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

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Test-Beds Integration and Deployment

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Abstract

This document presents the planning and development process for test-beds and trials within 5G-Xcast project to experimentally demonstrate point-to-multipoint transmission capabilities in future 5G networks.

Keywords

5G, test-beds, trials, development, integration

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Executive Summary

This document concentrates on the planning and development process for testbeds and trials within 5G-Xcast project. The trials have been planned to experimentally demonstrate multicast and broadcast features developed for dynamically adaptable future 5G network architecture, leveraging on the development of three test-beds, including two urban city test-beds: IRT/Nokia in Munich (Germany), 5G Innovation Centre (5GIC) in Surrey (UK), and TUAS in Turku (Finland).

Focusing on two use case verticals, i.e., Media and Entertainment and Public Warning, following trials are implemented in the three test-beds:

Hybrid Broadcasting Service trials are conducted in the Munich test-bed, including the incorporating components from project partners, e.g., simultaneous delivery of linear TV and on-demand content, multi-network connectivity and seamless transition between networks, and dynamic allocation of unicast/multicast according to traffic demand.

Object Based Broadcasting trials are implemented in the Surrey test-bed in the 5GIC in the University of Surrey, consisting of media objects delivered via a mixture of multicast and unicast.

Public Warning trials are conducted in the Turku test-bed, incorporating broadcast transmission of multimedia public warning messages. Spectrum trials are also carried out in the Turku test-bed, focusing on flexible spectrum allocation mechanisms and their evolution towards 5G.

The development of the test-beds is elaborated in this document, as an essential part of the roadmap towards the integration of the trials and the demonstration of the corresponding use cases on the test-bed. Elements such as Dynamic Adaptive Streaming over HTTP streaming, Multilink and MBMS Operation On-Demand are to be implemented in the Munich test-bed for the trials of Hybrid Broadcast Service. Object Based Broadcasting elements such as Dynamic Adaptive Streaming over Multicast are being added to the Surrey test-bed and the necessary components for the Public Warning and the Spectrum Manager are being implemented in the TUAS test-bed.

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List of Acronyms and Abbreviations

3G	3rd Generation
4G	4th Generation
5G	5th Generation
5G-PPP	5G Public-Private Partnership
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 Centre
BTS	Base Transceiver Station
BW	Bandwidth
CA	Carrier Aggregation
CC	Cluster Controller
CM	Cluster Member
CDN	Content Delivery Network
COTS	Commercial Off the Shelf
CP	Cyclic Prefix
DASH	Dynamic Adaptive Streaming over HTTP
DASM	Dynamic Adaptive Streaming over Multicast
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 Tunnelling Protocol
GW	Gateway
HD	High Definition
HDR	High Dynamic Range
HFR	High Frame Rate
HTTP	Hypertext Transfer Protocol
HW	Hardware
ILS	Internet Link Service
IMS	IP Media Subsystem
IoT	Internet of Things
IP	Internet Protocol
ISD	Inter-Site Distance

KPI	Key Performance Indicator
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	Multi-access 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
M&E	Media and Entertainment
NAS	Non-Access Stratum
NB-IoT	Narrowband IoT
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
PTM	Point-to-Multipoint
PTP	Point-to-Point
PW	Public Warning
PWS	Public Warning System
QCI	QoS Class Identifier
QoE	Quality of Experience
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	Synchronisation
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
WAN	Wide Area Network
WiFi	Wireless Fidelity
WRR	Weighted Round Robin

1 Introduction

The 5th Generation Public-Private Partnership (5G-PPP) phase-II project 5G-Xcast aims to design point-to-multipoint (PTM) capabilities for 5G as built-in delivery features, integrating point-to-point (PTP) and PTM modes under one common framework and enabling a dynamic use of PTM to optimise network and spectrum efficiency. The emphasis of the 5G-Xcast project is on the development of test-beds and technology demonstrators as expected for the phase-II of 5G-PPP. In the deliverable D6.2 “Development of Showcases and Demonstrators”, we present the development of the demonstrators, focusing on the use case verticals to be demonstrated: Media and Entertainment (M&E) and Public Warning (PW).

This document presents the trials developed within the 5G-Xcast project. A trial is equivalent to a demonstrator but implemented in a test-bed and may include a field test with an on-air signal and the capability to interact with commercially available equipment such as smartphones, tablets etc. A trial is usually testing of the new solution for a limited period of time. The aims of the trials in this project are: i) to illustrate the benefits of the 5G-Xcast project from a user perspective; ii) to validate the research results obtained iii) to provide feedback for use cases requirements and key performance indicators (KPIs) validation and for system design and optimization based on the tests performed; vi) to serve as a benchmark for comparing 5G-Xcast performance with existing technologies such as enhanced Multimedia Broadcast Multicast Service (eMBMS) in existing network deployment and reception conditions.

In order to cover relevant future 5G scenarios, trials are planned for three representative demonstration use cases: M&E hybrid broadcast service, M&E object-based broadcasting and PW messages. The trials are to be conducted in three test-beds: Institut für Rundfunktechnik (IRT) in Munich (Germany), 5G Innovation Centre (5GIC) in Surrey (UK) and Turku University of Applied Sciences (TUAS) in Turku (Finland), as briefly shown in Figure 1. This document also presents the development process of these test-beds.

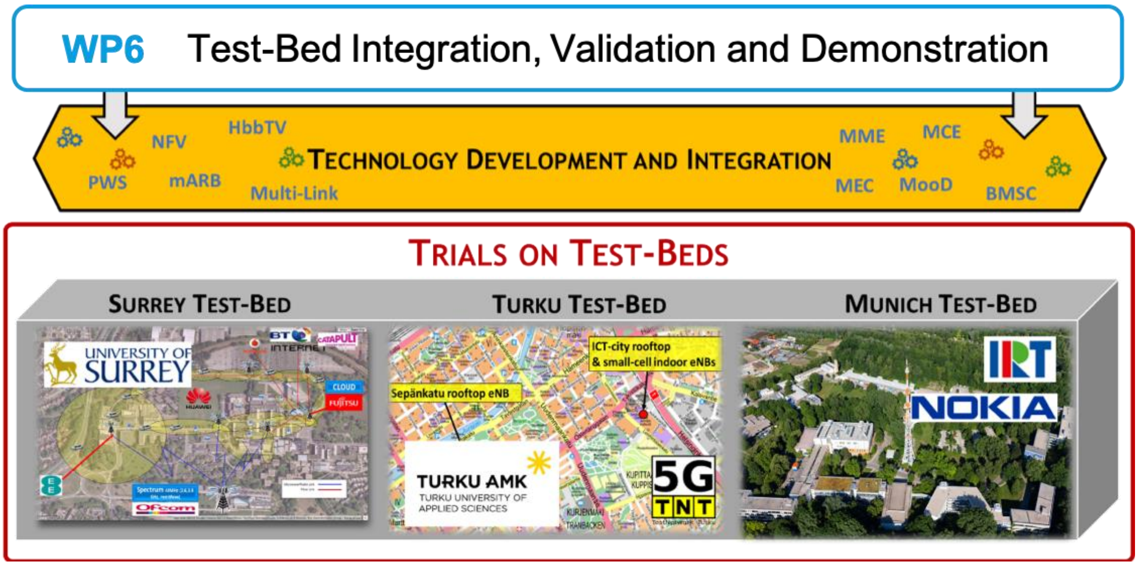

Figure 1. WP6 Scope: 5G-Xcast Test-bed Integration, Validation and Demonstration.

2 Overview of Test-beds

A number of existing facilities for experimental purposes have been created in the recent years to test technologies for several of the application areas currently envisaged for 5G. In order to allow rapid demonstrations of the 5G-Xcast technologies, the project are using the aforementioned three existing 5G test-beds. All test-beds incorporate fixed network capabilities, so that convergence scenarios between mobile, broadcast and fixed networks can be tested. An overview of the test-beds is provided in the following sections. More details can be found in Annex A.1.

2.1 Munich Test-bed

The Munich test-bed facilities provided by IRT and Nokia implement Long-Term Evolution (LTE) eMBMS release 9 with additional functionalities of release 10. A base station serving four sites via remote radio heads (RRH) ensuring synchronisation for Single Frequency Network (SFN) is operated in the surrounding of Munich, covering a wide part of its urban area as well as a significant area which is rurally shaped. The inter-site distances are in the range between 1.8 and 19.8 km, that permits investigating and testing of the various combination of signals either constructive aggregation as well as inter-symbol interference in Multicast Broadcast Single Frequency Network (MBSFN) with cyclic prefix (CP) 16.67 us. The sites are operated in LTE band 28 (706 to 716 MHz uplink, 761 to 771 MHz downlink). The transmit power of the network is 400 W EIRP per site/antenna.

Additional information of the Munich test-bed is provided in Annex A.1, including the test-bed architecture overview, network topology, optical transport network, frequency planning, radio network, core network, content playout, and testing devices.

2.2 Surrey Test-bed

5GIC regards an extensive fibre network as an essential component of 5G networks, where its existing campus-wide 5G testbed based on the University of Surrey in UK is being further developed to allow 5G technology demonstration and proof of concept of emerging PTM technologies. This revolutionises the potential to increase mobile broadband services, speed, capacity and coverage while using the same networks to connect large numbers of mobile users or devices who are interested in consuming broadcast/multicast contents and support new object-based media services which require flexible usage of time-frequency resources and guaranteed latency.

Currently conducting World-wide researches and innovations on software defined network (SDN), network functions virtualisation (NFV) and multi-access edge computing (MEC), the Surrey test-bed brings its radio access network (RAN) the flexibility to offer outdoor and indoor services and develops a fully virtualised and componentised network sliced architecture, to support mainly LTE-Advanced (LTE-A) at present and meet the requirements of 5G New Radio (NR) as well as broadcast/multicast specifications. More specifically, the outdoor RAN, covering dense urban, urban, rural and motorway, consists of three macro cells equipped 8T8R (eight-branch transmit and eight-brand receive) remote radio units/active-antenna-system-enabled RRHs along with 38 small cells with cloud baseband processing unit functions with programmable basebands, while the indoor RAN contains 6 LTE-A small cells and dozens of Wi-Fi access points. For the core network, 5GIC has designed its own fully-featured virtualised evolved packet core with 5G Flat Distributed Cloud (FDC) components [17], e.g., cluster member (CM) and cluster controller (CC). The 5GIC FDC solution operates as dynamic ‘Clusters of Infrastructure” which can be dynamically re-arranged horizontally by topology/user population load and vertically by network slicing according to user contexts. The architecture involves network entities that can be scaled in and scale out due to virtualised implementation, as well as a simple association-based control plane, separated from user plane which gives faster access, better performance and simple, stakeholder based scalable security. The network is context aware, thus enables changing connection point and service and slice provision dynamically by user context, within radio constraints. The FDC core is also capable of selecting Internet/Intranet breakout point and re-direct traffic according to context and content/applications requested by the users. Among the key innovation is the realisation of a control plane node where a non-access stratum (NAS) control plane is integrated with common control signalling (i.e., control plane plus user plane control). This expedited and integrated signalling allows context awareness, and full control plane and user plane separation. Such an approach improves the access speed and quality of experience (QoE), offering a high flexibility and capability to rapidly slice to suit user demographics. More details on the architecture overview, radio network, core network, FDC, network topology, frequency planning and testing devices are available in Annex A.2.

2.3 Turku Test-bed

The Turku test-bed (5GTNT – 5G Test Network Turku) focuses on spectrum below 6 GHz. Currently 700 MHz, 2.3 GHz and 3.4-3.8 GHz bands are supported for LTE.. The test network sites are in TUAS campus area in Turku, Finland. The testbed is an integral part of 5G Test Network Finland (5GTNF) environment. 5G Test Network Finland (www.5gtnf.fi) coordinates the integration of Finnish 5G testbeds. Current testbeds are located in Turku, Espoo, Tampere, Oulu and Ylivieska. Fibre connections to all other 5GTNF sites are available.

In addition to the cellular systems the testbed incorporates technologies such as Digital Terrestrial Television (DTT) broadcast network, Industrial radio modems, TV White Space radios, Narrowband Internet of Thing (NB-IoT) and LoRa Wide Area Network (WAN). Further, a spectrum observatory network has built in a GlobalRF Spectrum Opportunity Assessment project in WIFIUS program, which was jointly funded by the NSF in the US and Tekes in Finland. The project built an international network of Radio Frequency (RF) spectrum observatories continuously collecting long-term spectrum data to study the trends in spectrum utilisation and to identify frequency bands where spectrum sharing could be feasible. More information of the Turku test-bed is available in Annex A.3, where the test-bed developing roadmap, supporting technologies, frequency use plan, testing network and equipment are introduced.

3 Trials in Test-Beds and Technology Enablers

The target of the trials is to prove that the concepts developed for 5G in the project are valid. In addition to proving the validity, trials may point out issues that should be enhanced in the future to enable certain functionalities and better resource utilisation.

3.1 Hybrid Broadcast Service – Munich Test-Bed

Several functionalities in the scope of the Hybrid Broadcast Service use case are to be implemented in the Munich testbed. Corresponding field trials will evaluate the provision of multi-network connectivity based on the Multilink paradigm; and the provision of eMBMS operation on-demand according to user consumption, thus, exploiting the 3GPP MBMS operation on Demand (MooD) concept.

3.1.1 Multi-network connectivity and seamless transition between networks

Multi-connectivity supports simultaneous connectivity and aggregation across different technologies such as 5G, LTE, and unlicensed technologies such as IEEE 802.11 (Wi-Fi) to provide optimal user experience (e.g. high bandwidth, network coverage, reliable mobility).

The planned trial is to explore the scenarios in which high bandwidth is required (e.g. for high quality media delivery) or where service continuity needs to be ensured when a user connects to multiple networks or switches between networks. 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 User Equipment (UE) has access to Wi-Fi coverage.

These strategies require the implementation of a ML-GW (Multilink Gateway) to reroute the data packets through the different available links, and a ML-MW (Multilink middleware) which performs the adequate data merger operation at the UE.

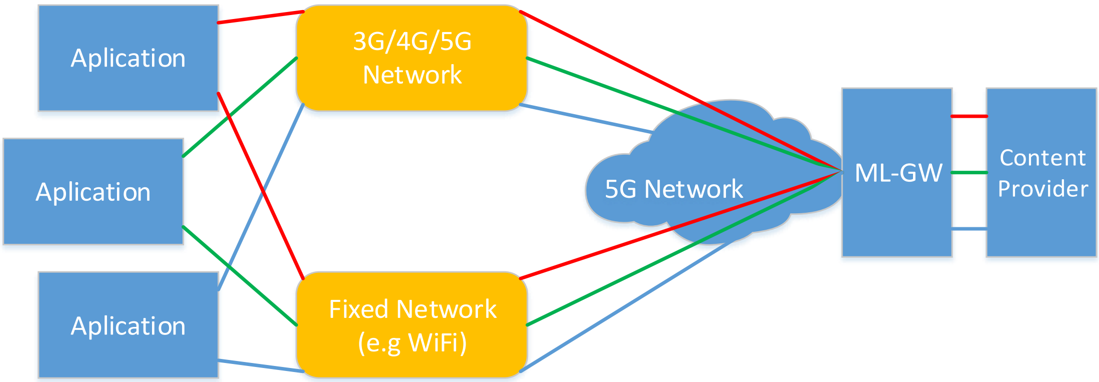

Figure 2. 5G Architecture with Multilink

The concept to be demonstrated is based on “Bonding” or “Aggregation”: This approach treats all available links as a single virtual broadband link and split all the content between all available links dynamically according to the performance of each of the links and the total available throughput (“goodput”).

Multi-link aggregation is currently implemented for unicast streams, bringing together distinct unicast connections to support a stream. A set of tests can be performed in order to extend the concept to multicast and/or broadcast transmissions with the following scenarios:

- Bonding of a cellular network link with another link of the same operator.
- Bonding of a cellular network link of one operator with a WiFi network link of another operator.
- Bonding of a cellular network link of one operator with a cable, xDSL or satellite IP link of another operator.
- Bonding of eMBMS session traffic with additional unicast traffic via cellular carrier
- Bonding of eMBMS session traffic with additional WiFi network link.

3.1.2 Seamless allocation of unicast/multicast traffic according to demand

Seamless allocation of resources between unicast and multicast traffic is enabled by MooD. 3GPP MooD permits the dynamic establishment of MBMS User Services according to actual consumption, in order to offload unicast content delivery and to efficiently use network resources when the traffic volume exceeds a certain threshold.

Figure 3 shows the 3GPP MooD solution architecture, especially for DASH content.

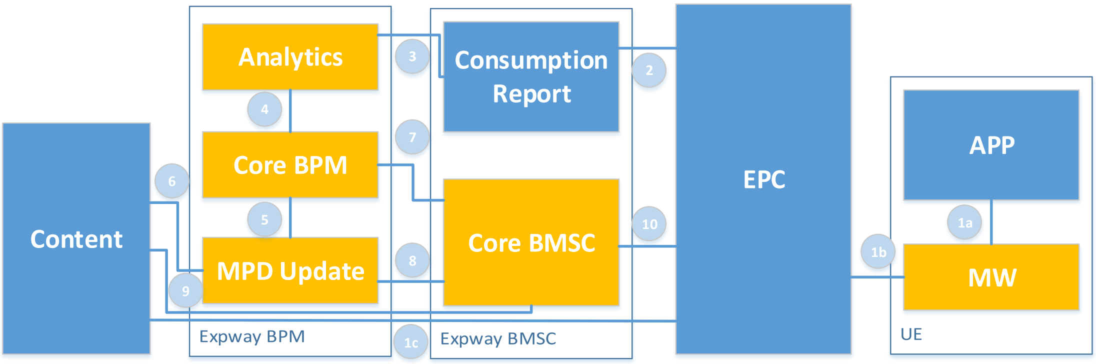

Figure 3. MooD solution architecture

The trial shows the benefits of MooD operation in the Munich test-bed. For such purpose a series of network functions should be deployed in the test-bed. The final implementation should be capable of operating in the following way:

The UE is equipped with a MW that periodically delivers Consumption Reports to the network, which analyses the statistics about content consumption. A decision is taken whether the transmission should be switched to eMBMS due to popularity or remain as unicast. The manifest for DASH content is updated according to the decision to add multicast or unicast profiles. If multicast is enabled, the BM-SC starts delivering content over eMBMS.

3.2 Object based broadcasting – Surrey Test-bed

Object based broadcasting (OBB), has been proposed and developed to offer flexible, interactive and customised entertainment experiences to each audience member. As shown in Figure 4, while linear, scheduled programs continue as in the traditional broadcast, the content in OBB can be delivered in a form that is capable of being adapted in a way that responds to the audience member, their time and context, the devices they are using, and even the preferences of the individual viewer.

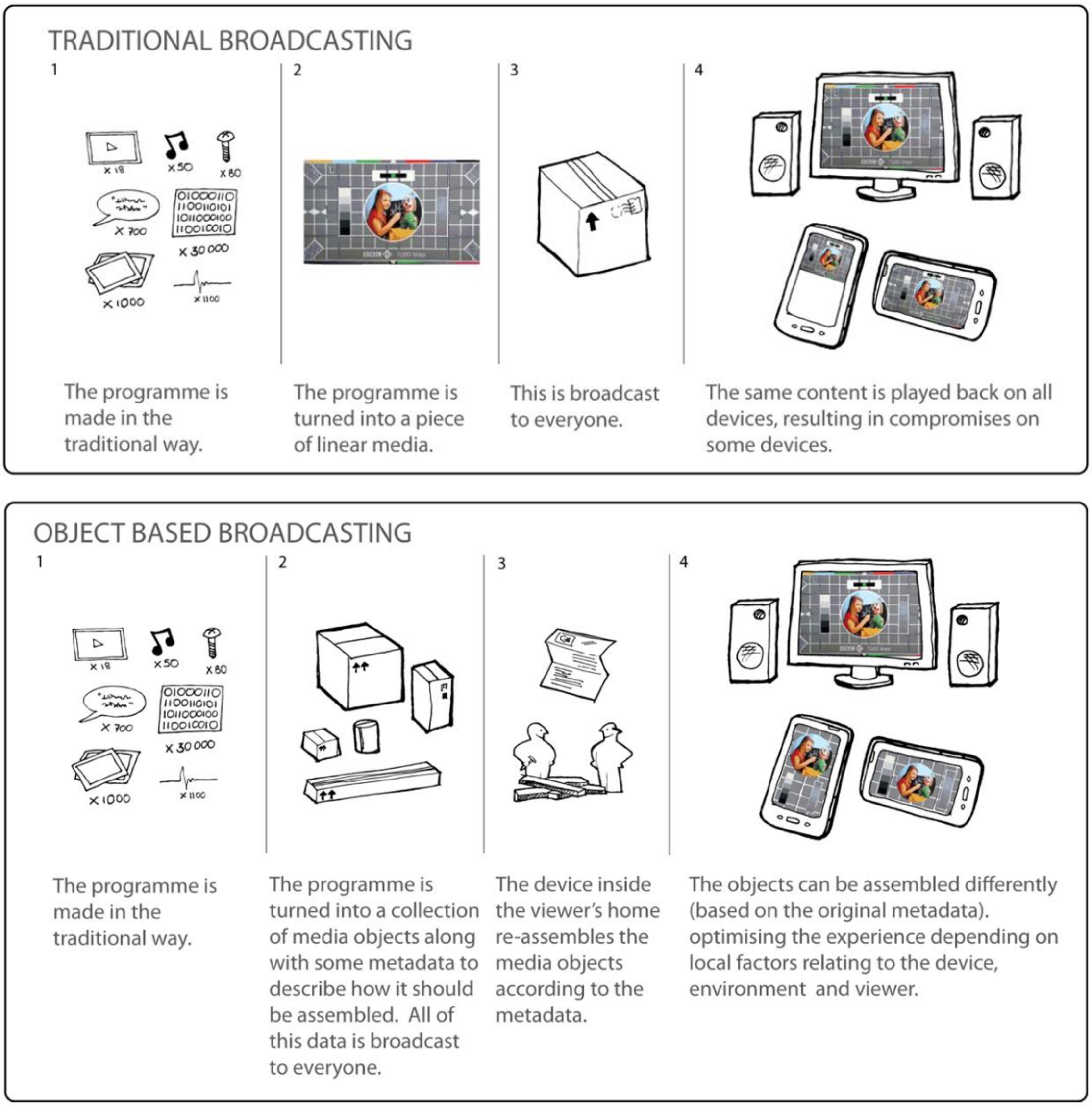

Figure 4. Traditional broadcast vs OOB

The OBB trials are based on the Dynamic Adaptive Streaming over Multicast (DASM) work developed by the BBC R&D team. The details of the DASM system are given in the deliverable D6.2 "Development of Showcases and Demonstrators".

Leveraging on the enabling functionalities in the Surrey test-bed, e.g., SDN, NFV and MEC, the intention of the OBB trial is to add flexibility and ability to the network in order to deliver the object-based media content. For example, PTM can be used to deliver commonly used and bandwidth-heavy objects to the edge to overcome scarcity of resources in the network. This could either be to a MEC node to overcome bandwidth limitations within the core or directly to the handset to reduce the use of radio resources. Meanwhile, more bespoke, personalised or less bandwidth-expensive objects can be delivered over unicast. The concepts developed within the content delivery framework can then be used to bring these different objects together in a seamless manner for the user.

3.3 Public warning -Turku Test-Bed

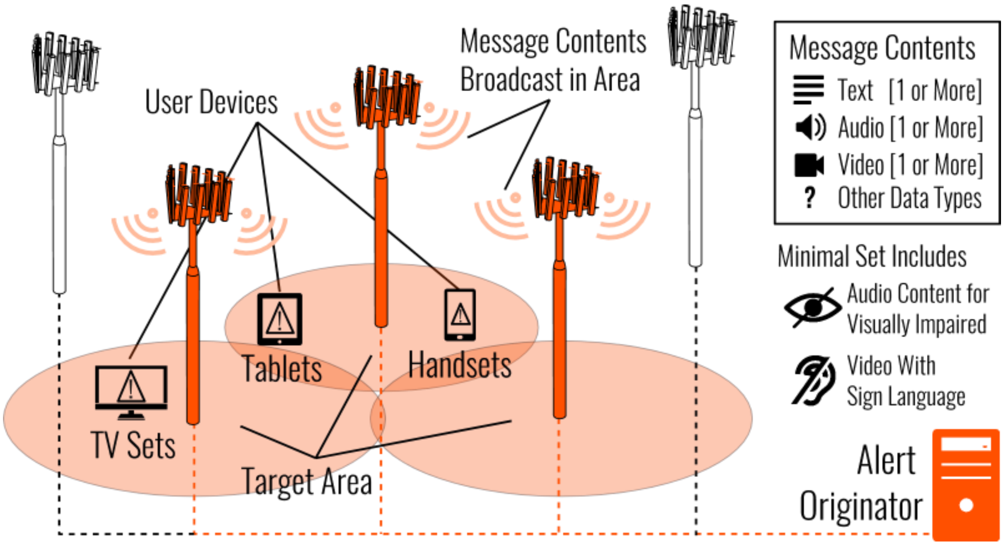

Figure 5. Public warning use case description

The public warning trials (as illustrated in Figure 5) aim at demonstrating both Amber alert and multimedia public warning alert use cases. The trials and demonstrations will be performed in the Turku test-bed described in section A.3. 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 versions of sending the public warning information would not have the 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 transmission and UE sides created by One2Many.The planned features to be trialled during the project are:

- Delivery of alert messages with multimedia content such as:
  - map of affected area
  - a picture of lost/kidnapped child
  - location of shelter on map
  - general instructions on things to do during a disaster
- Delivery of alerts for users with hearing and vision deficiencies
- Successful delivery of alert in various reception conditions (indoor, outdoor, mobile)
- Transmission of message in relevant area (i.e. not necessarily to all the cells of the network)
- Combination of public warning with multilink and spectrum sharing (proof-of-concept described in D6.2)

Content to be used in demonstrations

- The use case for the main trial is planned in cooperation with the Port Authority of Turku
  - The scenario considered is leak of dangerous chemicals, for which content is obtained from the port authority
- Video clips for instructions (File size TBD, repetition interval TBD)
  - Required bitrate depends basically on the file size and repetition interval

    - For the demonstration purposes short clips can be generated
- Pictures & Text
- Maps

3.4 Spectrum utilisation -Turku Test-Bed

The objective of the trials is to illustrate benefits and possibilities of dynamic spectrum utilisation between different actors in a flexible manner. The main intention is to show that the actor with highest priority can have access to spectrum when required and the ones with lower priority release the resources. The main technology enabling the spectrum trials is the spectrum manager from Fairspectrum.

Available spectrum bands considered for the trials are 2.3 GHz and the 5G candidate bands 700 MHz and 3.5 GHz. In the 2.3 GHz band the trials will focus on PMSE as the primary user, and mobile network as the secondary. For 700 MHz and 3.5 GHz the plan is to trial spectrum band sharing between PPDR, Military, and MNO with dynamic priority order, depending on the scenario. For example, PPDR would have priority in the case of an emergency. For 700 MHz also DTT can be considered.

Content to be used for demonstrations

No specific requirement regarding the content to be used for the demonstrations is foreseen. For example, in the first demonstration live streaming from the cellular phone was used. For visualising the spectrum utilisation, the content itself is not of primary importance. For the combined public warning, multilink and spectrum sharing demonstration, the same content as for the public warning trials is considered (port accident related).

4 Test-beds Development

4.1 Test-Bed Development Roadmap

Figure 6 summarises the WP6 development roadmap. Two independent phases are identified. The same figure also addresses the planned standardisation roadmap in 3GPP, as well as the targeted showcase, demonstrators and events as presented in the deliverable D6.2. In addition to the overall WP6 planning phase, WP6 phase1 covered both planning and development tasks to commit the initial 5G-Xcast trials. In phase2, the evolution to advanced trials has been carried out, towards advanced and final 5G-Xcast trials and demos.

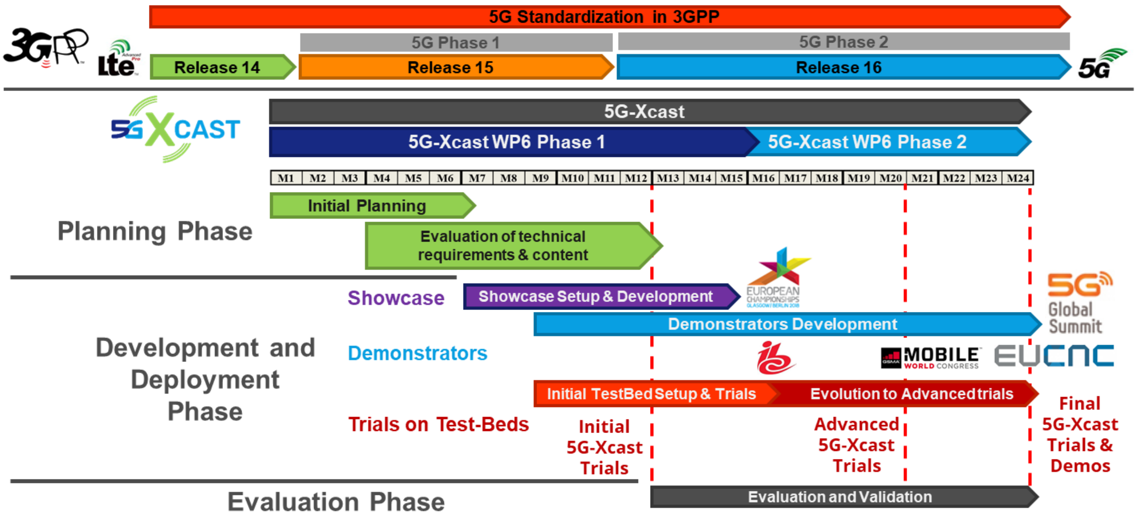

Figure 6. WP6 Development Roadmap

In the following sections, the development process of three test-beds aiming for the trial deployment are presented.

4.2 Developments on Munich Test-Bed

The Munich test-bed already implements LTE-A MBMS technology with a distribution network consisting of four sites Funkhaus, Freimann, Unterföhring and Ismaning, ranging from Munich urban city centre to the rural northern area. The sites can be operated as a broadcast SFN with ISDs ranging from 1.8 km to nearly 19 km. A complete description of the test-bed architecture and available equipment and is provided in Annex A.1.

The test-bed is planned to be evolved in two convergent directions in the scope of the Hybrid Broadcast Service to integrate Multi-Link and MooD. An overview of the roadmap for the development and integration of these functionalities is explained next. As a reference point, the architecture of the current test-bed is shown in Figure 7.

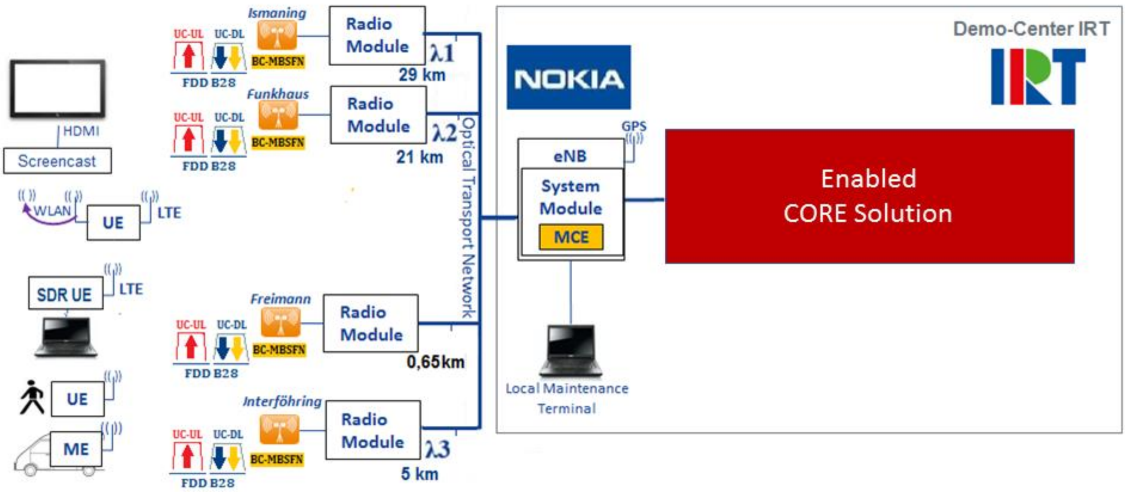

Figure 7. Munich Test-Bed Architecture

4.2.1 Integration of Multi-Link

Multilink is planned to be integrated in the test-bed via a LiveU unit that would permit traffic bonding at IP layer in the following main steps:

1. Evaluating in real time and continuously the changing application-level performance of each of the links (e.g. “goodput”, latency, jittery behaviour etc.) in each of the relevant directions (uplink, downlink)
2. Evaluate the total available “goodput” at each point in time
3. Split the ongoing stream of content-to-be-delivered on all available links according to the performance of each of them (i.e. not “overload” any of these links or WRR like mechanism)
4. Buffering. Buffer is necessary at the receiving side to accommodate out-of-order synch, missing packets retrieval etc.
5. Combining the split content into one common stream.
6. In some cases, where the content is for example live video, it is possible to add an integrated video encoding process which output a live encoded video stream that adaptively matches the momentary performance of the multiplicity of virtually bonded links. However, for 5G-Xcast this may be less relevant since while it’s more optimised, still this special way of live adaptive content encoding according to the actual performance of the links means that the content publisher has to implement this (which might complicate the business models), or the Telco/operator has to do it (which usually they are not involved in the application level).

Currently multi-link bonding is implemented for unicasts. The measurements of the performance of each of the links between the content starting point and end point (the bonding application running on the end user device) have different results over each of these links between users, so that a simplistic or naive multicast or broadcasts over a common set of links will not work in many cases. One of the challenges of the project is to see how a sophisticated non-naïve broadcast or multicast over multi-link can be achieved. With this, the 5G-Xcast solution can benefit not only from seamless transitions between broadcast, multicast and unicast with seamless experience but also from high-quality transmissions.

Here is a high-level description of the multi-link unicast architecture.

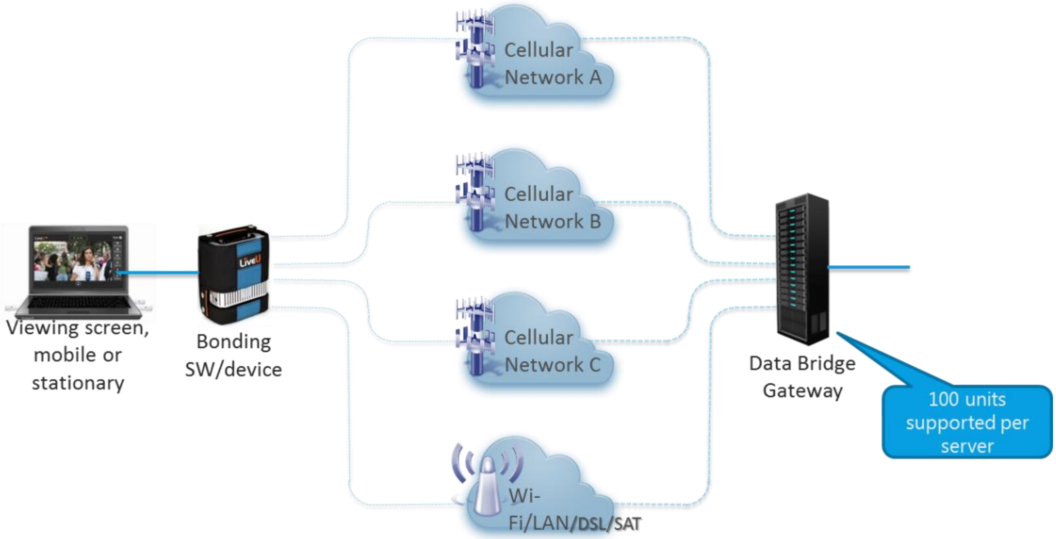

Figure 8. LiveU Multilink

The bonding device or SW at the viewing user side communicates with the bonding Gateway which is on the core network or even remotely, at the publisher or even the cloud. These two entities exchange information about the performance of each of the links. The content transmitted from the Gateway down to the viewing device is split over all available links, operators, technologies or IP routes according to their momentary performance. The content is then reassembled at the viewing device as a coherent data stream ready for viewing. In this architecture, the content itself is not manipulated in any way, i.e. the delivery is completely agnostic to the content. Hence complete seamlessness is achieved.

Typical transport level principals (LiveU)

- Bonding may be seen as a protocol that overlays UDP.
- The bonding encapsulates the packets in own protocol over UDP
- Usually there’s a back channel to report link performance such as latency to improve the transmitting side to utilise each of the available links at each point in time
- Both sides are time-synchronised
- Typically fault mechanisms are included such as types of FEC and retransmissions (limited)
- Buffer is added at the receiving side to accommodate out-of-order synch, missing packets retrieval etc. The size of the buffer may change, depending on links latencies and error-rates (e.g. satellite link has a relatively high latency which has to be accommodated)
- When delivering TCP-based traffic, the RTT and similar inherent problems of TCP over unstable and long-latency networks are addressed by mechanisms like UDP-termination, FEC/duplication, or others.

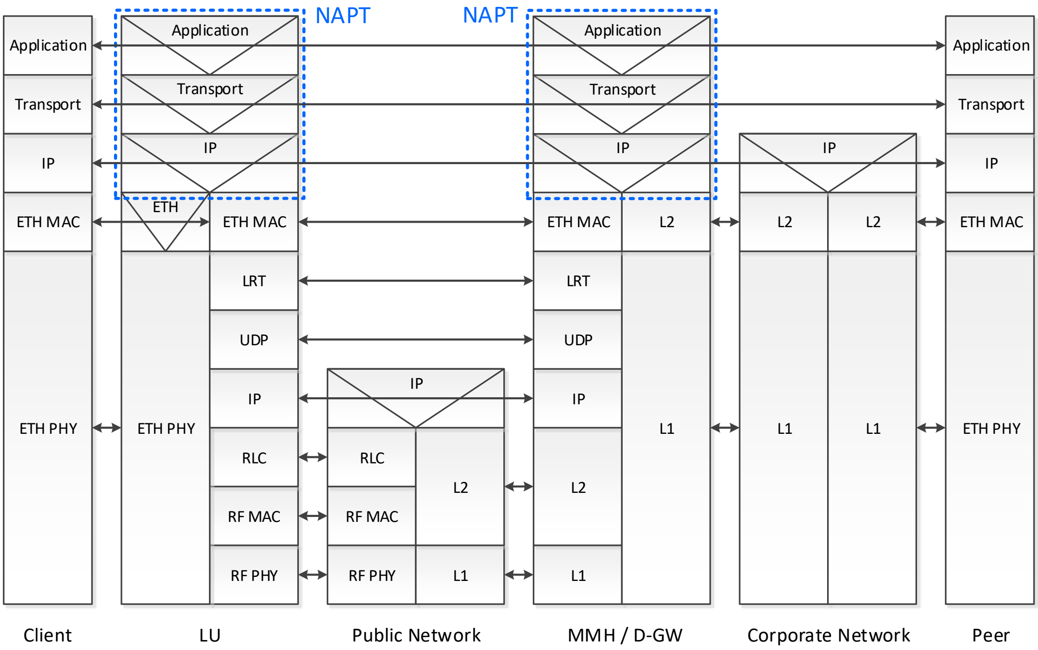

Figure 9. NAPT Based Solution Protocol Stack Diagram (ETH Interface)

Figure 10 represents the possible accommodation of a hybrid BC Multilink demonstrator into the Munich Test-bed facilities. The project aims to investigate the possibility of providing a unified test environment including MooD and Multilink solutions.

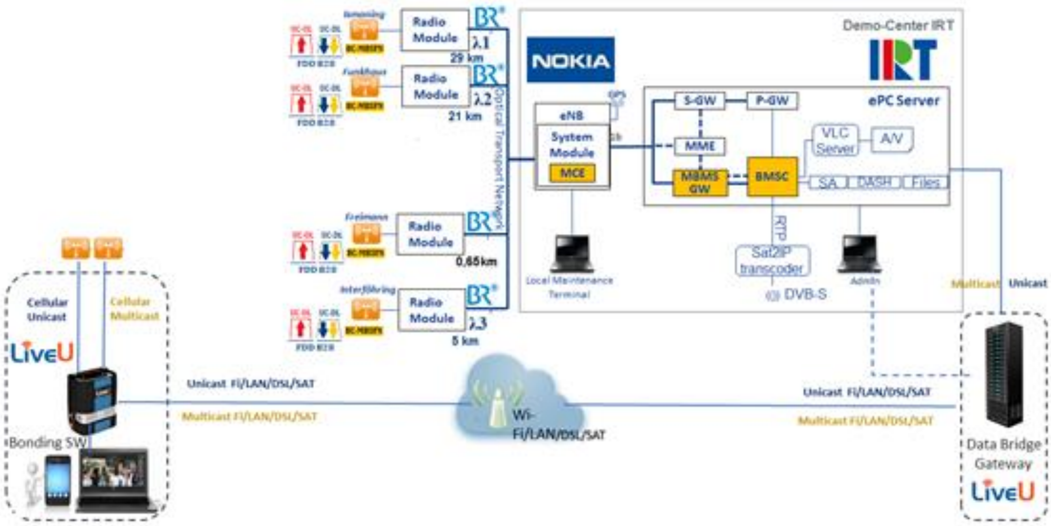

Figure 10. Munich Hybrid BB-BC Multilink Architecture

The first phase is to demonstrate the hybrid multilink unicast. Either multiple 5G modems or simulated modems, or 5G & LTE, or 5G and fixed network connectivity are combined. This shall be done at the application level. The impact of the demo is to adapt the multilink algorithms to the new 5G connections and the performance, such as latency, bandwidth and error rate.

The 2nd phase is to demonstrate the integration of hybrid/converged multilink including multicast/broadcast according to the architecture that is defined in WP4 and WP5 and the actual deployment of the relevant architectural functions in the Munich test-bed.

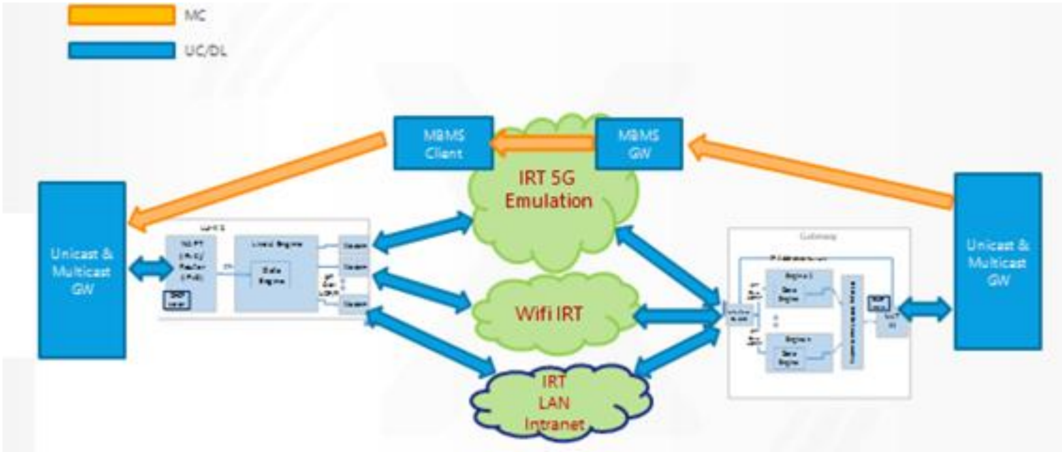

Figure 11. Munich Hybrid BB-BC Multilink Variant 1

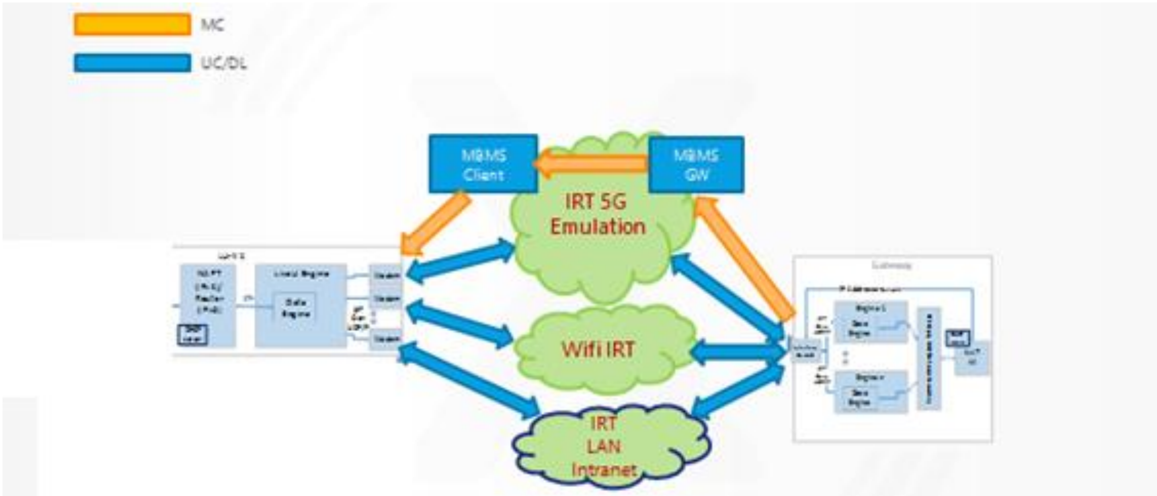

Figure 12. Munich Hybrid BB-BC Multilink Variant 2

4.2.2 Integration of 3GPP MooD

3GPP MooD is identified as a potential demonstrator in 5G-Xcast. Figure 13 provides a high-level overview of the current ExpWay MooD architecture.

In the operation of "MBMS operation on Demand", or 3GPP MooD, certain content that is initially delivered over the unicast network may be turned into an MBMS User Service, in order to efficiently use network resources when the traffic volume exceeds a certain threshold. The MBMS offloading may apply to unicast traffic carried over HTTP or RTP/RTSP. In the former case, the MBMS download delivery method is used, and in the latter, the MBMS streaming method based on RTP is used, for delivering the offloaded content.

Figure 13 represents the potential 3GPP MooD architecture integrated into the Munich large scale test-bed. The viability of such demonstrator is being further analysed.

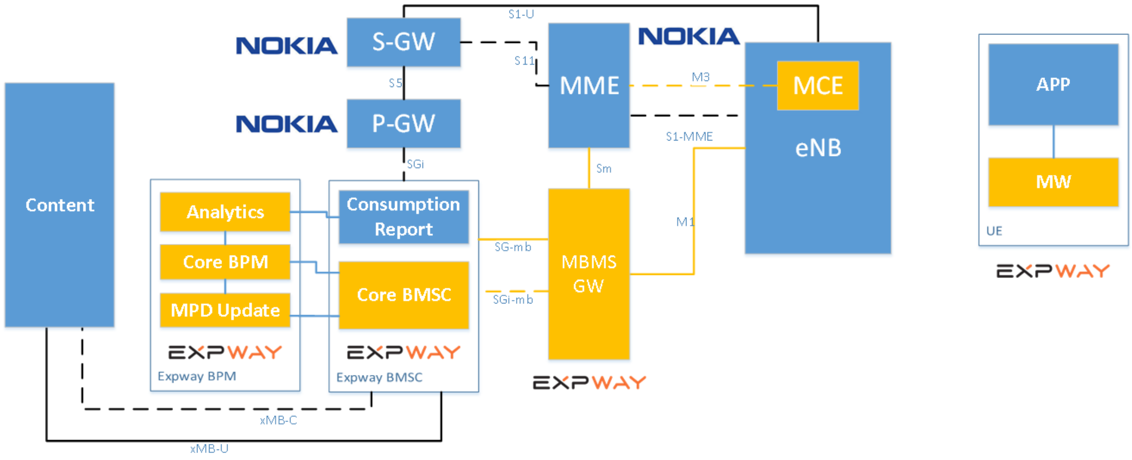

Figure 13. Munich Test-bed MBMS-MooD Architecture

4.2.3 Further eMBMS developments

Depending on the availability of the LTE Rel-14 eMBMS features in commercial Nokia SW releases within the time period of the 5G-Xcast project the Munich test-bed can be upgraded to support longer CP which is required to support MBSFNs with higher spectral efficiency in areas with large ISDs (e.g. 15 km or larger inter-site distance). The reduction of self-interference and improvement of coverage which is predicted in [15] could be practically verified with drive tests.

The Munich test-bed may also be upgraded to support SC-PTM (Single Cell – Point-to-Multipoint). The SC-PTM feature increases the efficiency of eMBMS in networks since it can be used to targeted group communication at cell level without SFN configuration. This is useful in a number of use cases, besides M&E, e.g. in critical communications as public safety. The availability of UEs with SC-PTM support would be essential to conduct drive tests.

4.3 Developments on Surrey test-bed

4.3.1 Additional features

In addition to the main components described in Section A.2, other components that currently available upon request or potentially available along with the Surrey test-bed are briefly introduced as following:

- **Software Defined Radio (SDR)**

Lime SDR: provided by Lime Microsystems, Lime SDR boards include MIMO Field Programmable RF (FPRF) transceiver, Altera Cyclone IV FPGA, 256 MB DDR2 SDRAM memory, USB 3.0 controller and oscillator at 30.72MHz, supporting continuous frequency range from 100kHz to 3.8GHz with bandwidth up to 61.44MHz, 6RX/4TX RF connection, 2x2 MIMO and up to 10 dBm power output. With micro USB power connector and 100mm x 60mm dimension, Lime SDR enables the portable demonstration.

Figure 14. Lime SDR v1.2s

NI-2944R (ER-USRP X310 + UBX x2): Universal software radio peripheral (USRP) provided by National Instruments, NI-2944R combines two extended bandwidth daughterboard slots covering DC to 6GHz with up to 160 MHz bandwidth, multiple interface options e.g., PCIe and Dual 1/10 GigE, and the user-programmable Kintex-7 FPGA. Portable demonstration functionality is available.

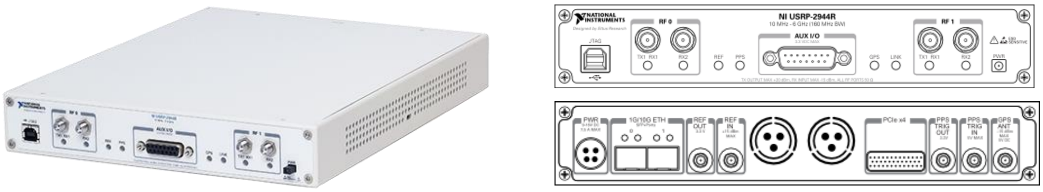

Figure 15. NI-2944R/ER-X310 Front/Rear Panel

- **eNodeB (eNB) and Evolved Packet Core (EPC)**

OAI eNB/EPC: provided by Eurecom, OpenAirInterface (OAI) soft eNB and EPC build an open-source software-based implementation platform, configured with LTE release 8.6 compliant, with a subset of release 10, FDD and TDD configurations in 5, 10, and 20 MHz bandwidth, transmission mode 1 (SISO), 2, 4, 5, and 6 (MIMO 2x2), as well as CQI/PMI reporting. Supporting both downlink and uplink channels are included: PSS, SSS, PBCH, PCFICH, PHICH, PDCCH, PDSCH, PMCH; PRACH, PUSCH, PUCCH, SRS, DRS. HARQ support (uplink and downlink) is available. For the E-UTRAN protocol stack, it implements the MAC, RLC, PDCP and RRC layers and supports protocol service for all Rel8 Channels and Rel10 eMBMS (MCH, MCCH, MTCH). MME, SGW, PGW and HSS implementations are available. OAI eNB/EPC are also compatible with Lime SDR and NI USRP.

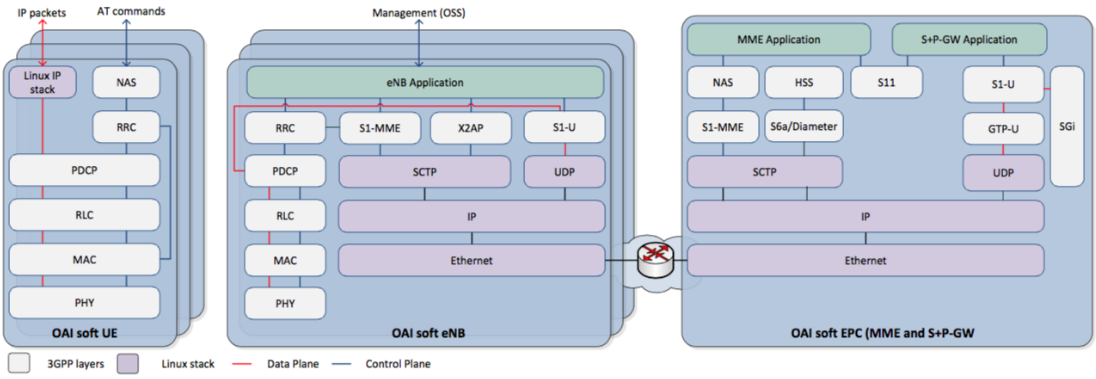

Figure 16. OpenAirInterface LTE software stack

Amarisoft eNB/EPC: potentially provided by Amarisoft, this LTE close-box solution is configured with LTE release 13 compliant, FDD and TDD configurations, tested bandwidths of 1.4, 3, 5, 10, 15 and 20MHz, transmission modes 1, 2 to 10 (MIMO 4×2), wideband CQI/PMI reports and HARQ support. 256QAM downlink support for PDSCH and MBMS in the physical layer, as well as MBMS support in protocol layer and network interface are available with Amarisoft eNB. For EPC, in addition to the MME, SGW, PGW and HSS implementations, MBMS GW is enabled with the user configurable list of service and multicast components, M2AP protocol support and built-in test RTP packet generator, as well as with generating one stream per service over the M1 interface (GTP + SYNC protocols). Amarisoft eNB/EPC also works with Lime SDR and NI USRP. Currently, the Amarisoft eNB is available.

- **Testing devices**

Available test terminals include Huawei Nexus 6P, Google Nexus 5P, Bittium tough mobiles. Android mobile devices are used for the object-based broadcasting trials.

4.3.2 Integration of Object Based Broadcast

In terms of the object based broadcast content for this trial, the use of broadcast or multicast lends itself to live, linear experiences (such as Forecaster) rather than variable-length experiences. We name this content "multicast source", and BBC R&D have an existing multicast source on the Internet with 2 video adaption sets and 1 audio adaption set. Each video adaption set has 5 representations.

Similar to current web page responsive design, the content can be tailored differently based on the requirements/device capabilities, such as in this trial, it can be rendered differently in the browser depending upon the aspect ratio of the browser window (which depends upon, for example, if a mobile device is in portrait or landscape). Multicast delivery to web browsers, however, is currently difficult and the use of proprietary browser extensions is no longer an option, since these technologies have been deprecated by browser vendors in favour of standards-based technologies such as W3C Service Workers which lack multicast support. Thus, this trial aims at a multicast end-to-end delivery, but the first phase is to use a DASM Client proxy (as described in section 3.2) with a unicast connection to the browser.

Relying on the 5GIC core network comprising MEC capabilities as mentioned in Section A.2.5, a first step is to deliver objects (in this case video/audio segments) over multicast across the Surrey test-bed from a BBC multicast source (DASM head end). As shown in Figure 17, the OBB trial takes the multicast source, passes the content directly through the 5GIC Core and terminates it on an edge node (here, MEC server) where the DASM Client Proxy receiver would reside in the form of a virtualised network function (VNF) instance. The connection from the UE application (e.g. web browser) to this edge node would then be over unicast HTTP. Note that the Bittium UE shown in Figure 17 is for illustration, while in practice, UE could be any Android mobile device, unless the PTM reception is required in future trials.

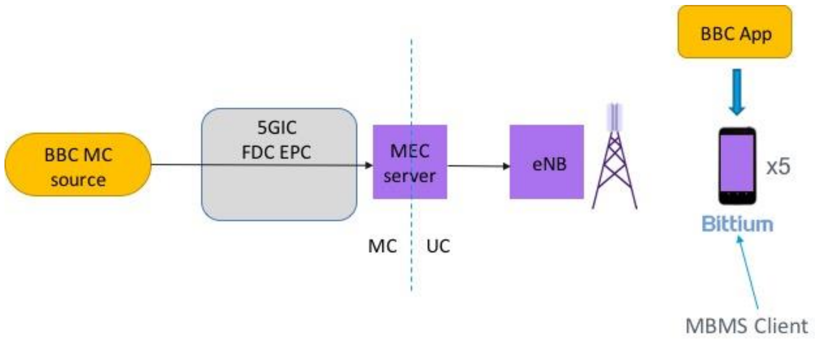

Figure 17. Block Diagram for Object Based Broadcast Trial

Regarding the DASM system for the trial, as illustrated in Figure 18, a DASM Client Proxy is instantiated at the MEC of the 5G Core from where it can receive multicast and convert it back to unicast to serve different UE devices running an object-based media playback application.

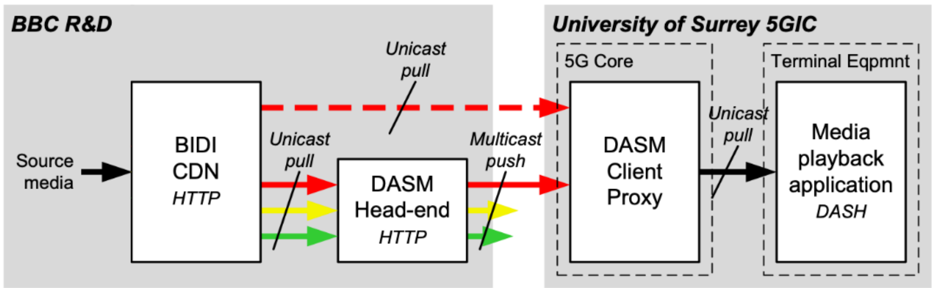

Figure 18. DASM system for Object Based Broadcast Trial

4.4 Developments on Turku test-bed

The planned timeline for the development of the Turku test-bed together with the aimed trials are shown in Figure 19. First spectrum sharing trials were performed in January (laboratory) and May (field) 2018 and target for the public warning trials in cooperation with Turku port authority is in May 2019. The development towards the combined public warning, spectrum sharing and multilink demonstration to be presented at EUCNC 2019 are scheduled for spring 2019.

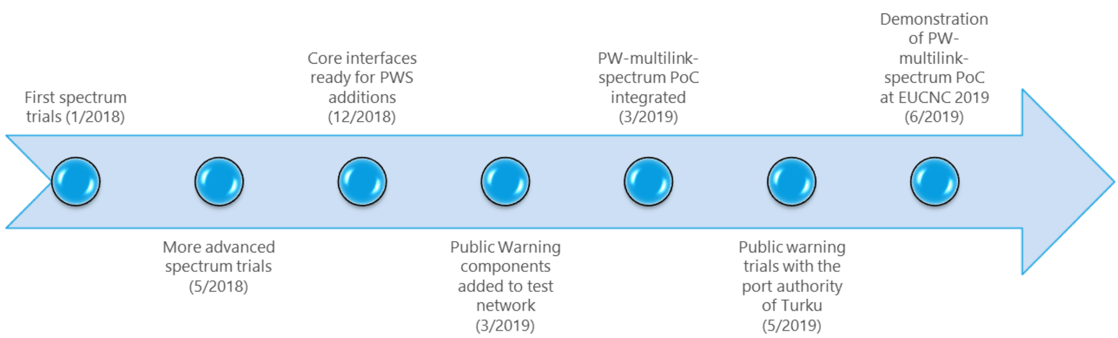

Figure 19. Planned trials and demonstrations timeline steering the test-bed development

4.4.1 Integration of Public Warning components

To enable Public warning trials in the test-bed developments to the initial implementation were required. The structure is depicted in Figure 20. The white elements (MME, HSS, S-GW, P-GW) were available in the core network. Sm and M3 interfaces have been implemented in the core to allow integration of the yellow components (MBMSGW, BM-SC and PWS content system) that are provided by One2Many. One2Many components are connected via remote connection between TUAS and One2Many laboratories or installed locally.

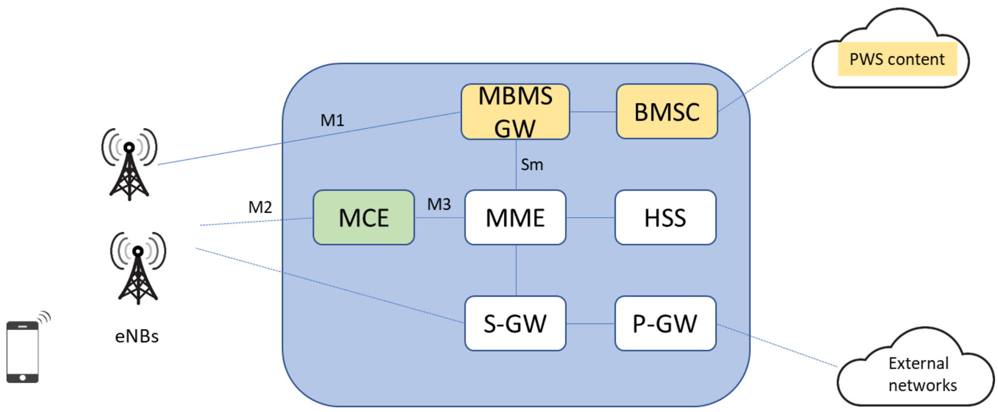

Figure 20. Developments towards PWS trials

Primarily base stations operating on 700 MHz band can be used for the trials. Terminals used in the trials in phase-1 are Bittium Tough mobile devices that are capable of eMBMS reception. Total four of them are available for trials and demonstrations. The application required in the UE for PW message reception is provided by One2Many.

The public warning trials are planned to be developed in two phases. The implementation of phase 2 depends on availability of 5G equipment during the project lifetime.

Phase 1:

The architecture of the trial system is illustrated in Figure 21. The public warning messages are generated by special software and transmitted to several users with broadcasting. Mobile phones with eMBMS support and an appropriate user App for the alerts are used in the trials.

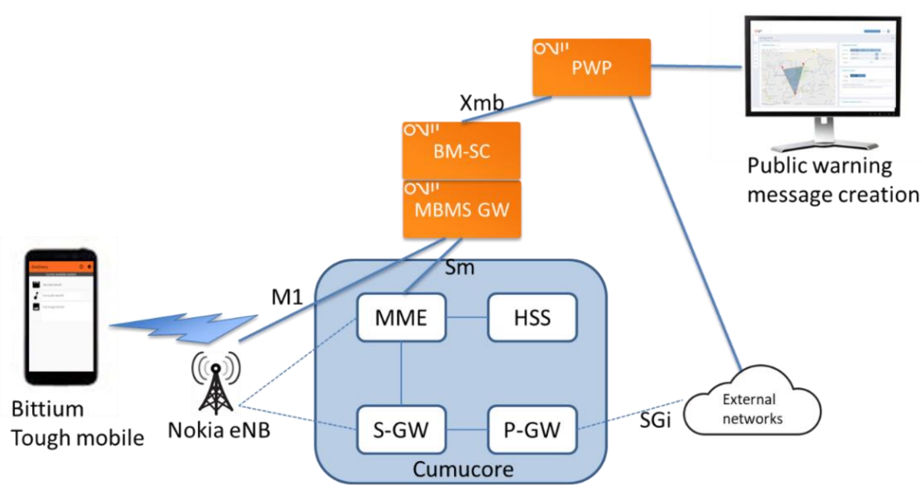

Figure 21. Architecture for transmission of public warning alerts

The steps for the delivery of the alert together with the user interface visible in the alert App is illustrated in Figure 22. The reception of the alert is triggered by HTTP push message in the phase 1 demonstrations using 4G radio and can be updated for phase 2 trials once 5G NR mechanisms for triggering are available. 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 22. Alert screen shots and high-level architecture of the system

Phase 2:

For phase 2 trials the triggering mechanism for the reception of the alert messages is considered to be updated to a more scalable one based on 5G NR. This would allow also other types of devices, such as read-only devices with no uplink connection to receive the alerts. This kind of devices together with devices for home use will be demonstrated if such devices are available at the time of demonstrations. Further, possibility of demonstrating the use of pure multicast in phase 2 trials is considered.

4.4.2 Integration of Spectrum Sharing components

To trial the spectrum sharing in 5G pioneer bands, previous implementation of TVWS (TV White Space) has been replaced by LSA (Licensed Shared Access) in the test-bed. Further, Fairspectrum spectrum manager controlling the base station and orchestrating the spectrum use has been upgraded to support the planned trials.

Terminals used for the demonstrations depend on the spectrum band utilised, as the supported frequency ranges on the terminals vary. For example, for 2.3 GHz sharing demonstration Samsung S8 devices were used as they support both 700 MHz and 2.3 GHz bands, while Bittium Tough mobiles support only 700 MHz.

The trials for spectrum utilisation are planned to be developed in two phases.

Phase 1:

The first planned demonstration focused on sharing 2.3 GHz spectrum between mobile network operator and wireless cameras using dedicated radio interface and LTE for video transmission. This demonstration links to the demonstration use case “Remote live production”. The demonstration was performed in January 2018 and further details are found in [3] and D6.2. The setup was further taken for a field trial in Turku archipelago in

May 2018 to further demonstrate the operation in a realistic environment. In this trial, 700 MHz LTE was used to provide the long-distance link from the mainland to enable connectivity for the private LTE network on 2.3 GHz to be set up in the island using LSA. In addition to PMSE users, this kind of network structure could be suitable for PPDR use in distant locations.

The 2.3 GHz frequency band could be used by a mobile network operator (MNO) when wireless cameras are not in use, which is often the case in many geographical locations. When the spectrum is required by the wireless video cameras (e.g. during a sports event) the transmissions of the mobile network in this frequency needs to be shut down (or at least its transmission power controlled) in the area to free the spectrum for the cameras. The architecture for demonstrating this idea is illustrated in Figure 23. Further, the broadcasters and other Program Making and Special Events (PMSE) stakeholders may have a mixture of system specific and LTE wireless technology on 2.3 GHz band. The demonstration system shows how broadcasters/PMSE stakeholders can gradually move from system specific 2.3 GHz wireless camera technology to LTE/5G operating on 2.3 GHz.

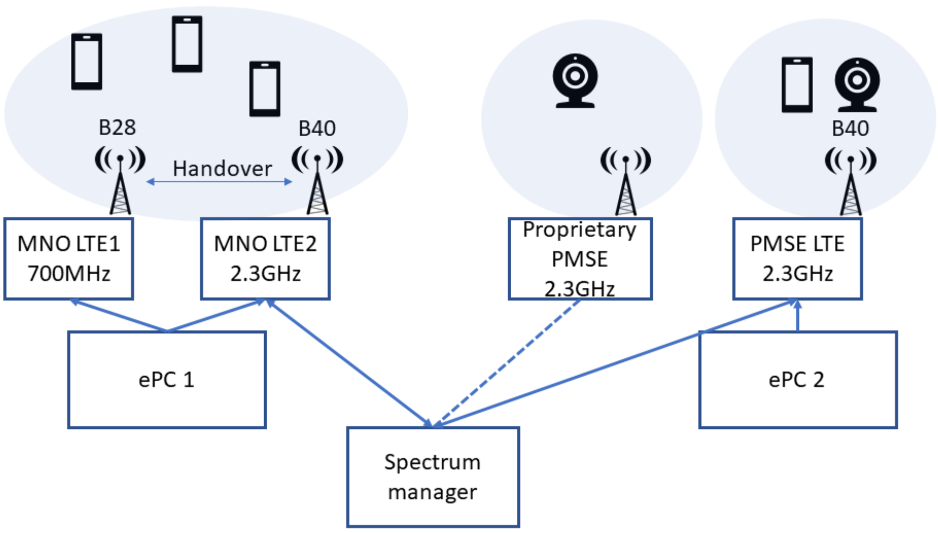

Figure 23. Spectrum demonstrator schema

This trial was shown in EUCNC 2018 conference in June 2018 and more details can be found in D6.2, D6.8 and [3].

Phase 2:

-2.3 GHz (MIL, PPDR, MNO)

The second phase trial shows how three different types of spectrum users can co-exist on the 2.3 GHz band. The importance of video transmission is increasing both in military and Public Protection and Disaster Relief (PPDR). The video applications in wireless networks require more spectrum capacity than there are allocations for military and PPDR. The communication technology, network, and device development for commercial networks has by-passed that the speed of military and PPDR communication systems. Due to these issues, the interest of military and PPDR to take the advantage of the commercial frequency bands has increased. In normal situation, the commercial bands should be used for commercial operation, but military and PPDR could utilise certain bands for training and testing in a limited area and time period. When the situation in the society changes due to safety, disaster, or military activity, the priority can be given to the governmental entities.

The novelty: the changing priorities in Dynamic Spectrum Access are a new concept and they have not been demonstrated earlier. The demonstration was carried out in collaboration with Finnish Defence Forces.

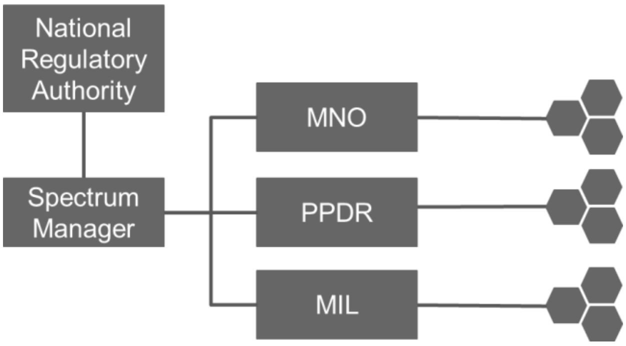

Figure 24. Spectrum demonstrator plan for 2.3 GHz

-700 MHz public warning trials combined with Multi-Link ➔ this demonstration of PoC will be presented in EUCNC 2019 conference in June 2019. Further details can be found in D6.2.

4.4.3 Integration of Multi-Link

The integration of Multi-Link at Turku test-bed follows the same procedure as described in section 4.2.1 for Munich test-bed. The purpose for integrating the Multi-link to Turku test-bed is to build the combined public warning-spectrum-Multi-link Proof-of-concept described in D6.2. The aim is to illustrate a situation, where additional spectrum (capacity) is allocated for public warning when the situation requires.

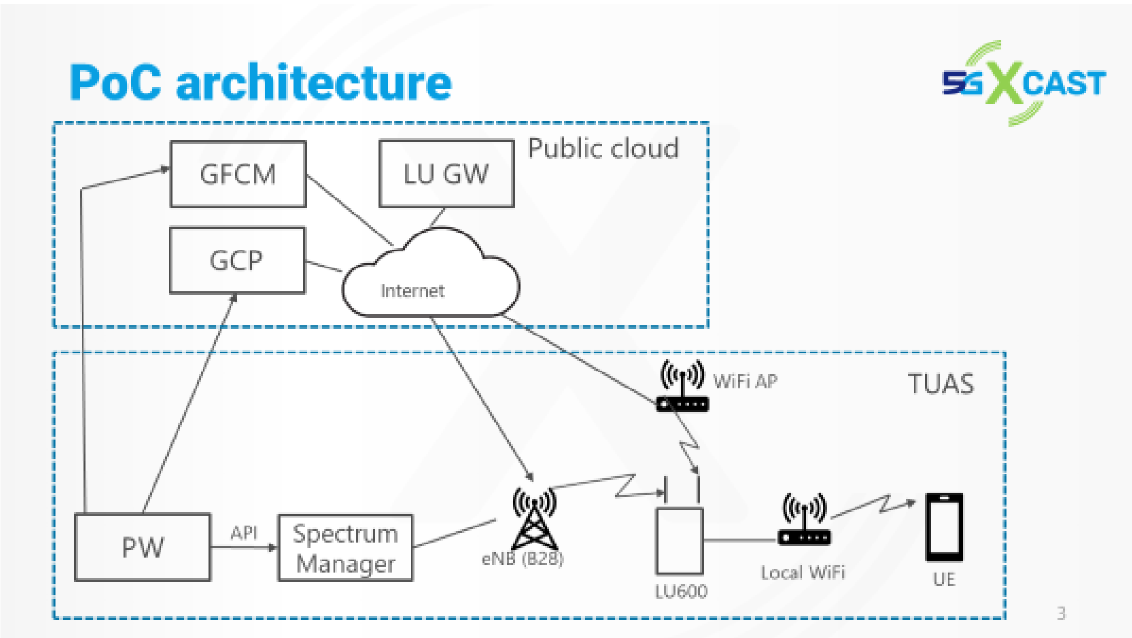

Figure 25. Architecture with Multilink and Spectrum sensing

A Detailed description of Test-beds

A.1 The Munich Test-bed

In this section, the detailed description of the Munich test-bed and its field trial setup of the LTE eMBMS network are provided.

A.1.1 Architecture Overview

An overview of the overall architecture of the test network is depicted in Figure 26. The setup is according to a 3GPP architecture [7] and consists of an LTE software emulated core network installed on a rack server, an enhanced Node B (eNB) with co-located Multicell/Multicast Control Entity (MCE) on Nokia Flexi Base Transceiver Station (BTS) installed in the same rack and Nokia Flexi RM remote radio frequency modules connected to the system module via an Optical Transport Network (OTN). The Broadcast/Multicast Service Centre (BMSC) is the entry point for the content provider to deliver services with MBMS. The main functions of BMSC are:

- MBMS user service provisioning, announcement and delivery.
- MBMS bearer service authorisation and initiation.
- MBMS transmission scheduling.

The MBMS Gateway (MBMS GW) is responsible for IP multicast distribution of MBMS user plane data to each eNB of the SFN. The radio resource allocation is done by MCE while the Mobility Management Entity (MME) supports MBMS by providing control plane interfaces for setting up the MBMS bearers and session configurations [7]. An end-to-end view of the protocol stack [1] from BMSC to the UE is shown in Figure 27. RTP streaming based end to end protocol stack. The grey layers represent the user service distribution of the TV streams, whereas the layers shown in white represent the bearer distribution between the MBMS nodes. The traffic between the MBMS-GW and eNB is tunnelled over user plane GPRS Tunnelling Protocol (GTP) along with the synchronisation information carried out by Synchronisation (SYNC) protocol [8].

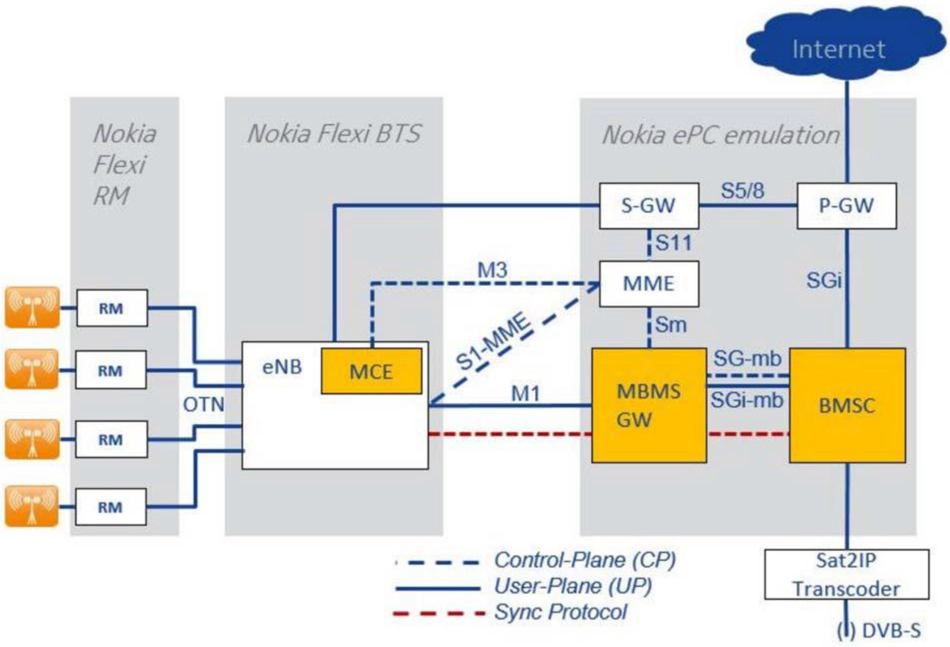

Figure 26. LTE- A eMBMS Implemented interfaces

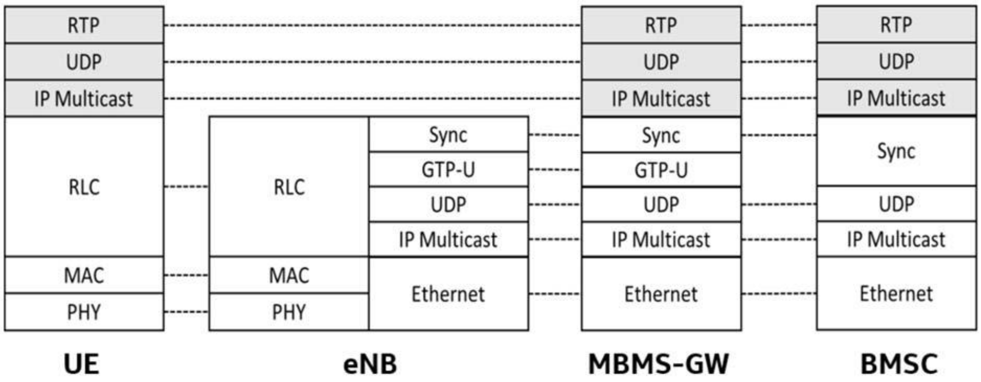

Figure 27. RTP streaming based end to end protocol stack

A.1.2 Network Topology

The topology of the network is shown in Figure 28 and consists of four sites Funkhaus, Freimann, Unterföhring and Ismaning, ranging from Munich urban city centre to the rural northern area. The sites are operated as a broadcast SFN. For three sites, existing towers and antennas are reused with an antenna height of 93 m, 107 m and 214 m in Funkhaus, Freimann and Ismaning, respectively. The site at Unterföhring is a roofmounted cellular network antenna with a height of 25 m. The transmit power is 20W per site which is significantly lower than that of normal high broadcast tower. The ISDs ranging from 1.8 km to nearly 19 km are summarised as follows in Table 1.

Table 1. Range of ISDs.

Sites	ISD
Funkhaus - Unterföhring	9.1 km
Funkhaus - Freimann	7.4 km
Funkhaus - Ismaning	18.9 km
Freimann – Unterföhring	1.8 km
Freimann – Ismaning	11.5 km
Unterföhring – Ismaning	9.9 km

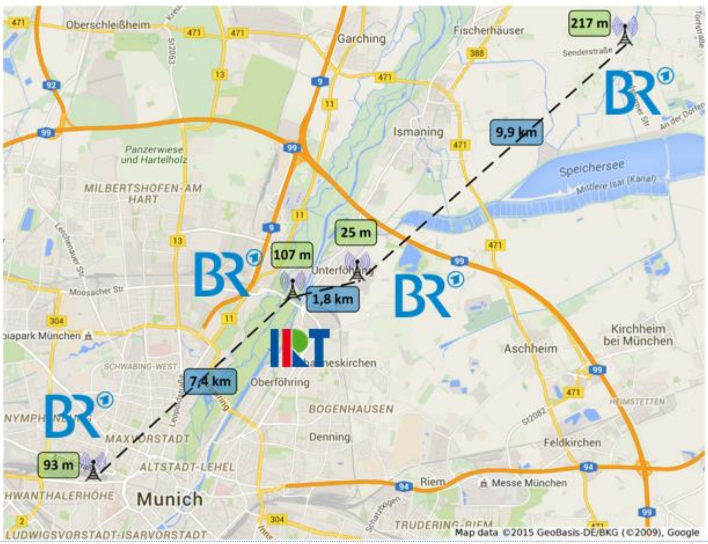

Figure 28. Sites locations of the Munich test-bed

A.1.3 Optical Transport Network

The four Remote Radio Modules (RRMs) of the sites are operated by one BTS system module located in the lab at Freiman. A Dense Wavelength Division Multiplexing (DWDM) OTN was set up by Bayerischer Rundfunk (BR) for the connection as shown in Figure 29. The longest fibre connection is 29 km which required to use transparent fibre and a fixed optical link speed of 3 Gbit/s to ensure synchronisation between RRMs and system module.

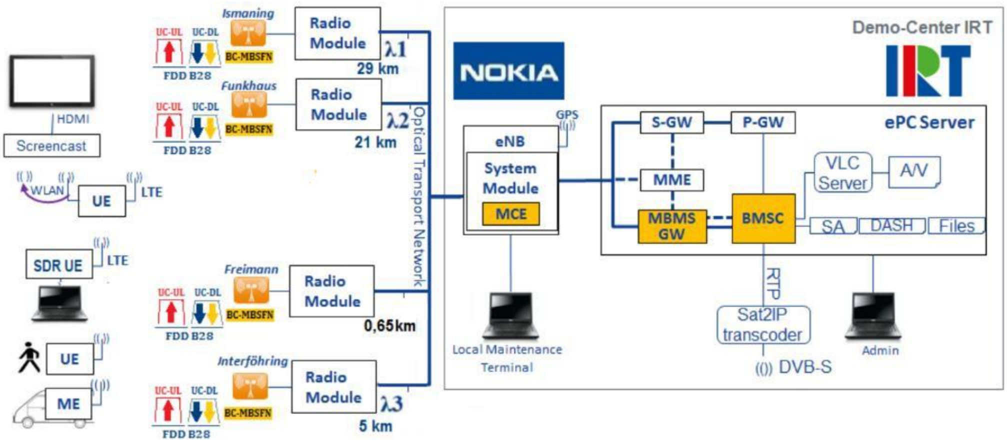

Figure 29. IRT Munich MBMS Demo-Centre

A.1.4 Frequency Planning

The network operates in the 3GPP LTE band 28 (FDD, 706 to 716 MHz uplink, 761 to 771 MHz downlink) which is supported by available APT700 UEs and falls into an existing frequency gap between DVB-T services that are on-air in Munich, see Figure 30. The polarization of the eMBMS sites is set to horizontal to minimise interference with neighbouring DVB-T channels played out from the Olympic tower in Munich. However, initial testing with the UEs showed bad performance in the uplink at Freimann, caused by interference from another horizontally polarised DVB-T transmitter operating in channel K53 which falls into the BTS uplink duplex filter range. The interfering transmitter (Hohenpeißenberg) is approximately 60 km away from the Freimann site with a Line-of-Sight (LOS) visibility, and transmits with 100 kW effective radiated power at a maximum height of 506 m. The issue was solved by installing a notch filter at the radio module in Freimann site. The same precaution was taken for the Ismaning site.

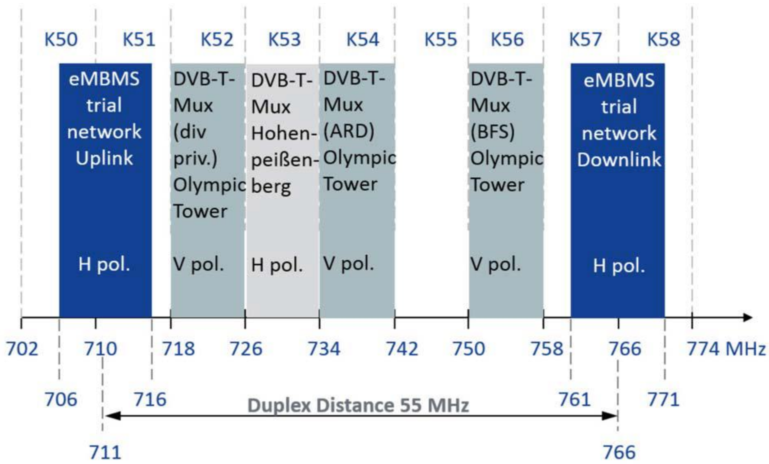

Figure 30. The IRT Munich Test-bed - Frequency planning

A.1.5 Radio Network

On the physical layer, the Multicast Broadcast Single Frequency Network (MBSFN) is operated in mixed mode (unicast and broadcast) with an extended CP of 16.67 us, 15 kHz subcarrier spacing and 10 MHz downlink bandwidth. All sites are configured as part of one MBSFN service area with the maximum MBSFN subframe pattern share of 60%. It must be note that the actual shared capacity can be modified accordingly to [9] in a range from (10%-60%). This means that up to 6 possible subframes of a radio frame can be used for MBMS. This can be achieved by configuring a subframe bitmap of 111111 for each radio frame in subframeAllocation defined in [9].

The radio frame allocation pattern follows the equation System Frame Number mod radioframeAllocationPeriod=radioframeAllocationOffset [9]. In the default configuration stablishes, radioframeAllocationPeriod and radioframeAllocationOffset are set to 4 and 0, respectively, i.e., System Frame Number mod 4 = 0. In other words, every 4th radio frame is consecutively used for MBMS. Because subframeAllocation [9] is set to 4 frames, i.e., 0xFFFFFF, all frames are allocated without subframe gaps.

In mixed MBMS/unicast mode, the OFDM symbols of the subframes are divided in MBSFN and non- MBSFN region. In this sense, the current setup network is configured with non- MBSFNregionLength = 2 which correlates to the first two OFDM symbols of the subframe that carry non MBSFN control channel information such as Physical Downlink Control Channel (PDCCH) [9].

The MBSFN subframes carry both control and traffic channels, i.e., Multicast Control Channel (MCCH) and Multicast Traffic Channel (MTCH) that are multiplexed to the Multicast Channel (MCH). As the MCCH contains the MBSFNAreaConfiguration message [9], which is required by the UE to decode the MCH scheduling and demultiplex the MBMS services, a robust Quadrature Phase Shift Keying (QPSK) modulation with Modulation and Coding Scheme (MCS) = 7 [21] is used (can be modified according trial needs). The MCCH frame allocation is configured as described in [9] with mcch-Offset = 0, mcchRepetitionPeriod = 64, mcch-ModificationPeriod = 512 and a subframe allocation sf-AllocInfo bitmap of 100000 so that the first subframe contains MCCH information. Scheduling changes are notified according to [9]. Basically, when the network changes (some of) the MCCH information, it notifies the UEs about the change during a first modification period. In the next modification period, the network transmits the updated MCCH information [9]. The rest of the subframes is used for the MBMS traffic channel that delivers the actual MBMS services data. For the MCS of the MBMS service data, four options have been configured to select between spectral efficiency and robustness. In this sense, a given service configuration is done by choosing a QoS Class Identifier (QCI) at the start of the MBMS service that corresponds to a specific MCS: QCI = 1 maps to MCS = 18, QCI = 2 to MCS = 15, QCI = 3 to MCS = 12 and QCI = 4 to MCS = 9 [21] (the available QCI mapping can be modified according to trial needs).

The MBMS network requires accurate time synchronisation from the core network over the BTS system module up to RRMs. For this purpose, the BTS system module is connected to a GPS module. At this point it is worth to mention that while the downlink broadcast transmission did not show any issues after synchronisation, the scheduler needed some manual refinement for the uplink (because of the long distance between the system module and the RRM in Ismaning). To overcome this issue, the scheduler timing was adjusted to delay the PUCCH receive requests for 60 microseconds using a software patch in the system module.

A.1.6 Core Network and Content Playout

The LTE core network is emulated in Software running on a rack mounted Commercial Off the Shelf (COTS) server. It includes the eMBMS specific nodes MBMS GW and BMSC. The nodes are internally connected via virtual interfaces with external Ethernet connections to eNB/system module, Internet and video streaming server (Sat2IP transcoder) as shown in Figure 29. By configuring forwarding rules, a live TV program, can for instance, received first via satellite, then transcoded and sent as MPEG transport stream over RTP to the BMSC. To test hybrid broadcast/ unicast services, the forwarding rules between Packet Data Network (PDN) GW and external Internet connection are set accordingly. Four different MBMS session types can be configured at the BMSC: RTP/UDP streaming, DASH/FLUTE streaming, FLUTE File Delivery and FLUTE Service Announcement. However, the current setup emphasizes on RTP/UDP video streaming with unicast feedback channel to evaluate Hybrid Broadcasting Broadband TV (HbbTV)-like services similar to DVB-T.

As representative example, the Sat2IP transcoder can be prepared to provide 2 HD TV programs that are transmitted over the eMBMS test network as shown in Table 2. For instance, the data rate of each channel can be configured to 4 Mbps. Additionally, further streams can be played out from pre-recorded local files (e.g., a video can be sent from VLC server instance to the BMSC). At the BMSC, the actual eMBMS services are started and the MBMS bearer context for broadcast mode is created by MBMS-GW, MME and radio access network [7],[10].

Table 3 summarises the most relevant configuration parameters used in the current test-bed configuration for setting up the MBMS bearer [7]. In addition, the GTP tunnel with Tunnel Endpoint ID (TEID) and multicast bearer distribution to the eNB is also provisioned, see Figure 27. The video streams are distributed as IP multi-cast MBMS user service data with synchronisation information over SYNC protocol [9]. Table 4. Configuration Parameters of MBMS User Session and SYNC Protocol. shows the relevant configuration parameters of MBMS user session and SYNC protocol used in field trial.

Table 2. Feed of TV Programs.

Feed of TV Programs	
Codec	Video: H.264, Main Profile, Level 4 Audio: AAC-LC
Resolution	Video: 1280 x 720p, 50 FPS Audio: Stereo
Data rate	Video: 4Mbps Audio: 128 kbps

Table 3. Configuration parameters for setting up the MBSM bearer.

Configuration parameters for setting up the MBSM bearer	
SessionType	RTP/UDP
TMGI	Temporary Mobile Group ID for MBMS bearer service (ServiceID:MCC:MCN)
QCI	QoS Class Identifier (user to select an MCS configuration for test purposes)
GBR	Guarantied Bit Rate = Maximum Bit Rate in kbps
MBMS Service Area	Area which the MBMS bearer service has to be distributed

Table 4. Configuration Parameters of MBMS User Session and SYNC Protocol.

Feed of TV Programs	
Dest. IP	UE destination IP Address
Dest. StartPort	UE destination start port
Dest. EndPort	UE destination end port
Synchronisation Sequence	Sequence duration for SYCN protocol: 40ms
Synchronisation Period	Synchronisation period for SYNC protocol (in umber of sequences): 250

A.1.7 Testing Devices

Different types of testing devices have been used for the evaluation of eMBMS on application- and physical-layer. The Rohde & Schwarz drive-test software ROMES can be used in combination with the RF scanner TSMW to measure the signal coverage and interference in the SFN. Furthermore, R&S ROMES can be setup to record Layer 1 to Layer 3 parameters of the LTE stack. Qualcomm MTP-8974AB and MTP-8994 developer devices in mobile phone and tablet form factor have been used in the scope of IMB5 project founded by the Bavarian Research Foundation [11] for quantitative testing and proof of concept. In case of Qualcomm MTPs, terminals were equipped with an eMBMS middleware and an Android application developed in-house, which provides a HbbTV look-and-feel. This application allows the toggling between broadcast and unicast services, i.e., while receiving MBMS broadcast video additional program information and on-demand content can be requested over the unicast feedback channel.

For 5G-Xcast project, a new set of MBMS enabled devices like the Bittium Tough Mobile (MBMS enabled) smartphones have been already integrated, see Table 5.

Table 5. Bittium Tough Mobile UE characteristics.

Bittium Tough Mobile UE
Specs
- Qualcomm Snapdragon 801 - Quad-core CPU up to 2.3GHz - Android 6.0 (Marshmallow) - 2GB LPDDR3 PoP RAM - 16GB eMMC Mass Storage - Wi-Fi 802.11 a/b/g/n/ac - Carrier Aggregation
LTE Bands
B2 (1900), B3 (1800), B4 (1700), B5 (850), B7 (2600), B13 (700), B14 (700), B17 (700), B20 (800)

A.1.8 Software Defined Radio – UE

Beyond the detailed tests on application and physical layer with the existing eMBMS standard, an additional aim of IRT has been to test physical layer waveform extensions to improve the existing eMBMS standard (E.g., an extension of the cyclic prefix length, implying the change of the FFT length in the demodulator).

Nevertheless, this is not possible with UE devices based on commercial LTE chipsets but with SDR platforms. Using SDR platforms, full access to the source code is given and modifications are possible which deviate from the already implemented, standardised transmission system.

A.1.9 Multilink equipment

The additional goal of the IRT testbed was to test integration with multilink technology for seamless transition between different coverage areas, for QoE at cell edges, fixed-mobile convergence support etc.

This is achieved by integrating the LiveU multilink equipment in the IRT core networks. A databridge LU600 is placed in the lab, having one modem that is being served by the IRT LTE-emulation network and another link using the IRT WiFi network. Both of these IRT networks provide access to the public network via standard public ISPs. A LiveU databridge Gateway (GW) is placed in a remote public cloud (Amazon AWS in Ireland). It has an IP address which the LU600 sends its packets split between its two modems and receives back packets also split over the two modems/networks.

The cellular modem that was used by the LU600 databridge to connect with the IRT cellular network is Sierra Wireless MC7430 (placed inside the LU600 over a specially designed RF board by LiveU).

The LU600 databridge:

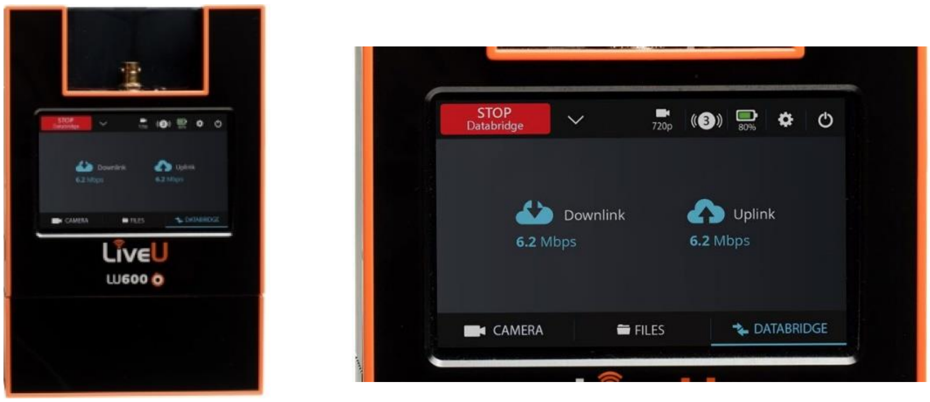

Figure 31. LiveU LU600 databridge.

Figure 32. LiveU Databridge IP flow

A.2 The Surrey Test-bed

In this section, we describe the Surrey test-bed developed in 5GIC in the University of Surrey (UNIS), Guildford, UK.

A.2.1 Background

5GIC has been developing 5G-compliant networks with potentials to revolutionise the network functionality to increase mobile broadband services, speed, capacity and coverage while using the same networks to connect large numbers of IoT devices and support new mission-critical and safety to life services which require exceptionally high reliability and guaranteed latency. All parts of the UK economy and public services have the potential to be transformed by the coming technology and 5GIC looks forward to helping the Government realise its vision.

In addition to developing new 5G research concepts, an important mission of the 5GIC is to carry out technology implementation and performance evaluation in a real environment. Proof-of-concept for selected ideas is to be implemented on bench test-beds and/or on a campus-wide test-bed to verify the core ideas. The aim is to test innovative algorithms and analyse their performance when applied to a practical system and scenarios. This way, the pros and cons for each scheme can be identified and fed back to optimise the overall design. Key 5G technology solutions are to be demonstrated in national and international workshops.

The 5GIC's existing campus-wide 5G test-bed is being further developed to allow further 5G technology demonstration and proof of concept of emerging 5G technologies. 5GIC is looking to build new and extend existing partnerships with the aim of realising the Government's vision of integrated fibre and 5G trials to allow the UK to be at the forefront of the build-out and use of the new networks.

A.2.2 Architecture Overview

5GIC is developing three test-beds, i.e., RAN, core network and IoT, which can provide appropriate APIs for remote connectivity and access at service and network levels. The three test-beds are connected via all fibre backhaul providing 100Gbits/s connections (including Duck Fibre front-haul and Metro-Ethernet for IP backhaul), routers that are capable of handling 400Gbits/s of traffic, and gateway. The cloud computing infrastructure, IP Media Subsystem (IMS) service platform and 20 test terminals are also available.

The Surrey test-bed is currently connected to Italy and Germany (Berlin) conducting Europe-wide research and innovation on Software Defined Network (SDN), Network Functions Virtualisation (NFV) and Mobile Edge Computing (MEC). The SDN/NFV related topic and focus of the Surrey test-bed contains MEC protocols, joint content caching/distribution and routing optimisation, new mobility management protocols, information centric networking, new transport protocol for IoT, and user, content and network provided data and context-based networking management. Various key performance indicators are available from the practical testing and implementation, including end-to-end latency, QoE, reliability and energy efficiency, etc.

In the following, we shall focus on the first two test-beds, i.e., RAN and core network, where the brief description of these two test-beds are given in the following sections.

A.2.3 Radio Networks

Mainly supporting LTE-A at the moment and potentially extending to multicast/broadcast with low mobility, e.g., 30km/hour, on the physical layer, the Surrey test-bed brings RAN the flexibility to offer both outdoor and indoor services, with the extended CP of 16.67

us, 15 kHz subcarrier spacing and up to 40 MHz bandwidth with carrier aggregation (CA). More specifically, the outdoor RAN spans over a geographical area of 4km^2 covering dense urban, urban, rural and motorway. In total 3 macro cell base stations are equipped outdoor, which are based on the radio platforms with the 8T8R (eight-branch transmit and eight-brand receive) remote radio unit (RRU) supporting 20W transmission power, or with the active antenna system (AAS) with remote radio head (RRH) to reduce network cost and enhance network efficiency. The outdoor RAN also consists of dense small-cells, i.e., 38 small cells, allowing cloud baseband processing unit (BBU) functions with programmable basebands. On the other hand, the indoor RAN consists of 6 small cells to support LTE-A (Lampsite from Huawei) or Wi-Fi (AP from ARUBA) services. More details and pictures of the RAN test-bed can be found in the following table and figure, respectively.

Table 6. Technical details of the Surrey test-bed RAN.

Site Type	# off Sites	# off Cells	Access Type	BW (MHz)	Mode	Handover	CA
Outdoor 2xSector	14	28	LTE-A	20	TDD	Yes	Yes
Outdoor Omni	5	5	LTE-A	20	TDD	Yes	Yes
Indoor Lampsites	6	6	LTE-A	20	TDD	Yes	No
Femtocell	6	6	LTE-A	20	FDD	Yes	No
Indoor AP	6	6	Wi-Fi	30	N/A	none	N/A

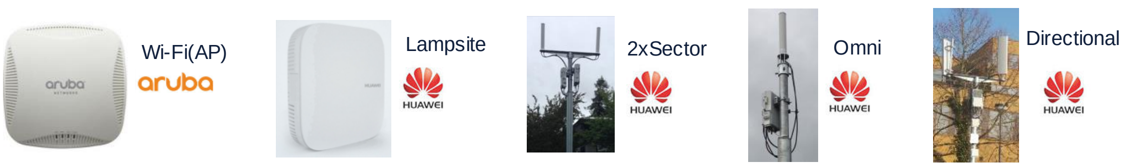

Figure 33. 5GIC outdoor/indoor radio platforms – Small-cells and AP.

A.2.4 Core Network

Test Core supported by Vodafone and Fixed/Soft Quortus Core are equipped in the Surrey test-bed. The former is connected to the outdoor fixed RAN, e.g., 2xSector and Omni as shown in Figure 33. Vodafone Intranet servers and Vodafone breakout server, whereas the latter is connected to the indoor/outdoor RAN, UNIS Intranet servers and Web breakout server. A fully-featured virtualised evolved package core from Quortus and 5G Flat Distributed Cloud (FDC) components, e.g., cluster member (CM) and cluster controller (CC) from 5GIC are considered. The FDC is a new core network architecture which will be further discussed in the next subsection. In general, the local Intranet services includes Web, Content, APP and MEC servers, implemented as bare metal instances. External Internet connection is through JANET university network 10Gbit/s from UNIS to network and easily provides 300Mbit/s per user towards the internet for capacity testing Wi-Fi and 100-200Mbit/s for LTE-A testing. The core network test-bed in 5GIC is shown in Figure 34, based on SDN/NFV implementations with MEC. More details can be found in [1].

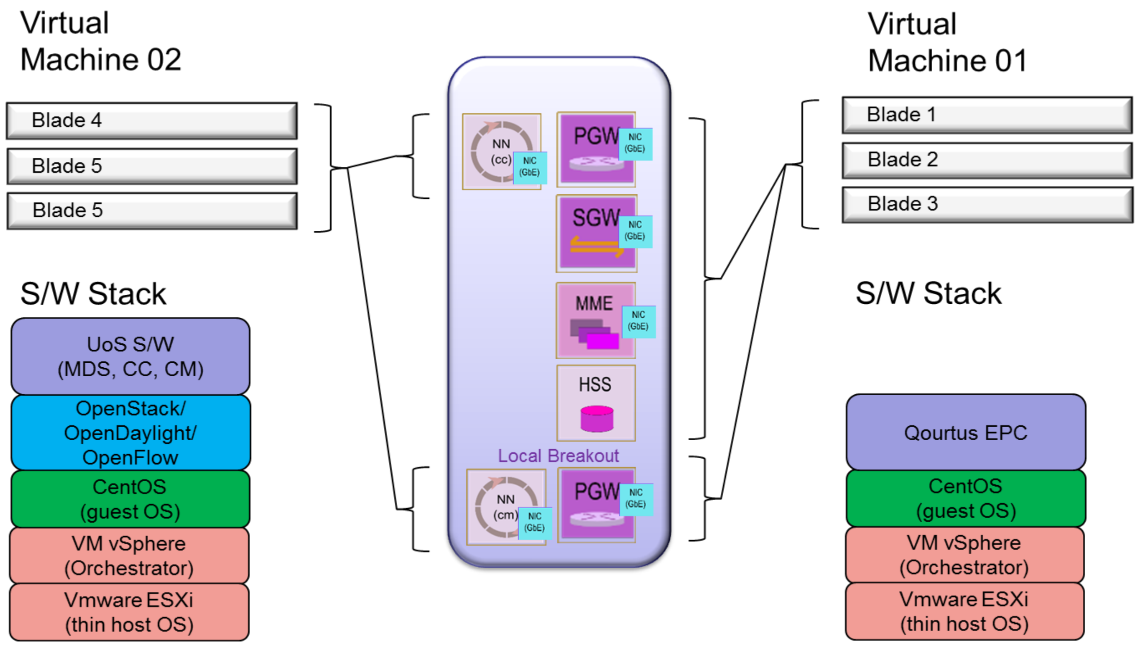

Figure 34. 5GIC Core Network Test-bed for SDN/NFV comprising MEC capabilities.

5GIC already have an implementation of a 5G Core based on draft 3GPP 23.501 with service-based interfaces, where in the new 5G architecture, the key features include Application Function (AF), Access and Mobility Function (AMF, with 70% functionality of old MME), Authentication & Security Function (AUSF, with rest of MME functionality), Data Network (DN) where includes Internet, Intranet & MEC, Virtual Private Network (VPN) - (private, utility, IoT public services etc.), Policy Control Function (PCF), Service Management Function (SMF), and 5G User Equipment (UE, with LTE + 5G NR capability), User Data Management (UDM), User Plane Function (UPF).

A.2.5 Flat Distributed Cloud

Previous 3GPP mobile network generations are a ‘one size fits all’ approach, due to the following reasons: 1) The existing 3G/4G architecture is hierarchical and rigid, meaning its latency may not be able to further improve; 2) The core network architecture is difficult to be implemented in a flexible manner, thus it can be costly to modify and suit new user type; 3) The current protocols are processing intensive, leading to the high processing cost; 4) There is no inherent user security, thus it can increase the cost of “fixing/managing” constant threats; 5) The network is not User Context Aware, but simply one size fits all “universal web user”; 6) Content and Applications are all Over-the-Top (OTT), so the operator cannot access revenue; 7) Quality of Service is rarely implemented beyond Voice & Data classification; 8) Control and User planes are still not separated, leading to slow access, poor mobility support and poor user performance.

In considering the disadvantages of the current network architectures and the requirement of the 5G network, 5GIC has designed a Fully Virtualised and Componentised Network Sliced architecture [17], with a high flexibility and capability to rapidly slice to suit user demographics. Network entities can be scaled in and scale out, due to virtualised implementation. The 5GIC FDC solution operates as dynamic ‘Clusters of Infrastructure” which can be dynamically re-arranged: 1) Horizontally by topology/ user population load and 2) Vertically by network slicing according to user context(s). The architecture involves a simple ‘Association’ based control plane, separated from user plane which gives faster access, better performance and simple, stakeholder based scalable security. The network is context aware, thus enables changing connection point and service and slice provision dynamically by user context, within radio constraints. The FDC is also able to select Internet/Intranet breakout point and re-direct traffic according to context and content/applications requested by the user(s). Among the key innovation is the realisation of a control plane node where the Non-Access Stratum (NAS) control plane is integrated with common control signalling (control plane + user plane control). This expedited integrated signalling allows context awareness, and full control plane and user plane separation. Such an approach improves the access speed and QoE. The 5GIC FDC architecture in the context with New Radio and LTE is presented in Figure 35, where the key features are highlighted. More details can be found in [17].

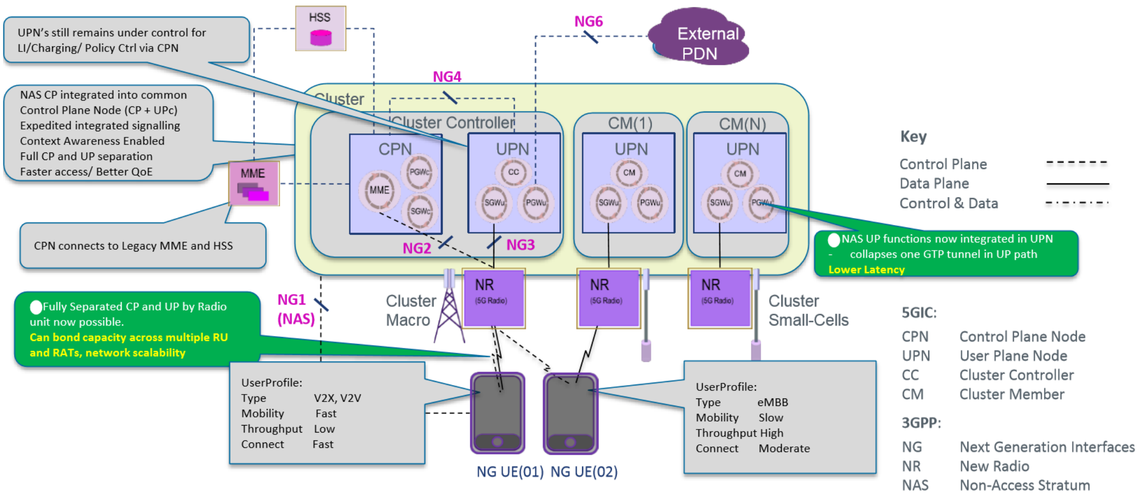

Figure 35. 5GIC Flat Distributed Cloud (FDC) Architecture – NGR & LTE (with key features).

A.2.6 Network Topology & Frequency Planning

The topology of the Surrey test-bed is illustrated in Figure 36 and Figure 37, including the information of the involved members' contribution (Huawei, Vodafone, Ofcom and BT, etc.). As mentioned in Section 0, the test-bed facility consists of 3 macro base stations which support 8T8R RRU with 20W transmission power and AAS with RRH. The centre of antenna gravity height is 25m. The inter-site distances between the macro cells are around 500m, covering the Stag Hill campus of UNIS in Guildford. It also contains 38 outdoor and 6 indoor small cells, with an antenna height of 5m to 25m. The transmission power is from 0.1W to 5W for different use cases, and the inter-site distances among these small cells are from 75m to 150m. The main operating frequency band for the outdoor testing is the 3GPP LTE band 38 (TDD 2600, 2570MHz – 2620MHz), and the 3GPP LTE band 41 (TDD 2500, 2496MHz – 2690MHz) for the indoor LTE, as well as the 2.4GHz WiFi band. In addition, as shown in Figure 36, the frequency band of 3.8GHz and millimetre wave band are available supported by Ofcom.

Figure 36. 5GIC Campus-Wide Test-bed Components.

Figure 37. 5GIC Outdoor Campus-Wide Base Station Deployment.

A.2.7 Testing Tools

Supported by the industry partners collaborated with 5GIC, different testing tools/software are equipped align with the Surrey test-bed. In particular, the radio planning tool, ASSET, that provided by TEOCO, can support the path loss predictor and signal coverage planning with the open input interface for LTE parameters. The network testing tool provided by ASCOM enables the testing and analysing on the practical map, along with the network protocol analyser, Wireshark. The signalling trace tool developed by Huawei can provide the base station signalling trace and the cell/user performance monitoring.

A.3 The Turku test-bed

A.3.1 Background

TUAS radio laboratory has strong knowledge on DTT broadcasting research from the past 15 years. Interoperability tests, mobility tests, verification and validation of rotated constellations and measurements of interference and coverage for DVB-T/H/T2 (Digital Video Broadcasting - Terrestrial/Handheld/Second Generation Terrestrial) have been conducted in several different projects, including EUREKA-Celtic projects WING-TV, B21C and ENGINES.

Since 2010, the focus of TUAS research has been in spectrum sharing, especially in TVWS and LSA. In spectrum sharing, it is essential to study the technical protection conditions to enable the coexistence between secondary and primary (incumbent) users through field measurements in real test network environments. Turku TVWS test environment was set up during in WISE, WISE2 and ReWISE (Reliability Extension to White Space Test Environment) projects (2011-2014) to develop and validate technical solutions, accelerate commercial utilisation of white spaces, and to contribute to the regulation and standardisation work. TVWS equipment has also been installed and trialled in the use-case pilots of WISE2 project in different locations in Helsinki. The test network was the first in Europe to have a full geolocation-based radio license for the TVWS frequency range 470 MHz - 790 MHz in the 40 x 40 km area.

FUHF (Future of UHF) [12] project continued to study spectrum sharing in the UHF TV band. The main focus was on field measurements to study the feasibility of exclusive shared spectrum access through LTE Supplemental Downlink (SDL) concept. The project also observed the regulatory and technical developments to determine the most feasible spectrum utilisation methods for the UHF TV broadcasting band.

TUAS also co-operated with CORE+ project and was a full project consortium partner in the follow-up project CORE++. These projects studied the LSA and SAS concepts by developing the framework, participating in the regulatory work and field trialling the developed systems. TUAS participated in the development of repositories for both LSA and SAS and in developing the spectrum sensing system fulfilling the requirements of ESC in SAS. The ETSI work on defining LSA for 2300-2400 MHz band was recently finished and is expected to evolve into a spectrum sharing method which could assist in meeting the spectrum demand for 5G.

There are two separate private networks for industrial IoT validation and trialling purposes in the TUAS test environment. The first network is a LoRa low power wide area network (LPWAN) to study deep indoor propagation characteristics of a LoRa network. The network consists of two base stations at TUAS premises in ICT-City and Sepänkatu (Figure 41), one base station at Kuusisto TV-mast and additional base stations operated by a private corporation. The network is operated on three 200 kHz channels at 868.1, 868.3 and 868.5 MHz. The transmissions have a 125kHz bandwidth and a maximum duty-cycle constraint of 1%.

The second network consists of industrial radio modems, which provide a mission-critical communications solution and are based on private radio networking technology. They provide reliable long-range data connectivity and very high availability for mission-critical applications under severe circumstances. The radio modems allow to build a private network that is not dependent on mobile network operators. The master base station is installed at ICT-city. The network consists of 5 base stations and is operated at 428 MHz.

A.3.2 Technologies supported & frequency use plan

The TUAS 5G test-bed focuses on spectrum below 6 GHz [2]. The frequencies of the current test network components are illustrated in Figure 38. Radio licenses need to be acquired for each of the frequency bands, and permission from the MNO is needed in the bands which have been allocated to LTE.

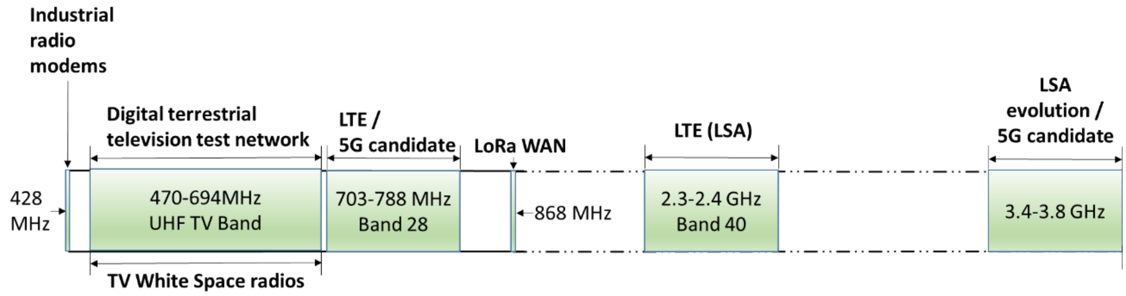

Figure 38. Spectrum utilised in the TUAS test-bed

The overall TUAS 5G test-bed service architecture is illustrated in Figure 39. The test-bed infrastructure, backbone and the Operations, Administration, and Maintenance (OAM) are located in the TUAS radio laboratory at ICT-city building in Turku, Finland. The internal LTE virtual EPC (vEPC) and the LSA are operated on servers of the TUAS radio laboratory network. The ETSI LSA architecture reference model is used. The blocks in grey colour describe the equipment under the management of TUAS radio laboratory and the blocks in white the equipment outside TUAS control. Thus, the LSA controller is currently an external service. The Microsoft Azure portal and the external LTE EPCs are connected to the TUAS radio laboratory infrastructure through a firewall and a Virtual Private Network gateway (VPN-GW). The green blocks illustrate the air interfaces of different test-bed services and the orange box the spectrum monitoring and sensing systems.

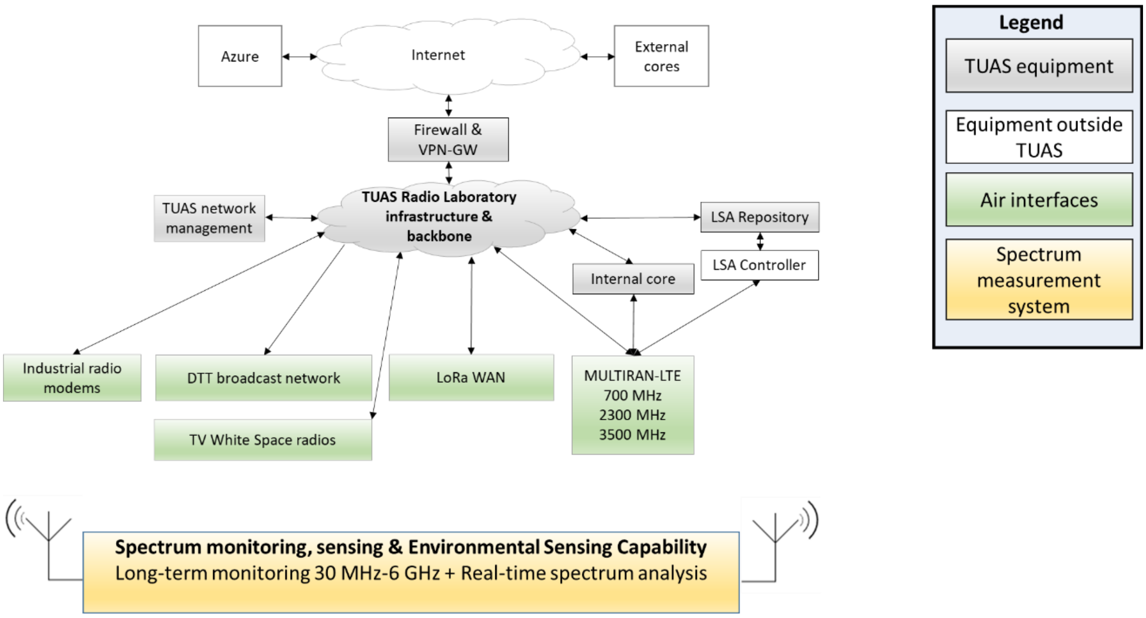

Figure 39. TUAS test-bed architecture

One of the major challenges in the 5G experimentations and trials could be the user terminals. Especially the supported frequency ranges, the level of flexibility the terminals allow, and the available software applications may largely determine for which purposes the terminals can be used for.

A spectrum observatory network was built in a GlobalRF Spectrum Opportunity Assessment project in WIFIUS program, which was jointly funded by the NSF and Tekes. The project built an international network of RF spectrum observatories continuously collecting long-term spectrum data to study the trends in spectrum utilisation and to identify frequency bands where spectrum sharing could be feasible.

Three spectrum observatories are operational in Chicago, US, Virginia, US, and Turku, Finland. The measurement data from the spectrum observatories in Finland and the US is collected and stored into a single location at Illinois Institute of Technology in Chicago. The RFeye nodes manufactured by CRFS measure the whole frequency band from 30 MHz to 6 GHz in each of the locations.

A.3.3 LTE test network

The main sites of the network are located at TUAS campus buildings. Figure 40 and Figure 41 gives a more detailed description of the LTE part of the test-bed along with the installation locations of the LTE Evolved NodeBs (eNBs). The 3.5 GHz base stations will be installed into a factory environment in the near future.

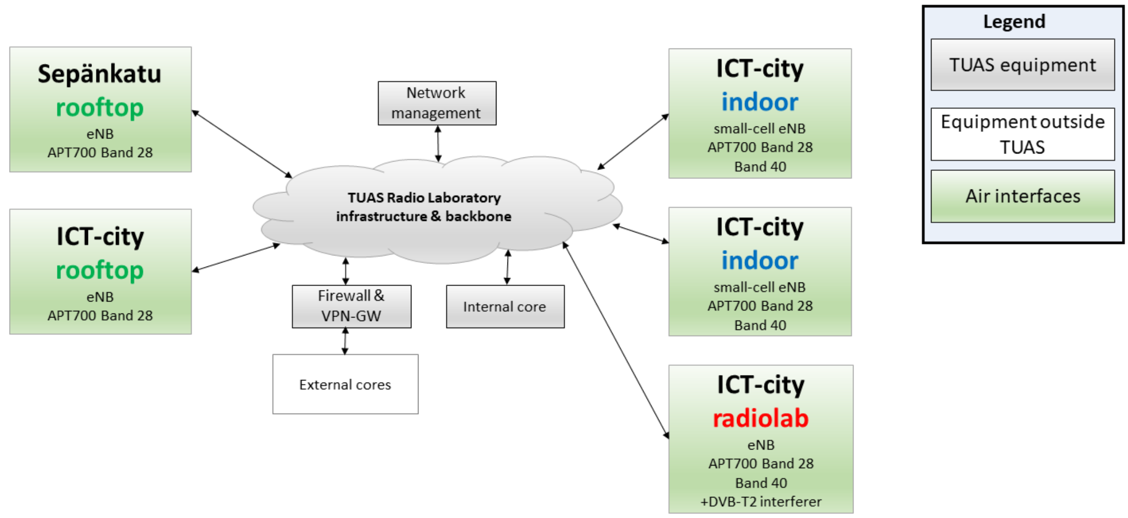

Figure 40. TUAS LTE test-bed structure

Two small-cell eNBs are installed at ICT-city premises for indoor trialling purposes, one rooftop eNB is installed at ICT-city and a second rooftop eNB at TUAS premises at Sepänkatu. The test network infrastructure includes an optical transport network (OTN) between the premises at ICT-city and Sepänkatu. In addition to LTE eNBs, the locations have the following services:

- Sepänkatu: long-term radio spectrum observatory system, LoRa base station and industrial radio modem base station.
- ICT-city radio laboratory: on-demand real-time spectrum analysis, LoRa base station, industrial radio modem base station and DTT transmitter.

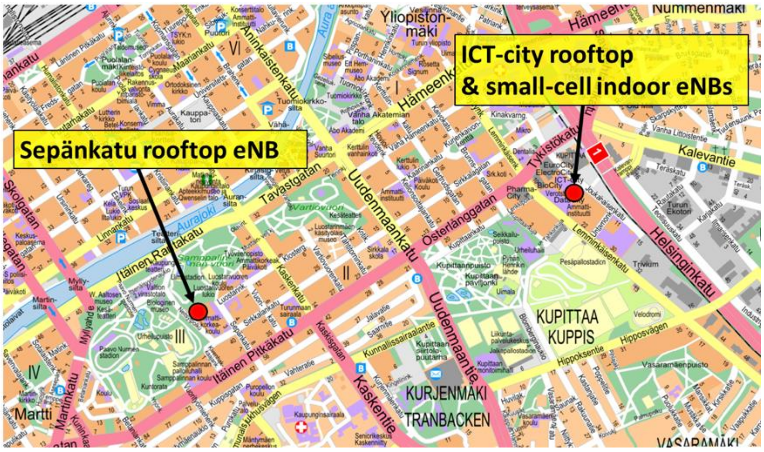

Figure 41. Main sites in the test-bed

A.3.4 Equipment

Main test-bed equipment related to 5G-Xcast is listed and described below:

- Base stations: Nokia Flexi APT 700 Macros, Nokia 2.3 GHz picos, Nokia 3.5GHz macro and picos
- Test terminals: Samsung S8, Samsung S9, HTC, Bittium Tough mobile (native eMBMS support), Nemo Handy Handheld Measurement Solution
- Core: Cumucore

Software-based LTE packet core to be deployed in the cloud including mobility, user management and traffic optimisations. PWS case related components from one2many (indicated with yellow) to be incorporated.

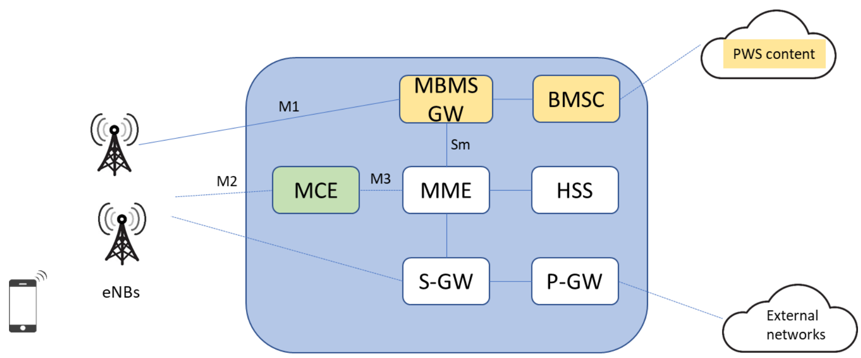

Figure 42. TUAS test-bed components

- TUAS network management & Internal core
- LSA repository

The LSA Repository is a database containing up-to-date information about LSA spectrum bands together with the conditions for the use of each band. LSA Repository could serve as an interface between the incumbent, the regulator and LSA Controller. LSA Repository collects, maintains and manages data on spectrum use and tracks whether LSA band is available for other purposes (as LTE in our case) or if it is in the incumbents' own use. LSA Repository contains information on organisation, equipment, licenses, time, location, frequency, and type of the incumbent usage. Based on this information, protected areas are defined based on the underlying regulatory requirements. These protected areas are exclusion zones where the LSA users are not allowed to use the given LSA band.

- Spectrum sensing

The RFeye node manufactured by CRFS measures the whole frequency band from 30 MHz to 6 GHz in each of the locations. General measurements covering every frequency band up to 6 GHz are not sufficient to comprehensively analyse the multitude of different radio systems operating within these bands, but they provide a good overview on the spectrum utilisation. When a specific band is studied, the measurement parameters need to be adjusted according to the transmissions under study. An example on sensing the 470-900 MHz band is illustrated in Figure 43. As can be seen from the figure, the 5 DTT multiplexes have been grouped to the 470-694 MHz UHF TV broadcasting frequency range, but the 700 MHz MBB is not operational yet. Three 10 MHz blocks of frequency division duplex (FDD)-LTE downlink transmissions are active in the 800 MHz band [100].

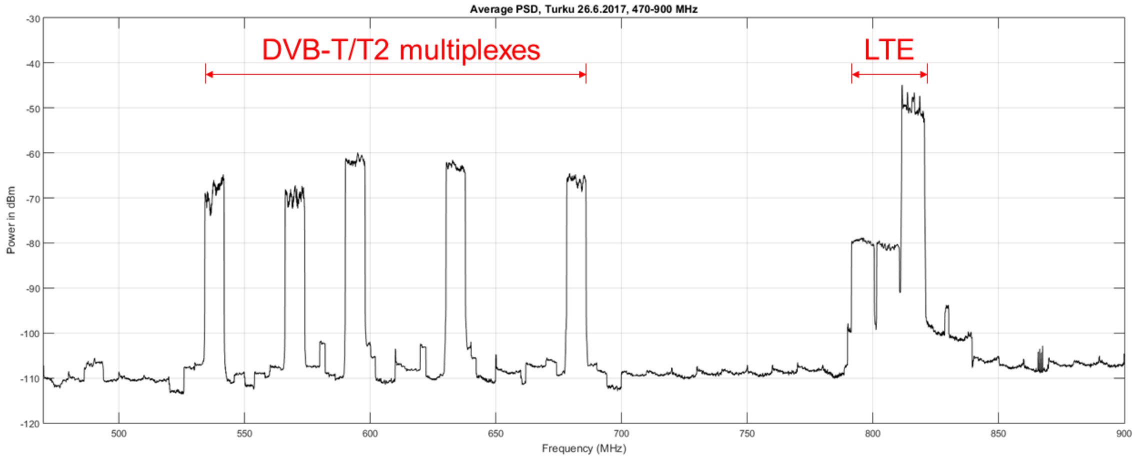

Figure 43. Example of sensed spectrum

A.3.5 Multilink equipment and integration

As the LiveU Multilink LU600 field unit is very portable, it is also used in the Turku testbed integrated into the Turku cellular network and its WiFi and fixed network.

The use case being served is the PWS media alert use case.

The LiveU equipment and integration are exactly the same as in the IRT lab (see A.1.9).

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