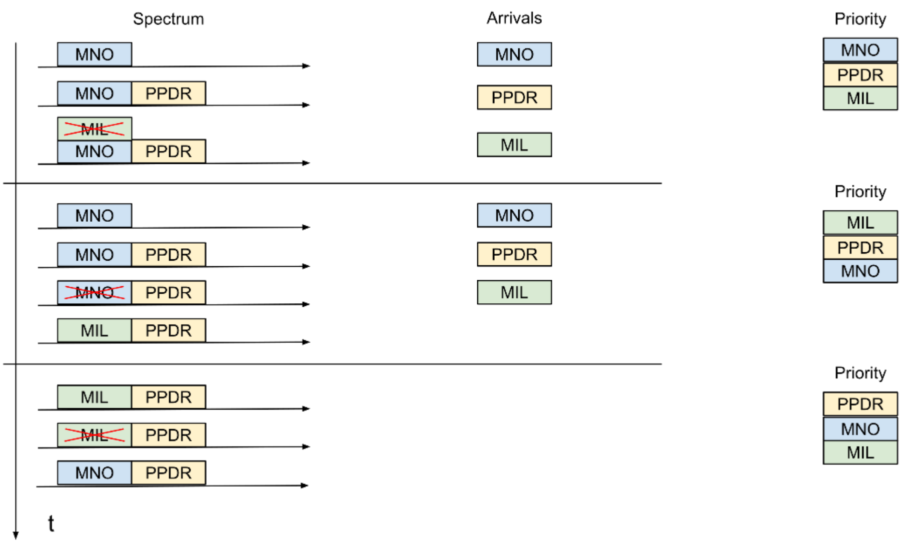

Figure 66: Changes in the demonstration spectrum use

6.3.1.5 *Results*

The main spectrum management controls are the transmit power, and its special case of permission to transmit, transmitter center frequency, and the nominal bandwidth of the transmitter in the demonstration. The MNO center frequency cannot be changed to another operator's frequency block and the change of center frequency within the operator's band would also cause deterioration of the mobility service. Narrowing the bandwidth could in theory be possible, but most likely it would cause unexpected behavior in the network and should be avoided. Thereby we assumed that wide area MNO networks are only controlled by transmission power by the Spectrum Manager. The center frequency and bandwidth changes of MIL and PPDR are not as restricted as they are in the MNO networks. The mapping of the spectrum management controls and user groups are summarized in Table 5.

Table 5: Mapping spectrum management controls and user groups

Control	MNO	PPDR	MIL
Power level	Possible	Possible	Possible
Center frequency	Restricted	Possible	Possible
Bandwidth	Restricted	Possible	Possible

In the standard dynamic spectrum management, the controlled devices, such as White Space Devices (WSD), LSA Licensee, and Citizen's Broadband Radio Device (CBSD), are homogenous, and they have the same controls available. On the other hand, the systems employed by priority users are heterogenous, and the way how the protection requirements are derived from the priority users varies a lot. The main reason for this is that the incumbents are considered legacy systems. The secondary devices are new, and the same capabilities can be required from them. When the controlled secondary systems are legacy systems, a possibility for heterogenous controls are required. In this demonstration system, we have shown that a plurality of control mechanisms for secondary systems can co-exist and their capabilities can be defined in the rules and algorithms of the Spectrum Manager.

We demonstrated the feasibility to use priority profiles to implement a spectrum management system with changing priorities. The stakeholders of the sharing arrangement negotiate the possibility for priority changes, related spectrum ranges, and the authority to initiate the priority change in advance. By default, the mandate for priority changes is associated with the NRA, but it may also be given to the PPDR organizations. The PPDR has pre-defined rescue plans for a wide range of catastrophes. The plans may include area definitions and rescue times. Both areas and time periods can be included in the priority profiles or they can be left to be defined at the time of need. When a spectrum priority profile is taken into use, it defines the priority of different user groups, the frequency range, geographic area, and the period for the priority profile to be active. A country may have several priority profiles active simultaneously, and the profiles should also have a mutual priority order.

In this study, we developed a UI for NRA to create, manage, and operate the priority changes in a dynamic spectrum management system. The UI has a map interface to define the areas, as illustrated in Figure 67. Separately defined region or municipality areas can also be used. The location definitions can be named and stored for later use. The spectrum priority order and the frequency range are stored and named. Finally, a period with begin and end time (or permanently) are bound together with the area, frequency range, and priority order definitions. The defined and active priority orders are presented as a list where the position in the list defines the priority order between the priority profiles.

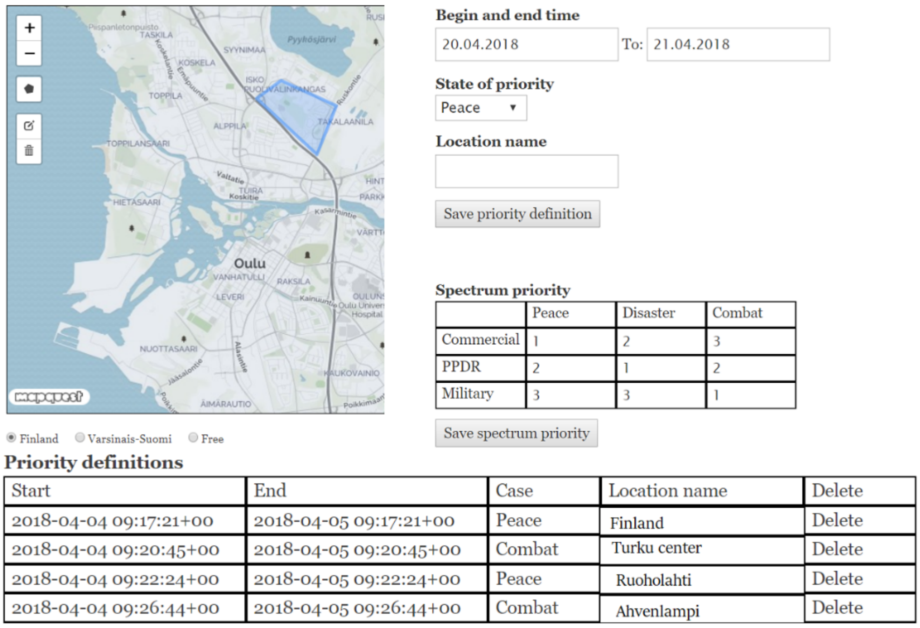

Figure 67: User Interface of the NRA to control changing priorities

7 Public Warning Service: Demonstrators

7.1 Demonstrator: Multimedia Public Warning

The Multimedia Public Warning system demonstrates how dynamic spectrum management can support multimedia messaging in public warnings . Dynamic spectrum management, multi-link and broadcast technologies are integrated to send public warning multimedia alerts to the user equipment. The schematic of the demonstrator is shown in Figure 68.

The system contains public LTE connectivity and a private LTE network to demonstrate the performance improvement by integrated multilink, broadcast and dynamic spectrum management. In the demonstration, a private LTE network is taken into use before sending a multimedia public warning. The additional capacity of the private LTE network is used for broadcasting the multimedia data to supported devices. Multilink technology brings even more unicast data transmission capacity for multimedia public warning so that capable devices can receive a higher quality or larger media content, such as video alerts showing the incident or evacuation instructions etc..

The trigger for the PW alert is sent to the UE using unicast either in the created private LTE or public LTE network. The UE fetches the multimedia components with eMBMS when the UE supports eMBMS. The devices without eMBMS capability fall back, depending on the availability, to 4G unicast or WiFi. Wifi and LTE are bonded by multilink.

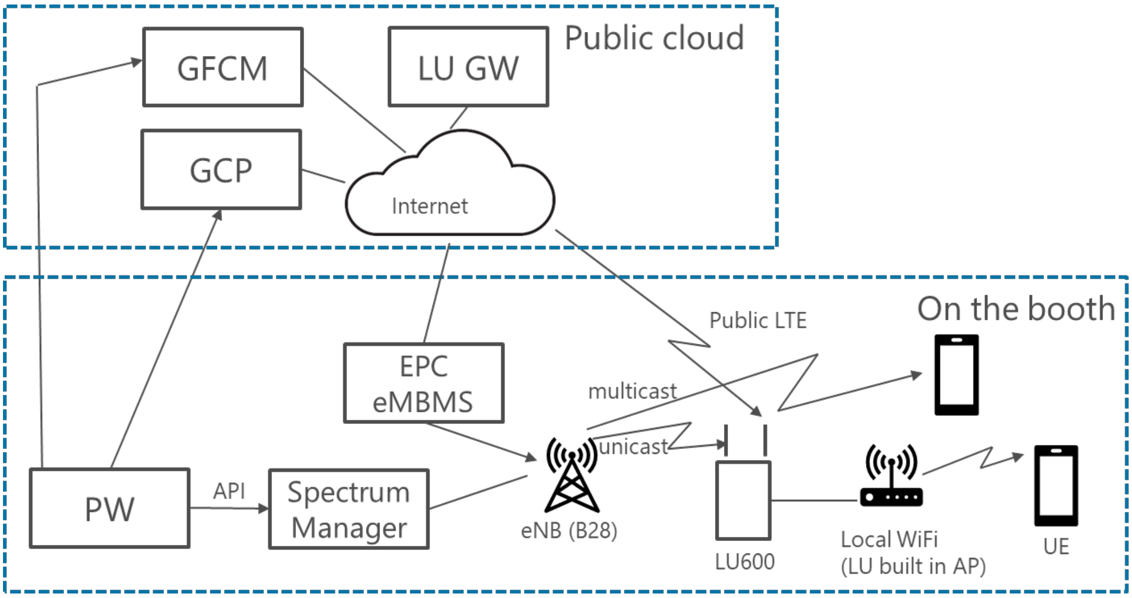

Figure 68: Multimedia public warning demonstrator

The spectrum management system creates an LTE channel in the 700 MHz band (B28). The content is by default sent to broadcast capable devices over eMBMS and to devices without broadcast support by unicast. Multilink enhances the public LTE connection by bonding it with the unicast capacity of the created private LTE network.

The system consists of a UE, eNodeB, Evolved Packet Core (EPC), eMBMS components (BM-SC and MBMS-GW), Public warning message generation and a Spectrum manager (SM). The User Plane and Control Plane traffic are routed from eNB to EPC. The SM operates in the Management Plane independent of EPC. As there is no OEM for network management, the SM communicates directly with eNB using a vendorspecific protocol in this pilot. In this demo the multilink local gateway is done via an LU600 databridge, capable of serving multiple local devices. It is then connected to the local Wifi to which the UE is connected. The LU-GW resides in the cloud and provides multilink gateway and routing function for multiple databridges and UEs. The network connections of equipment are visualized in Figure 70. Panasonic ToughBook PC is used for both spectrum analyzer and eNB commissioning.

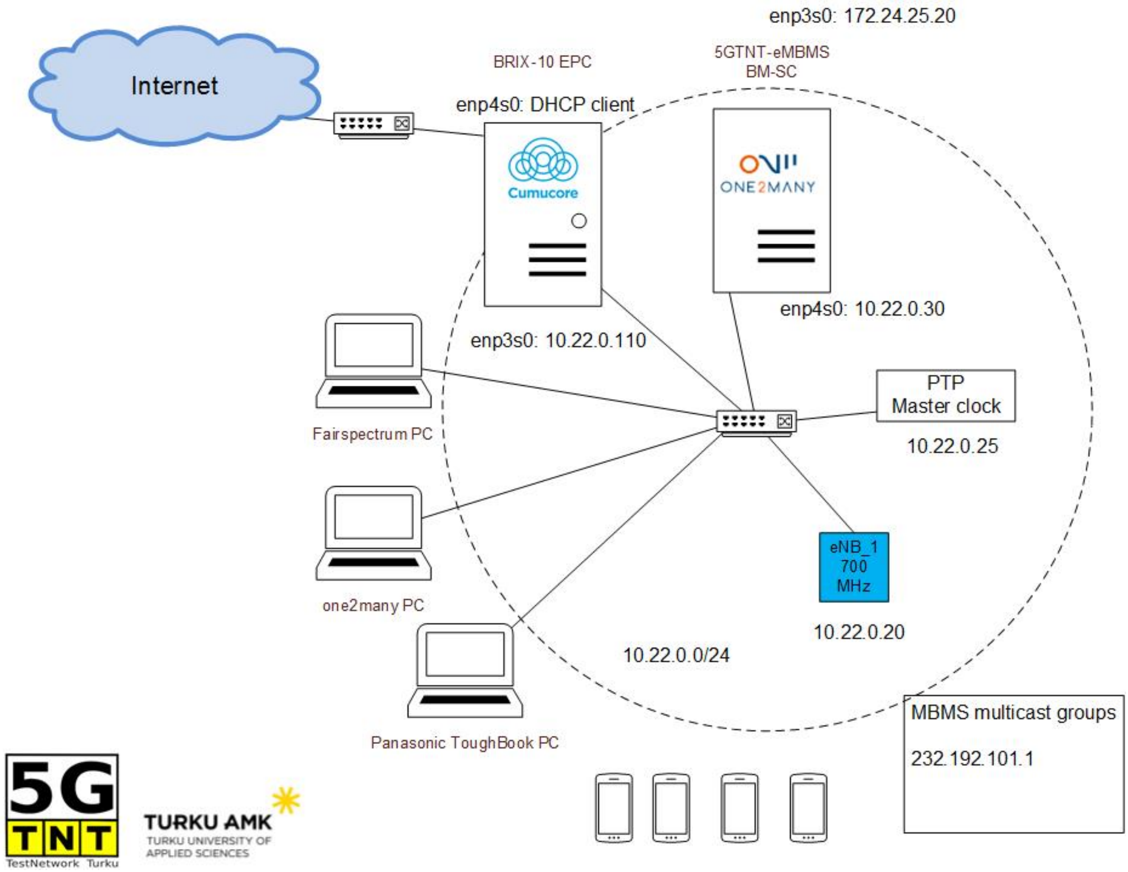

Figure 69: Connectivity of the demonstrator setup

The verified demonstration system presents a mechanism to transmit multimedia public warning messages over several networks to achieve maximum capacity and reliability.

More information about this Demonstrator is contained in D6.9 [12].

7.2 Demonstrator: Spectrum Management

The spectrum management demonstrator system consists of PMSE equipment operating occasionally in the 2.3 GHz band and an MNO LTE network operating in the 700 MHz and 2.3 GHz bands. The latter one represents MNO employing additional capacity in the 2.3 GHz band using, for example, carrier aggregation. Proprietary PMSE equipment represents an OFDM based digital data link for wireless cameras operating in the band. PMSE LTE is a rapidly deployable LTE network, which can be used for PMSE purposes. Different EPCs (Evolved Packet Cores) are used for the MNO LTE and PMSE LTE networks. EPC2 is a limited feature core used for the private PMSE LTE network. It includes only the necessary components for data transmission enabling rapid deployment when combined with a base station.

The spectrum manager controls the radio frequency use of the different systems in the shared 2.3 GHz band. PMSE system information is collected with a web-based reservation system. The users of the devices make reservations for their intended use. The reservation system has been piloted and deployed in radio administration of the Netherlands in 2017-2018 and 2019, respectively. The control of the PMSE devices is carried out through the reservation system so that the user of the devices is informed about the required spectrum use changes with an email, and the user has to deploy the respective configuration changes in the devices. Both PMSE LTE and MNO LTE systems have a direct machine-to-machine interface between the radio equipment and the spectrum manager. When the priority user changes the configuration of the LTE network, a notification about the change is automatically received in the spectrum manager. The spectrum manager processes the changed spectrum situation and evaluates if the lower priority use may cause harmful interference to the higher priority use. If there is a risk of interference, the spectrum manager evaluates which changes are required to accommodate the higher priority use and to maintain the best possible service level for the lower priority use. The service level optimization is implemented so that if there are frequency channels available, the lower priority use is transferred to those channels. If there are no other channels available, the power level of the secondary user is ecreased, or the transmission is denied. In this demonstration, the higher priority user is able to select the frequency channel to be used. An option for this could be that the higher priority user has the right to the spectrum resource in the band, but the specific frequency channel is determined by the spectrum manager. The setup in the laboratory is shown in Figure 70.

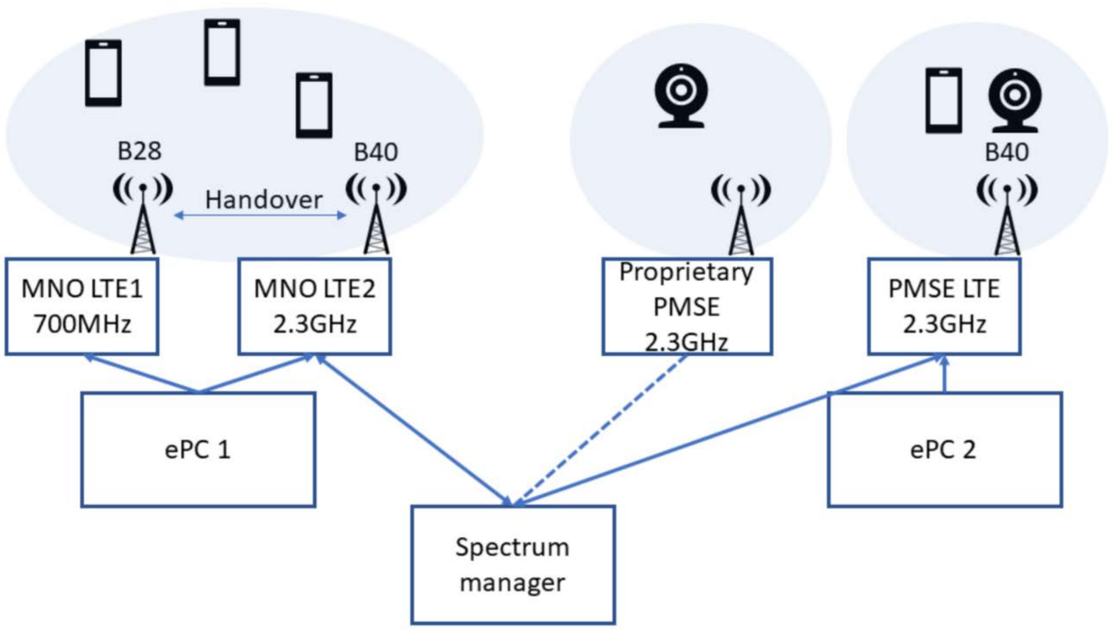

Figure 70: EUCNC18 Spectrum management demonstration

More information about this Demonstrator is contained in D6.8 [20].

8 Conclusions

5G-Xcast has been able to prove the advantages of including multicast/broadcast components in future 5G releases by means of trials and demonstrators. The lack of multicast/broadcast capabilities in the 5GS has not been an impediment for such purpose given the possibility to integrate the latest commercial equipment and software components coming from the partners of the project with a prominent commercial position as well as the ability to integrate some of the first proof-of-concept prototypes developed in the technical work packages of 5G-Xcast.

The trials and demonstrators have mainly focused on the validation of media and entertainment use cases and public warning as two of the most suitable verticals to benefit from multicast/broadcast functionalities.

In summary, the main conclusions linked to the use cases tested under WP6 are:

- Hybrid Broadcast Service
    - The assessment of QoE at the user equipment for video traffic delivered in broadcast mode requires a close attention to the mapping between the traditional BLER 1% threshold used for unicast as the CNR thresholds may become insufficient to provide acceptable QoS. The measurements conducted by IRT and BBC demonstrate a high difference between simulations and laboratory measurements.

    - Regarding data rate, there is a clear benefit for using broadcast to deliver media content as the network load will increase massively in cells allocating a high number of users. The possibility of using standalone networks for provisioning broadcast services or the use of MooD (or an equivalent unicast to broadcast switching mode in 5G) in MNO networks should be considered.

    - The use of multicast/broadcast as internal network optimization bring the opportunity to use unmodified applications that already exist for unicast, therefore minimizing the impact for service provides, developers and users. This is an advance over current systems such as eMBMS that require MBMS-aware applications and extensive service specific configuration. The approach taken in one of the 5G-Xcast demos uses the existing unicast interface with content service providers and is applicable to both fixed and mobile networks.

    - System-level simulations using 5G-NR demonstrates that unicast-only delivery consumes more resources compared to multicast-only cases for all investigated MCS indexes. In addition, the resource consumption is higher in multilink case compared to multicast case at the same MCS indexes, since there is additional PTP links in multilink case. Therefore, for multilink to be favourable against multicast in terms of resource consumption and not to cause network congestion, in multilink case, higher MCS index and possibly lower multilink switching threshold need to be chosen. It can be concluded that in terms of spectral efficiency, multicast scales better than multilink and multilink can potentially bring benefits for low density of UEs.

    - The use of multi-link becomes beneficial in order to guarantee a high degree of availability and the possibility to extend coverage e.g. to indoor environments with poor 5G connectivity and the ability to aggregate content coming from different networks.

- Object-Based Broadcasting
  - The results of the trial shows that when multicast and unicast are being used the service bitrate remains relatively constant, whilst when only unicast is used the bit rate increases at a linear rate. This supports the hypothesis that delivering some carefully chosen content over MC can offer substantial savings with regard to network load.

- Public Warning
  - The trials verified that it is possible to configure a delivery mechanism to transmit multimedia public warning messages over several networks to achieve maximum capacity, coverage and reliability launching multimedia messages with alerts in a timely manner.

  - The trials indicated that the spectrum management using the tested equipment enables dynamic spectrum use in the frequency band. The spectrum manager allocates suitable frequencies for the LTE based equipment and follows the user priority order when spectrum is requested by the incumbent.

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