Multimedia Public Warning Alert Trials Using eMBMS Broadcast, Dynamic Spectrum Allocation and Connection Bonding

Tero Jokela, Juha Kalliovaara, Menno Bot, Heikki Kokkinen, Baruch Altman, Carlos Barjau, Peter Sanders, David Gomez-Barquero, Jarkko Paavola

***Abstract*—The European Commission requires all European Union (EU) Member States to use telecommunications networks to alert the population of an ongoing crisis or an upcoming threat by June 2022. Public Warning System in Long Term Evolution (LTE) and 5G System currently supports a text-based warning using Cell Broadcast technology. Cell Broadcast does not support multimedia warning message delivery. This paper analyses requirements that need to be fulfilled to support multimedia warning message delivery in the 5G System and describes trials of a broadcast multimedia public warning alert system. The trials demonstrate delivery of multimedia public warning messages using Evolved Multimedia Broadcast Multicast Service (eMBMS), dynamic spectrum management and bonded connections. By using eMBMS the public warning messages can be sent with additional robustness and in multicast mode, resulting also in less congestion to the network as the messages do not need to be sent separately to each user. Dynamic spectrum management system allows to dynamically obtain spectrum resources for the public warning system messages and the bonded connections improves the throughput and reliability of the delivery by combining the capacity of several different networks.**

***Index Terms*—Public warning system, multimedia, cellular networks, 5G, broadcast, eMBMS, multilink, bonded connections, dynamic spectrum allocation, trials.**

I. Introduction

THE European Electronic Communications Code in Directive 2018/1972 of the European Commission requires all EU Member States to use telecommunications networks to alert the population of an ongoing crisis or an upcoming threat by 21 June 2022 [1]. The Netherlands, Lithuania, Romania, and Greece already have deployed a Public Warning System (PWS) based on Cell Broadcast technology and many other Member States are investigating their options. PWS, based on Cell Broadcast technology, is also operational outside the EU in the United States, Canada, Chile, New Zealand, Japan, Taiwan, the Philippines, Oman, the UAE and India. Android, iOS and Windows Mobile devices all support PWS via Cell Broadcast technology.

PWS in Long Term Evolution (LTE) and 5G System (5GS) currently supports a text-based warning using Cell Broadcast technology as specified in 3rd Generation Partnership Project (3GPP) TS 23.041 for Release 16 [2]. PWS with a multimedia warning message delivery is currently not specified in 3GPP. This paper analyses requirements that need to be fulfilled to support multimedia warning message delivery in the 5GS and describes trials of a broadcast multimedia public warning alert system.

A feature called Advanced Emergency Information (AEA) is implemented in Advanced Television Systems Committee (ATSC) 3.0 [3]. AEA allows transmission of multimedia based alerts to all TV receivers in a selected area. For alerting cellular devices, however, this mechanism is not suitable, due to lack of ATSC 3.0 capable receivers in the devices.

The delivery of common content to a large number of receivers is very important in 5G systems. The common content can be accessible by all receivers in the network (broadcast) or by a subset of receivers (multicast). Unlike the one-to-one transmission (unicast), broadcast/multicast represents a very efficient way of delivering content in a spectrally efficient way. For this purpose, 3GPP has developed Evolved Multimedia Broadcast Multicast Services (eMBMS) [4], [5], [6], [7], [8]. 3GPP is introducing multicast and broadcast support in 5G New Radio and 5G Core in Rel-17, while the 5G broadcast up to Rel-16 is LTE-based [4]. There has been a vast array of studies contributing to the development of efficient media delivery for 5G [9], [10], [11], [12], [13], [14].

5G-Xcast project [15] studied eMBMS in 5G networks and recognized that the User Equipment (UE) should not continuously be monitoring for public warning (PW) messages as that would lead to unnecessary battery consumption. Therefore, the network needs to send a trigger that wakes up the UE to start receiving multimedia PW content. Two mechanisms are foreseen: Cell Broadcast and Paging.

Cell Broadcast can be used to broadcast text-based warning messages in a specific target area as is done with current PWS. Such a text message may contain one or more embedded links to additional information. In case of an Amber alert (missing child alert) this could for example be a picture of the missing child. The user can click a link if he or she wants to see additional information. Upon clicking the link, the UE will fetch the multimedia content. In current PWS this would be via a unicast connection, potentially leading to network overload if all users try to fetch the content simultaneously, resulting in a delay in the reception of the vital information. 5G-Xcast project studied the delivery of that content via transparent multicast, which would prevent overload and ensure timely delivery to all users.

Paging could also be used to notify the UEs about a

T. Jokela, J. Kalliovaara and J. Paavola are with Turku University of Applied Sciences, Turku, Finland, e-mails: { tero.jokela, juha.kalliovaara, jarkko.paavola }@turkuamk.fi.

M. Bot and P. Sanders are with One2many, Deventer, Netherlands e-mails: { menno.bot, peter.sanders }@one2many.eu.

H. Kokkinen is with Fairspectrum, Helsinki, Finland, e-mail: heikki.kokkinen@fairspectrum.com.

B. Altman is with LiveU, Kfar Saba, Israel, e-mail: baruch@liveu.tv.

C. Barjau and D. Gomez-Barquero are with Universitat Politècnica de València, Valencia, Spain, e-mails: { carbare1, dagobar }@iteam.upv.es.

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broadcast of multimedia warning messages. UEs are required to receive the paging message during every paging cycle. Such a notification already exists for Cell Broadcast.

The multimedia content that is delivered over broadcast could consist of multiple files. The files include one or more text files containing the warning in text in one or more languages, one or more video files containing for example the warning in sign language and one or more audio files containing the warning in spoken words for those who have a visual impairment.

Spectrum sharing enables efficient utilization of valuable spectral resources. Spectrum sharing can be divided in exclusive spectrum use, i.e. no spectrum sharing, static sharing with radio licenses, dynamic sharing using electronic control like geolocation database or listen before talk equipment, and license-exempt public access. In this paper we dynamically allocate additional frequency resources in band 28 to obtain additional capacity for public warning services when needed. By bonding connections, the delivered content can be split between multiple IP/wireless connections for simultaneous transmission thus increasing capacity and reliability.

The PWS application on the UE should be able to select and display the appropriate files according to user preferences. This paper describes how this can be achieved at a reduced cost and power consumption.

This paper is organized as follows. Section II describes the considered use cases and scenarios, followed by section III illustrating the technology used in trialing the multimedia public warning. Section IV discusses the trials performed on broadcast transmission of multimedia public warning messages. Section V extends the trials with introduction of dynamic spectrum use and bonded connections to further enhance the transmission of multimedia PW alerts. Concluding remarks are given in section VI.

II. Use cases for multimedia PW

In the Multimedia public warning alert, users are notified with alerts carrying multimedia and manifold information, which improves the effectiveness and reactivity of the users' responses. Alerts include a description of the type of alert and multimedia data providing instructions, advice and additional information to users (e.g. instructing them on how to better react to the alert). The digital structure of a message encompasses several types of alerts. Multimedia data carries the kind of information which is difficult to squeeze in the limited amount of text an alert typically has, such as pictures, audio and videos (e.g. audio for visually impaired and video with sign language for hearing impaired, speech in several languages), telephone numbers, Uniform Resource Locator (URL), recommended actions, and geographical information.

Every message includes at least a minimal set of multimedia components used to convey the message to both able-bodied and disabled people, in particular: textual information for able-bodied individuals, audio content for visually impaired persons, and video with a sign-language interpreter for deaf people. Depending on the type of alert, this use case can be time critical as ability to quickly receive input from the community contributes to a timely and hopefully positive outcome. The alert is sent to a targeted location. Within that targeted location, all users need to be notified promptly. The use case is illustrated in Fig. 1

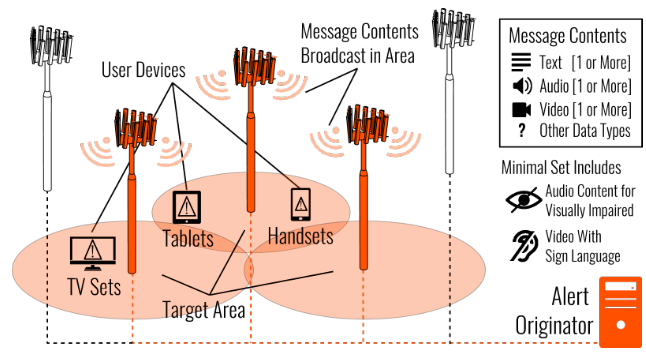

Fig. 1. Public warning use case [16].

Three scenarios for the utilization of multimedia based public warning alerts were considered in 5G-Xcast project: Amber (missing child) alert, flooding alert and accident at a port. The port accident scenario has further been demonstrated with the setup described in section V.

The Amber alert consists of a single alert and asks members of the public to look for a missing child. The alert has four components: a text-based message, a photo of the child, the text message spoken in an audio file and the text message spoken in sign language in a video file. The message is broadcast in wider area and is repeated and repetitions of messages that have already been displayed to the user will be ignored. All four components are broadcast in a single message and the app on the mobile device is configured by the user to display only the relevant components, where the photo is shown to every user after having seen/heard the message.

The flooding scenario considers a situation in which a river is going to flood due to heavy rainfall and people are requested to stay away from the riverbanks. Later, the flooding becomes so bad that houses along the riverbank in downtown get destroyed and people need to evacuate. A map is provided to show where shelter can be found. The alert consists of two messages which are broadcast with an appropriate interval between them. The second message has two components; text and a map.

Port accident scenario contains an oil tank fire in a harbor. Due to a large fire, toxic smoke is emitted which is drifting into city area. The city of Turku in Finland was considered as an example as the public warning system was trialed there.

A. Alert contents used in the trials

The content developed for the trials and demonstrations animates the aforementioned oil tank fire in Turku harbor. The alert consists of one message with the following information:

- One text message consisting of headline and description. Both Finnish and English are possible, but not at the same time.
- Polygon of Turku area
- Picture of the oil tank on fire

- Picture of the alert location
- Graphical instructions (depicting smoke from fire, close window/door)
- English audio message
- Finnish audio message

The English message could be: ”Oil tank on fire in the Turku harbor resulting in toxic smoke drifting to the Turku downtown area. Please go inside and close all windows and doors. Message send by Southwest Finland Emergency Services.”

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 on the UE are shown in Fig. 2. The total size of data in the alert is roughly 300 kilobytes.

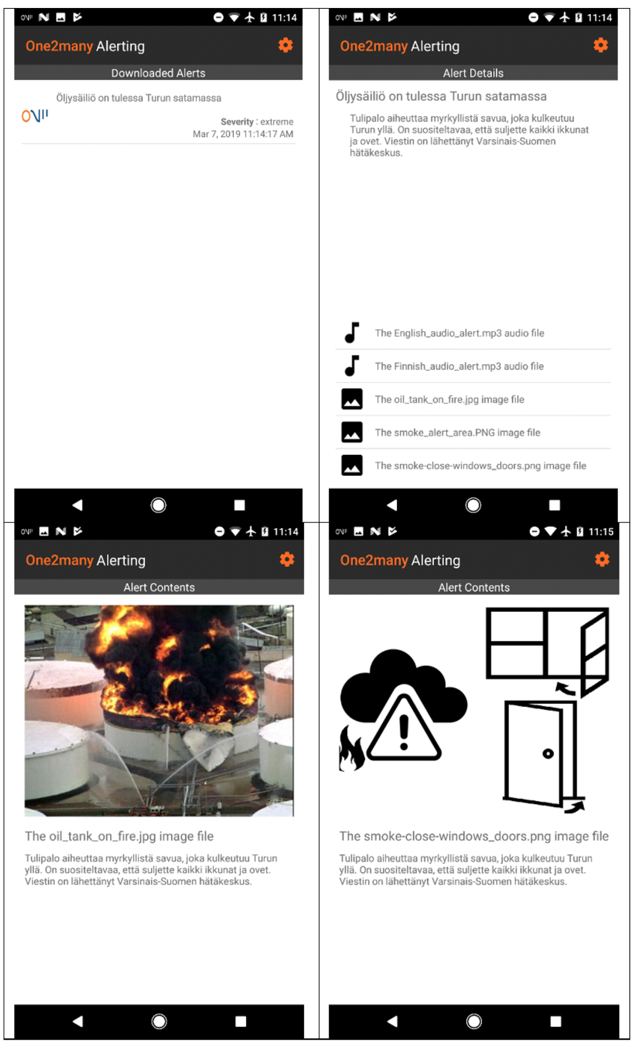

Fig. 2. Screenshots of the alert contents.

B. *Requirements for alert transmission*

A key requirement for PW applications is secure and reliable delivery of alert messages to the general population in emergency situations. 5G point-to-multipoint [13] capabilities developed in 5G-Xcast project ensure that PW messages reach a large number of users simultaneously without causing network congestion or even significantly increasing the traffic load [16]. Also, the battery life of the user equipment shouldn't be dramatically shortened due to the availability of the public warning service. This calls for signaling to enable triggering the reception of the public warning only when necessary. Full list and detailed description of the requirements for public warning service and how they were addressed during the 5G-Xcast project can be found in [17] and [18].

III. Technology for Public Warning

A. *Public Warning alert creation with multimedia content*

The PW alert content is created by using the graphical user interface of the Public Warning Platform (PWP) developed by one2many and shown in Fig. 3. 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

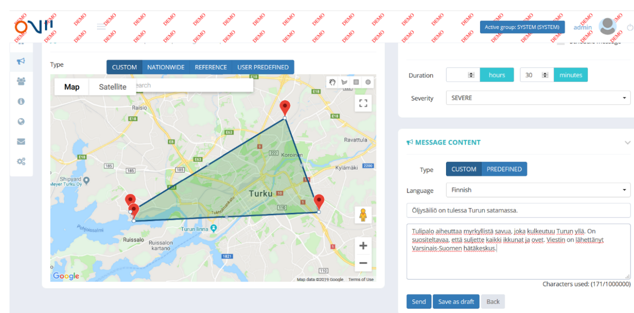

Fig. 3. Screenshots of the PW alert creation.

The addition of multimedia content requires the alert originator to add 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). 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. The Common Alerting Protocol (CAP) [19] was used to specify the alert as an Extensible Markup Language (XML) message.

B. *Linked and embedded content*

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

- Embedded - the content as 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 supports both methods. In the 5G-Xcast project both methods were tested. The first solution used embedded alerts resulting in a single large file that was broadcasted using eMBMS. This worked well for receivers which are eMBMS capable, but in case of unicast delivery the download of the very large file to each phone caused strain on the network. The fact that the content is base-64 encoded also further increases the size of the message.

For the trials with multilink and spectrum management in Section V it was also required to deliver the alert using LiveU bonded connections (cellular with WiFi of the UE) which can only achieve benefits 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).

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). This would likely increase performance of the download and thus faster content delivery to the UE, allowing bonding from the edge to deliver higher grade content (more video files) to supporting UEs.

C. Middleware to facilitate multimedia alert delivery

Alert delivery to the UEs using eMBMS and/or unicast, with linked or embedded content, requires several steps to be completed. These steps were developed in a separate transmission side software called here transmission middleware. Transmission middleware is responsible for the following actions:

- Receives the CAP message through HTTP from PWP and sends positive response to PWP
- Storing the multimedia content into the Google Cloud CDN (optional)
- If dynamic spectrum management is used: Defines area (using polygon of the alert), asks for spectrum from spectrum manager and waits for spectrum management to have setup the spectrum. Dynamic spectrum management is used to allocate additional resources for public warning when required, as described in Section V.
- In case of delivery using eMBMS: 1) Copies the multimedia content onto the Broadcast Multicast Service Center (BM-SC), 2) Logs in the BM-SC Representational State Transfer (REST) Application Programming Interface (API), 3) Schedules the content for broadcast in defined time window (of the alert) on broadcast bearer with defined characteristics: area, bitrate, QoS Class Identifier (QCI), Forward Error Correction (FEC), etc.
- Notifies the UEs using Google Firebase Cloud Messaging (GFCM). Two different methods were tested: 1) When embedded alerts are sent, the notification is only a trigger containing a message with the filename of the alert and 2) In case of linked alert, the actual alert is sent in CAP format

It should be noted that the benefit of linked alert here is that when the alert is delivered to the UE (by GFCM), 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 [20]. This is a low-code programming platform for event-driven applications which lends itself well for implementing proof-of-concepts.

D. Google Firebase Cloud Messaging for push notifications

Using Cell Broadcast or paging to trigger the eMBMS reception in the UEs would be the ideal solution. As these functionalities were not available in the testing environment, an alternative solution based on GFCM was developed for trialing purposes. GFCM was used to deliver the alert as a notification to the UEs. GFCM supports both Android and Apple devices. 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 notification instructs the UE to start receiving the alert. Therefore, the performance of delivering the notification (that is, how quickly the UE receives the notification) has a great impact how quickly the the alert becomes available on the UE. When the UE has an active Packet Data Protocol (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. Further, when the Cell Broadcast or paging is used, the delay of the notification is expected to be shorter than that of the GFCM used in the trials of this paper. In case of dynamic spectrum, the notification is delivered as soon as the UE re-attaches itself to the network.

E. eMBMS delivery of multimedia alerts

The one2many eMBMS components were used to deliver the multimedia alert to eNB. These components consist of BM-SC and MBMS GW. The transmission middleware schedules the delivery of the eMBMS session. A unique identifier is created for each alert, allowing the eMBMS session to be correlated with the actual alert in PWP. The eMBMS session used in the trial 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

F. 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 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) (mainly MCS number 18 (64-QAM), while also MCS 10, 9, 6 (16-QAM) and 4 (QPSK) were tested). The lower MCSs were also tested as they are required when for example deeper indoor coverage is required. 10% of the carrier capacity was allocated for eMBMS. Synchronization period length of 60 seconds was used in the trials and the UEs were using Network Time Protocol (NTP) from the core network for synchronization. The selection of synchronization period and time reference were observed to be important to be correctly set, as the eNB will otherwise drop packets with timestamps outside the buffering range.

G. PW reception

The public warning reception application developed by one2many receives trigger from GFCM utilizing unicast capacity of the carrier. Once the trigger is received, the 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.

IV. eMBMS TRIALS

The primary target of the trials was to study the behavior of the end-to-end public warning message transmission in 5GTNT (5G Test Network Turku) facilities [21]. For this purpose, the following performance indicators at the UE side were studied:

- Time to receive the alert
- Robustness of the transmission

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

LTE equipment and transmission parameters used in the trials were the following:

- eNB: Nokia Flexi Zone (band 28), 250mW output power (further attenuated by 30 dB with step attenuators), 10 MHz bandwidth, 10 % capacity allocated for eMBMS
- Agilent step attenuators for signal strength measurements
- UEs: Bittium Tough Mobile phones for eMBMS reception

A. Signal strength measurements

To study the effect of the signal strength on the performance of eMBMS reception of the public warning messages in the laboratory, step attenuators shown in Fig. 4 were attached to the Radio Frequency (RF) outputs of the eNB. Same amount of attenuation on both RF outputs was used each measurement. The amount of attenuation was confirmed from the spectrum view. The signal level 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 considered in the configuration of the transmission parameters.

Further, the performance of the FEC with 25% additional redundancy incorporated in the File Delivery over Unidirectional Transport (FLUTE) transmission of the packets was studied.

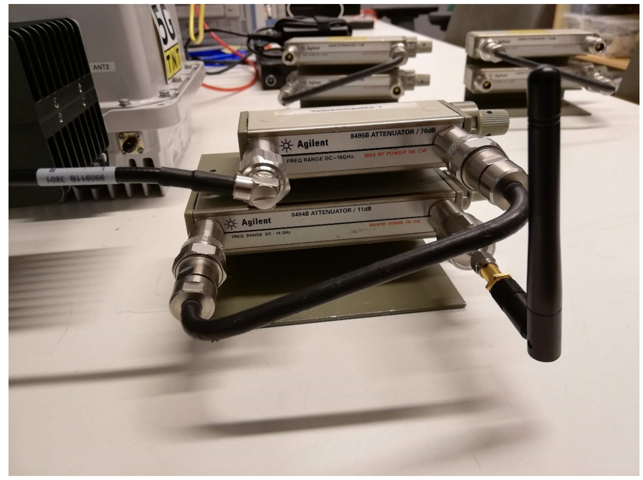

Fig. 4. Step attenuators used to control the signal strength.

Packet loss was observed in some scenarios and the applied FEC allowed the files to be re-constructed. The performance of similar FEC mechanism for data transmission over DVB-H system is studied in [22]. The results are shown in Table I. For example, the first row represents 0 dB attenuation with MCS 18 for both the announcement and payload sessions. In this situation the signal level is good enough for successful reception of the alert over eMBMS with all UEs every time with around 4 seconds delay from the start of the alert transmission. Increasing the attenuation in general increases the packet loss and makes the download time longer. Further, 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 Table I contains only four UEs, meaning that the results are not statistically reliable but serve rather as an indication of the performance.

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 1 shows that at the attenuation level (25 dB) 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.

B. 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 Fig. 5.

Interfering signal level when the unicast communication was barely operational (rather low bitrate, UEs having troubles to attach to the network) was sought. While unicast transmissions remained operational, successful eMBMS file download

TABLE I
MEASURED DOWNLOAD TIME FOR THE ALERT AND RESPECTIVE PACKET LOSSES.

	UE1		UE2		UE3		UE4	
Attenuation	**time (ms)**	**packet loss**	**time (ms)**	**packet loss**	**time (ms)**	**packet loss**	**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	-	-

was found impossible with this kind of interference even with the most robust modulation and coding parameter. 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 for eMBMS this is not possible. As can be seen in Fig. 5, the 8 MHz DVB-T signal does not affect all the subcarriers of 10 MHz LTE downlink, thus there are unaffected subcarriers at the upper and lower frequency parts of the LTE signal that can be utilized for unicast transmission.

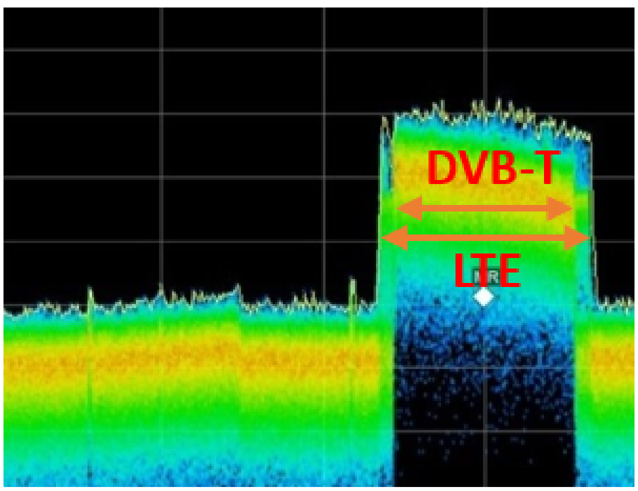

Fig. 5. Interfering DVB-T signal added on top of the downlink signal.

V. TRIALS WITH DYNAMIC SPECTRUM MANAGEMENT AND CONNECTION BONDING FOR PUBLIC WARNING

A. System for demonstrating the concept

In addition to broadcast transmission of the public warning message alert contents, dynamic spectrum management was applied to allow for additional dynamic capacity for transmission of alerts to for example phones that are not broadcast reception capable. The spectrum manager processes the changed spectrum situation and evaluates if the lower priority use may cause harmful interference to the higher priority PWS 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, that is the public warning network, is able to select the frequency channel to be used. For the proof-of-concept presented here the spectrum manager is connected to public warning system so that when the alert is activated, spectrum manager allocates spectrum resources in band 28 for public warning alert transmissions. More details on the applied spectrum manager can be found from [23], [24].

Further, multilink technology was trialed to bond several LTE connections, including the dynamically managed public warning network 5GTNT LTE and three public LTE networks, for increased capacity and delivery reliability. The 5GTNT LTE network is used to demonstrate the performance improvement achieved with multilink and dynamic spectrum management. The system architecture is shown in Fig. 6. In this system, a new spectrum resource in band 28 is dynamically defined and created in the spectrum manager. The additional spectrum capacity is added to the public LTE link as a second link in the same network by using the bonded multilink. The trigger for the PWS alert is sent using the public LTE to the UE. The UE will receive the multimedia components using the eMBMS broadcast. Further, the receivers that are not broadcast capable will fetch the content via the bonded unicast capacity.

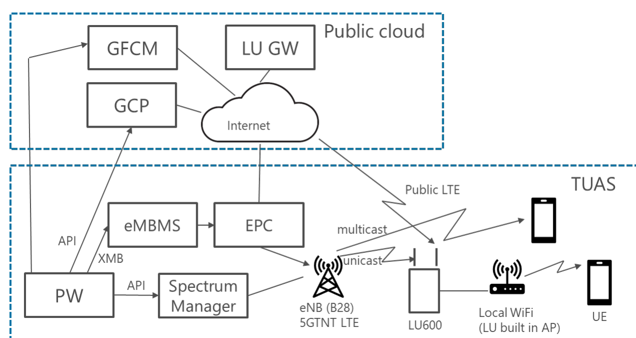

Fig. 6. Dynamic spectrum management and connection bonding trial system architecture.

B. PW and spectrum management flow

Starting point of the call flow is that the PWS has an alert to send to the UEs. The alert contains multimedia components. Using the CAP specification, the multimedia component can be embedded together with the alert or provided as separate files which are referenced by the alert using URI. The steps for delivering the alert to the UE are:

- Request dynamic LTE spectrum from spectrum management system.
- Push the content to content Google Cloud Platform (GCP) server.
- Perform unicast trigger over WiFi or LTE (GFCM).
- Application on the UE receives a trigger.
- Request the content from Wi-Fi or from eMBMS reception middleware in capable UEs.
- Fetch the content from the content server, bond LTE links by multilink to improve throughput and reliability of the delivery.
- Display the content.

The setup consists of the eMBMS public warning setup extended with spectrum management and LiveU Databridge multilink. Picture of the setup in the laboratory is shown in Fig. 7. The 700 MHz band 28 base station is shown on right and the LiveU LU600 multilink device in the middle. The LiveU multilink device is connected to a LiveU Gateway (LU GW) through public Internet. Some of the terminals on the table are connected directly to eNB for eMBMS and unicast, and some via WiFi to multilink device operating as WiFi access point. This WiFi access point is connected/served via public LTE networks. The laptop on the left is running the software used for creating an alert.

Fig. 7. Laboratory setup of the demonstrator.

Once an alert is to be transmitted, the additional spectrum and capacity is allocated for the alert transmission by spectrum manager. The correct functioning of the additional capacity allocation was confirmed by spectrum analyzer. 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 LTE networks (Telia, DNA, Elisa) and 5GTNT network (LTE band 28) as dynamic additional capacity were used. The multilink device screen when the alerts were transmitted is shown in Fig. 8. 5GTNT network is shown as "No Name".

When the additional spectrum is allocated and the second network becomes available, the multilink LU600 identifies this automatically and starts using it for unicast. Rich media content (of size between 50 and 1000 kilobytes) can then be unicasted to connected devices, split over the networks by the LiveU 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 alerts containing visualization of the incident or clear evacuation or other instructions, may be delivered to these UEs quickly and reliably. The operation

Fig. 8. Multilink device connection status when the alert is being transmitted.

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 device middleware log-files.

After the alerts are received via eMBMS, unicast or multilink, the terminal displays the alert contents.

VI. CONCLUSIONS

The trials in this paper have demonstrated the delivery of multimedia public warning messages using eMBMS, dynamic spectrum management, and bonded connections.

The delivery using eMBMS is robust in the measured scenarios. In more challenging conditions, the robustness of the transmission could be further improved by lowering the MCS, which would also result in lower data rates. If a limit can be set on the amount of multimedia content that can be combined into a single message, then the subsequent delivery times can also be predicted.

Dynamic spectrum allocation was trialed successfully. In the trial both multilink and eMBMS devices connected almost instantaneously to the dynamically added network as soon as it became available. Bonding connections with multilink was demonstrated with multiple LTE networks being used concurrently to deliver the data to several UEs using WiFi, where the multilink device acts as a WiFi Access Point with LTE networks bonded together. It would be advantageous if technology for bonding connections could be supported by the UE middleware, allowing both higher bitrates and redundancy. This would benefit multiple use cases in addition to PW.

Raptor 10 FEC was used in the tests. On some occasions where packet loss was observed (in the radio) the phones used the FEC information to repair the received content. The content was also sent repeatedly. However, it seems that the middleware did not use multiple repetitions to combine content (in case FEC is not sufficient). This could be further investigated. In addition, it is also possible to deploy eMBMS file repair, allowing a phone to fetch only the missing information over unicast (versus the whole file), which should improve the robustness even further.

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