Implementation and Validation of Multimedia Broadcast Multicast Service for LTE/LTE-Advanced in OpenAirInterface Platform

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Abstract—**Evolved Multimedia Broadcast Multicast Service (eMBMS) is a point-to-multipoint content delivery solution designed for LTE/LTE-A. It distributes efficiently the broadcast and multicast service to a massive number of mobile devices located in a given geographical area. eMBMS can be used to boost the network's capability for providing high-quality multimedia service in high user-density area such a stadium during an entertainment or sport event. The aim of this paper is to validate and evaluate the performance of eMBMS following the 3GPP standard (release 10) implemented in the context of the OpenAirInterface SDR platforms. The difference between the OpenAirInterface in-lab system validation platform with respect to existing simulation/emulation tools such as OPNET, matlab, NS-2/3 is that firstly it is built with a high level of realism supporting real-time operation (based on RTAI and RT-Preempt); secondly it is part of the integration and validation chain for a real-time RF experimentation. The results show that eMBMS performance in the OpenAirInterface satisfies the requirement of 3GPP standard in terms of BLER. Furthermore, the theoretical user throughput proposed by 3GPP have been validated through experimentation.**

Index Terms—**eMBMS, LTE,LTE-Advanced, Validation, Performance Evaluation, OpenAirInterface.**

I. MOTIVATION

The evolution of mobile devices with higher multimedia capabilities together with the deployment of high capacity mobile network recently have made an immense growth in user data traffic especially multimedia content. High quality video services such as live streaming, online interactive gaming or mobile TV always attract a great attention from telecommunication industry. To meet this tremendous demand, many technologies are developed to provide mobile multimedia broadcasting such as DVB-NGH, DMB or MediaFLO. Following the trend, the Third Generation Partnership Project (3GPP) has defined the Multimedia Broadcast Multicast Service (MBMS) and later evolved MBMS (eMBMS) [1] built on top of its standard cellular network.

Thanks to the inherent benefits of OFDM and Single-Frequency Network (SFN) technologies, eMBMS in LTE can provide better services than MBMS did in 3G network. Many telecommunication companies have invested and deployed eMBMS as an efficient and low-cost means to deliver multi-media content. In 2012, Qualcomm and Ericsson demonstrated their eMBMS solution at Mobile World Congress (MWC). Earlier 2013, they demonstrated eMBMS on live test network in cooperation with two operators Verizon and Telstra announced plans to launch a live video broadcast service for sport events based on eMBMS technology. Alcatel Lucent and Huawei also introduced their end-to-end solution to support broadcast video delivery in LTE network. Samsung joined with test-equipment company Anritsu to demonstrate LTE broadcast with intention to commercialize the service in near future.

Not only telecommunication companies, research community has also paid a lot of attention to (e)MBMS since its appearance. A. Alexiou and F. Hartung are among the researchers who have thoroughly studied about MBMS in cellular network from UMTS to LTE. F. Hartung et al. in [14], [15] present the evolution of MBMS and its performance in 3G network. In [11]–[13], A. Alexiou and his colleagues focus on cost analysis, power saving and spectrum efficiency in difference MBMS configuration. The efficient content delivery broadcast/multicast service in LTE are addressed in [16], [17]. Although these works are very well studied, they still have some issues: *i)* some research have used WCDMA as air-interface technology rather than OFDMA that is used in current cellular network; *ii)* most of them used regular simulation tools which have abstraction in some crucial parts of the network stack that can hide important issues. They can be only revealed when implementing and deploying on a large scale. For the best of our knowledge, there are very few complete implementation of eMBMS service in LTE simulator/emulator tools (one was introduced in [16] using LTE-sim). Besides, eMBMS is still in standardization phase, many aspects should be addressed like service continuity or MIMO transmission; therefor an emulator/simulator tool that can provide an accurate, more realistic performance evaluation and be able to implemented in a real system is in need. That is the motivation for us to implement eMBMS on our open-source platform - OpenAirInterface [8]. This emulator platform relies on a full real-time implementation of the layer 2 protocols and the physical layer (PHY), which allows protocol

and application performance evaluation and validation as well as system testing.

The rest of this paper is organized as follow: section II gives an introduction to eMBMS in LTE network and its characteristics, the OAI platform and the implementation for eMBMS are described in section III, simulation result will be mentioned in the section IV and finally the conclusion comes at section V.

II. EMBMS IN CELLULAR NETWORK

In this section, the broadcast/multicast service in LTE network will be introduced. In addition, the way of allocating resources among different services in the network side as well as the procedure to receive MBMS service in the terminal side are also mentioned.

A. eMBMS Overview and Architecture

Multimedia Broadcast Multicast Service standard was first introduced in 3GPP specifications release 6 (Rel-6) for Universal Mobile Telecommunications System (UMTS) to provide broadcast service over cellular network. Since then, it has been evolved in subsequent releases and still in the state of standardization until now. In 3GPP Rel-7, MBMS over a Single Frequency Network (MBSFN) was introduced to overcome cell-edge problem of MBMS. In SFN operation, an identical waveform is transmitted from multiple cells with a tight synchronization in time. From 3GPP specification Rel-9, together with the appearance of Long Term Evolution (LTE), MBMS over SFN was included in Evolved Universal Terrestrial Radio Access Network (E-UTRAN) under the name of Evolved MBMS (eMBMS). The user equipment (UE) would not realize the difference in signals from multiple cells in MBSFN transmission as they are perceived as the same signal received with multi-path effect from one big cell.

An evolved architecture is required to support eMBMS transmission in LTE network. Such an architecture is depicted in the Fig. 1. Following the 3GPP specifications, there are new logical network entities proposed for eMBMS operation:

- **BM-SC (Broadcast Multicast Service Center)**: entity that connects the Content Provider and the Evolved Packet Core. It plays the role of traffic shaper and authorizing content provider/terminal request. It is also in charge of SYNC protocol to synchronize transmitted data among eNBs. SYNC protocol associates a specific header to IP packets, providing Time Stamps and session information.
- **eMBMS GateWay**: entity that is located between BM-SC and all eNBs. Its principal function is to deliver MBMS user data packets to eNBs by means of IP Multicast. When an MBMS session arrives, it allocates IP multicast address to which the eNB should join to receive MBMS data and maintains the IP Multicast group. Futhermore, eMBMS GateWay is responsible for MBMS session announcement and it also performs MBMS Session control Signaling (Session Start/Stop) toward E-UTRAN.
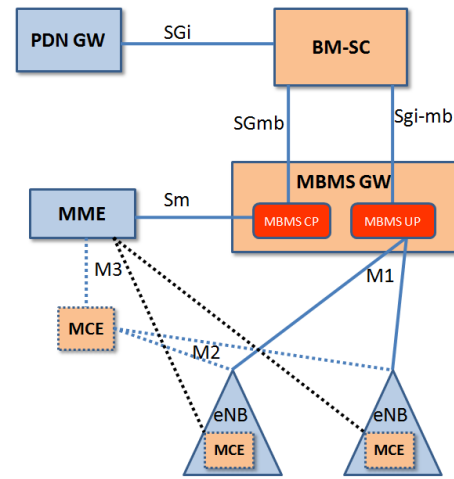

Fig. 1: Network Architecture for eMBMS

- **MCE (Multi-cell Coordination Entity)**: logical entity whose responsibility is doing admission control and allocation of the radio resource using for MBSFN operation. The MCE is expected to be a part of e-UTRAN and can be integrated as a part of a network element. Fig. 1 shows two envisaged alternatives for deployment in practical system: MCE is either part of eNB (which is considered as "distributed MCE architecture") or a stand-alone MCE (a.k.a "centralized MCE architecture").

To connect these new entities with others components in the network, new interfaces are also defined:

- **M1 interface** is a user plane interface connecting eMBMS-GW and eNB. IP multicast is used to deliver point-to-multipoint MBMS data packets over the M1 interface. SYNC protocol is used over the M1 interface to keep the content synchronization in MBMS data transmission. There is no control information transmitted over this interface.
- **M2 interface** is a control plane interface locates between MCE and eNBs. An Application Protocol (M2AP) is defined for this interface to convey at least radio configuration data for the multi-cell transmission mode eNBs and Session Control Signaling. The M2 interface would not exist if the "distributed MCE architecture" is deployed.
- **M3 interface** connects MME and MCE. M3-Application Part allows for MBMS Session Control Signaling on E-RAB level (i.e. it does not convey radio configuration data).This interface supports Session Control Signaling, e.g for MBMS session initiation and termination (MBMS Session Start and Stop as well as MBMS Session Update).

B. Resource Allocation for eMBMS

One desired feature of eMBMS in LTE is the ability to allocate the radio resource in a flexible way, it means we can adjust the amount of resource dedicated for broadcast/multicast services depending on the situation (e.g. if there
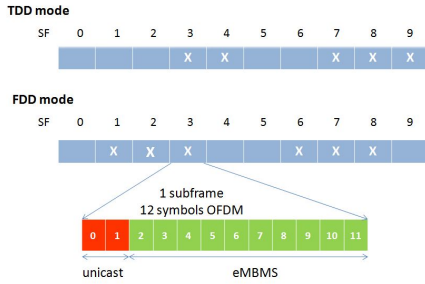
Fig. 2: Subframe allocation for eMBMS

is an live event taking place, the operator can assign maximum resource for eMBMS, otherwise only one or two subframes are used for broadcast service). As specified in the standard, in one radio frame (10ms), there are up to 6 out of 10 subframes can be allocated to eMBMS services. Depending on LTE duplex mode TDD (Time Division Duplex) or FDD (Frequency Division Duplex), subframes in pre-determined positions can be assigned for eMBMS transmission as shown in the Fig. 2.

Through SIB13/MCCH, the terminal is informed about the position of subframes assigned to eMBMS (also called MBSFN subframes) in one radio frame. In practical implementation, this information is conveyed through a string of six bits, each of which corresponds to the eMBMS subframe. If a subframe is chosen to convey eMBMS data, the corresponding bit will be set to 1. The standard allows two options in allocating subframe for eMBMS: one-frame pattern (6-bit string) or four-frame pattern (24-bit string). By this way, the network can be very flexible in allocating resources for unicast or broadcast/multicast services. Furthermore, inside one MBSFN subframe, 1 or 2 first symbols are reserved for the unicast transmission in physical downlink control channel (PDCCH), which are mainly used for the uplink scheduling grant purpose.

In MBSFN operation, a group of cells that are synchronized to transmit the same broadcast/multicast content in a geographical region is called MBSFN area. One or more services are provided in a certain MBSFN area. These services are classified into different groups base on their requirement in Quality of Service (QoS), i.e. those that have the same quality will be in the same group. Due to the same quality requirement, all services in one group can be transmitted
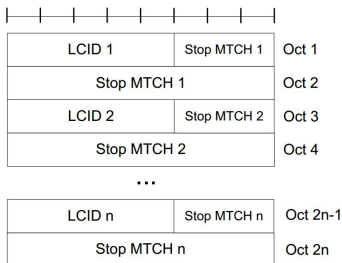

Fig. 3: MSI MAC control Element (3GPP TS36.321)

using one modulation coding scheme (MCS) by a specific transport channel for eMBMS so-called Multicast CHannel (MCH). This design allows one MBSFN area to provide multiple eMBMS services that are multiplexed in time-domain according to the 3GPP specifications and transported through MCHs.

The time period in which all MCHs sharing resources is named Common Subframe Allocation (CSA) period and given in the unit of radio frame. The exact position and number of subframes allocated for an MCH are provided periodically in dedicated eMBMS control information message, called the Multicast Control CHannel (MCCH) message.

Knowing that several services requiring the same QoS class are transported within the same MCH, resources allocation for a particular service is performed as follows. Each service corresponds to a Multicast Traffic CHannel (MTCH) and the eNB multiplexes these MTCHs at MAC layer. The scheduling information is provided repeatedly in a MAC control element called MCH Scheduling Information (MSI). In one MSI as shown in Fig. 3, all services (MTCHs) of respective MCH are listed together with both their logical channel identity (LCID) and the last subframe number assigned for this LCID (called Stop MTCH).

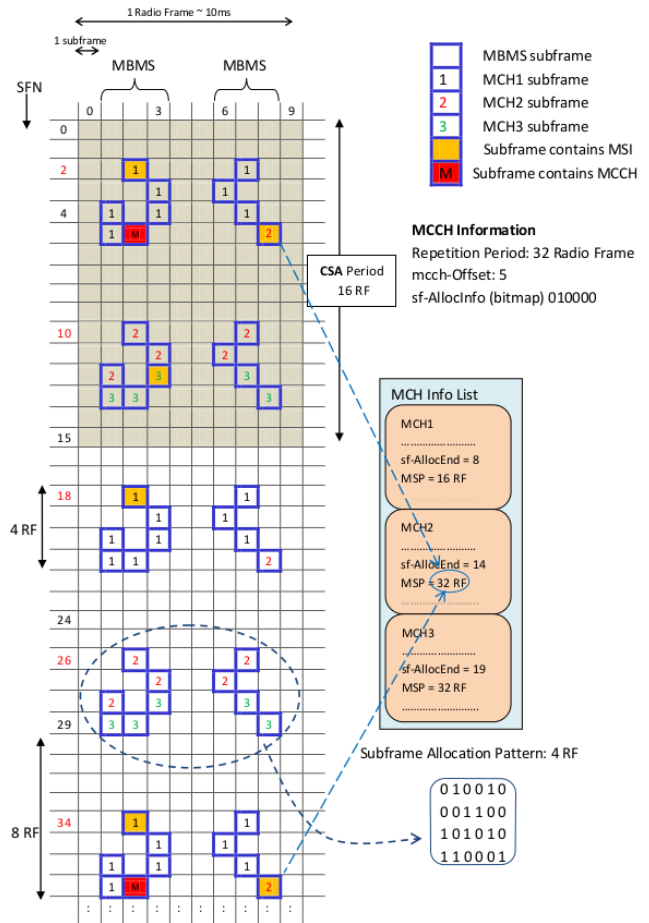The MSI is transmitted at the beginning of an MCH

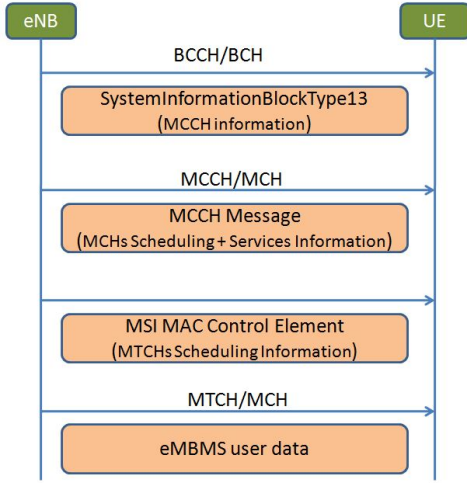Fig. 4: eMBMS resource allocation example

Fig. 5: eMBMS step-by-step reception

scheduling period (MSP) and this period is quite small in comparison with the period of MCCH message making the mutliplexing/scheduling of MTCHs (i.e. eMBMS services) over a particular MCH more dynamic. Fig. 4 shows an example configuration in resource allocation for eMBMS.

In the figure, horizontal axis represents ten subframes in 1 radio frame (RF), vertical axis represents radio frames. This example illustrates the MBSFN resource allocation in system with FDD configuration mode (subframe 1,2,3,6,7 and 8 can be assigned, see Fig. 2). A four-frame pattern is applied for MBSFN subframes using 24-bit string (matrix 4x6 in the figure) and it repeats every 8 radio frames. Subframes allocated for eMBMS are represented with numbered squares (blue-borderline elements) in the grid. The MCCH message (in red subframes with M labeled) is chosen to repeat every 32 radio frames. There are three service groups or MCHs and they are time multiplexed in a period of 16 RFs. Subframes for each MCHs are given in MCCH message and marked with the number corresponding to the index of MCH (1, 2 or 3). We can see in the example, last subframe for MCH 1 and 2 is 8 and 14, respectively (parameter *sf-Allo-end* in the figure), it means MCH 1 will take from subframes index 0 to 8 and subframes index 9 to 14 are reserved for MCH 2 (notice that the index here takes into account only MBSFN subframes). Subframes containing MSI control element are in yellow color and the repetition period of MSI for each MCH can be different (16RFs for MCH1 and 32 RFs for MCH 2).

C. Service Reception in eMBMS

Previous part explains how the data of specific service are allocated to MBSFN radio resources by the eNB. The user terminal will have to do an inverse procedure in order to know where it can get its interested services. A step-by-step reception procedure is described in figure below:

The control information related to eMBMS is stored in the message which is transported by logical channel MCCH, hence the UE firstly need to know how to get this message. This information is given to the user by means of System Information Block Type 13 (SIB13) which is defined for eMBMS. The position (which frame, subframe) and configuration (repeated period, mcs) of MCCH message are conveyed in SIB13.

The information in SIB13 allow UE to acquire the important MCCH message. As mentioned earlier, this message contains a list of eMBMS-service groups and their respective position among MBSFN resources. Each group, which is corresponding to on MCH, tells user about the MCS used for all services in this group and how many service does it has together with the information to identify a certain one like: service identity, session identity and logical channel identity.

After MCCH message acquisition, the user terminal knows the group/MCH, frame & subframe where it can find its services of interest. The only thing left is where exactly its desired services are located. The MAC control element MSI that is transmitted at the beginning of an MCH will help to do this task. Once the UE retrieves the information in MSI, it can actually access the interested services.

III. IMPLEMENTATION OF eMBMS IN OPENAIRINTERFACE

A. OpenAirInterface Platform

OpenAirInterface (OAI) is an open-source SDR-based hardware/software development platform targeting 4th generation wireless systems (3GPP LTE/LTE-A) as well as medium-range rapidly-deployable LTE mesh extension. The platform comprises both hardware and software components providing all-IP wireless networking and can be used for link-level simulation, in-lab system emulation and indoor/outdoor realtime RF experimentation. It comprises the entire protocol stack from the physical to the networking layer, including standard-compliant (Rel-8 and a subset of Rel-10) implementations of the 3GPP-LTE access-stratum (PHY, MAC, RLC, PDCP, RRC) for both eNB and UE and a subset of the 3GPP-LTE evolved packet core (EPC or core network) protocols.

The methodology in OAI platform is to use the real stack to perform more realistic and reliable simulations. This also reduces development time since the code can be ported to the final real-time implementation with very little redesign. The objective of this platform is to provide methods for protocol and algorithm analysis, performance evaluation and system and application testing. In addition to the protocol emulation environments described above, a fully-functional real-time two-way RF hardware (5 MHz channels at 1.9 GHz) is provided and has been made available to industrial and institutions partners.

When configured for the in-lab radio network experimentation, OpenAirInterface makes use of only the software platform and allows the full protocol stack to be run in the emulation mode either with the full PHY layer or with the PHY abstraction layer. In the latter case, the effective SINR mapping (ESM) method is used to provide the higher layers with necessary and accurate link quality metric related to the modem performance while improving the emulation efficiency [9], i.e., block error rate (BLER) or packet error

rate (PER). In both cases, the protocol stack is virtualized within the same or multiple physical machines. Inside the same physical machine, the virtualization is done within the same operating system instance and the Linux IP protocol stack is shared among nodes. Nodes in the network communicate via direct-memory transfer when they are part of the same physical machine and via reliable multicast IP over Ethernet when they are in different machines.

The results presented in this paper are obtained from the OpenAirInterface in-lab system emulation platform with the full PHY layer.

B. Implementation Details

As we mentioned in section II, there are two alternatives for deploying Multicell Coordination Entity: either centralized or distributed MCE. The latter one is chosen for implementing in the OAI platform, where the MCE resides at eNB. Although, OAI adopts the distributed MCE to reduce the complexity of the implementation, the actual design choice depends on the operators' requirements and type of network deployment.

Based on the structure described in previous section, new components and functions for eMBMS service are added to OAI platform. In the control plane at eNB side, the specified system information SIB13 and MCCH message are generated at Radio Resource Control unit in eNB side. Similar to system information in unicast transmission, eMBMS control information are transferred directly from RRC to MAC sublayer via BCCH and MCCH logical channel as described in Fig. 6. Another task of RRC is configuring the data bearers for eMBMS services at PDCP and RLC sublayer using the parameters given in SIB13 and MCCH message. It also store the parameters necessary locally at MAC for the scheduling purpose. In the other side, when the UE gets SIB13 and MCCH message, it uses the received information to configure the corresponding radio bearer for eMBMS service at PDCP and RLC as well as to prepare the decoding procedure at MAC.

In data plane, we fully implement the protocol stack for eMBMS user data according to the standard at layer 2 including PDCP, RLC and MAC sublayer. As stated in [2], PDCP is not used when eMBMS service is broadcasted in the E-UTRAN, therefore, PDCP in OAI operates in transparent mode. That means the Protocol Data Unit (PDU) is handed directly to RLC in eNB (or to upper layer in UE) without header and trailer appended.

At Radio Link Control (RLC) level, eMBMS uses the Unacknowledged Mode (UM) and one RLC-UM instant is created for one data bearer (or an eMBMS service). These RLC instants are responsible for segmenting the received SDU into smaller packets depend on the size demanded by MAC. They also add few bits for RLC header in these packets and then send them to MAC via MTCH logical channels in the transmitter side. The inverse procedure is applied in receiver side to reassemble these segments.

When control information and user data packets arrive at MAC of the eNB, they will be multiplexed into different transport channels before being transfered to physical layer or
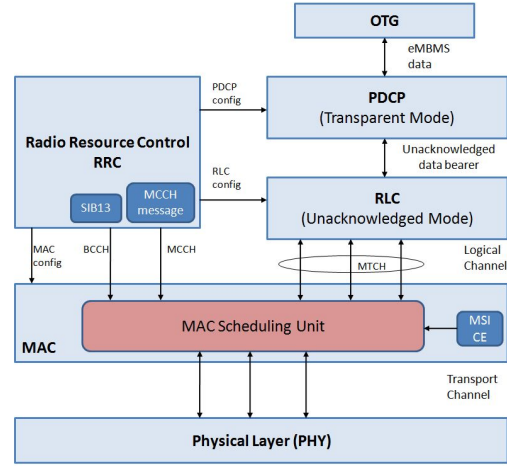

Fig. 6: eMBMS protocol stack in OAI

more precisely, the MCCH and MTCHs will be mapped onto different MCHs at this sublayer. Depending on the number of MCH channels (eMBMS service groups), one or more MSI control elements (CE) are periodically created for each MCH channel. Each of these MAC CEs contains the resource allocation information of services in the corresponding group such as Logical Channel IDentity (LCID) and the last position of each service.

A new scheduling unit for multiplexing MSI, MCCH and MTCHs is also implemented in this level. One thing to be noticed here is that a single MAC Protocol Data Unit should carry data of one MCH, which means there could be several services (MTCHs) that have the same quality requirement and maybe MCCH plus MSI CE in one MAC packet for eMBMS. Another point is, in EUTRAN, only mixed-cells (cell that are transmitting both unicast and broadcast/multicast) are supported for eMBMS; hence, the scheduling should be modified so that it will not affect the unicast traffic.

The eMBMS scheduling function in MAC uses the parameters sent by RRC to identify which subframes carry eMBMS data. If a subframe is reserved for eMBMS, no unicast data can be scheduled except the notification for uplink assignment which is transported on PDCCH in the two first OFDM symbols of that subframe. Using the result from the first step, MAC will create the control element MSI or get the MCCH control information and MTCH user data from RRC and RLC, respectively. The Transport Block Size (TBS) as well as Modulation Coding Scheme (MCS) is aslo calculated in this step. Finally, the MAC header is generated and added to the Service Data Unit (SDU) to complete the PDU and send it to PHY through MCH transport channel. It is worth noting that the Hybrid Automatic Repeat Request (HARQ) is not used in eMBMS.

The MAC sublayer of UE does not have the scheduling task but it does need to know the position where eMBMS data are transported through the information get from MCCH message.

At physical layer, most of PHY procedures for eMBMS are the same with those for unicast downlink transmission.

The Cyclic Redundancy Check (CRC) calculation, channel coding scheme (turbo encoder with coding rate equal 1/3) and rate matching for MCH and DL-SCH transport channel are identical [6]. In the scrambling procedure, there is a small different in calculating the initial value of scrambling sequence for eMBMS as specified in [7]. As in Physical Downlink Shared CHannel (PDSCH), three modulation schemes (QPSK, 16QAM and 64QAM) are available for PMCH. Nonetheless, only four MCS (2, 7, 9 and 13) values can be used in the subframe carrying MCCH message or MSI control element while with subframe transporting eMBMS user data, all MCS values are eligible. The biggest difference in PHY for eMBMS is the reference signals which are generated for channel estimation purpose. These MBSFN reference signals shall be transmitted at MBSFN region on antenna port 4 with a special pattern given in [7] and its sequence generating is also defined in the same document. At MBSFN subframe, the cell-specific reference signal can be generated at non-MBSFN region (2 first symbols). The PMCH can only be transmitted at MBSFN region in MBSFN subrame and the extended cyclic prefix should be used.

For user data in eMBMS, we use a tool called OpenAirInterface Traffic Generator (OTG) [10]. This tool is a realistic packet-level traffic generation tool for emerging application scenarios. Developed in C under Linux environment, OTG allows to generate realistic traffic pattern with both soft real-time and hard real-time constraint. When OTG is attached directly to user-plane protocols, it is capable of reproducing the packet headers as in a real networking protocol stack according to the user-defined configuration. In the simulation required to validate our implementation, OTG is used to generate eMBMS data and transmit to PDCP in layer 2.

IV. SIMULATION RESULT

To evaluate the performance of the implemented eMBMS system, we use the emulation tool built on top of the OpenAirInteface platform. The hardware platform is a laptop equipped with an Intel core i7 CPU running OAI emulator and protocol stack using Linux on Ubuntu 12.04. We carried out measurements in the soft real-time mode for LTE operating in FDD frame for 5MHz bandwidth, in a simple cellular network topology composed of one eNB (enhanced-NodeB) and one static User Equipment to measure the best case performance. The scenario with only one service group (one MCH) and one eMBMS service (MTCH) is applied in the experiment. More detail about simulation parameters can be found in table I.

TABLE I: Simulation Parameters for eMBMS

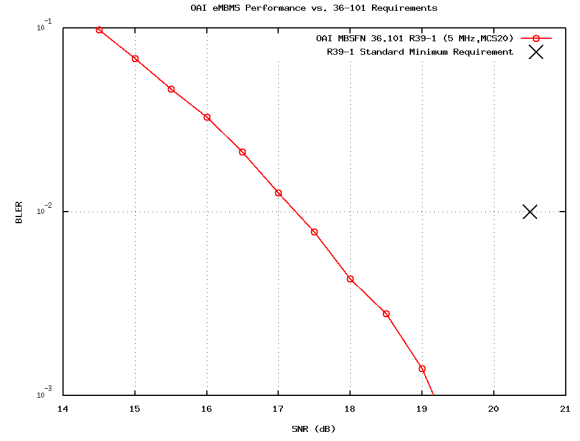| Parameters	Setting
Transmission Bandwidth	5MHz
Number of pairs of RBs available for eMBMS	25
Simulation time	10.000 radio frames
CSA period	16 radio frames
MCCH repetition period	32 radio frames
MSI repetition period	16 radio frames
Number of symbols per MBSFN	6 symbols (FDD)

Fig. 7: eMBMS performance in OAI

First metric we want to measure is Block Error Rate (BLER) which is indicated in 3GPP standard. According to [3], the minimum requirement for eMBMS transmission's BLER in both FDD and TDD configuration is 1% at SNR=20.5(dB) with the R.39-1 reference channel model and the Transport Block Size (TBS) corresponds to Modulation Coding Scheme (MCS) equal 20.

Fig. 7 shows the performance of eMBMS system in OAI platform in comparison with the LTE standard. As we can see in the figure, the eMBMS transmission in the simulation obtains a gain of 3dB at BLER=1% against the standard requirement (the x point in the graph). Our simulation was done with the same condition as used in the standard requirement (R.39-1 channel, MCS=20).

Moving from 3G to LTE, one major benefit of using LTE for eMBMS is that the bit rates for real-time services such as video streaming, video conference or interactive games are much higher than for MBMS in 3G network (UTRAN). Therefore the user throughput is an importance metric when assessing eMBMS performance.

The eMBMS user throughput of our simulation was shown in Fig. 8 together with the theoretical value. The red bars represent the user throughput of eMBMS system calculated
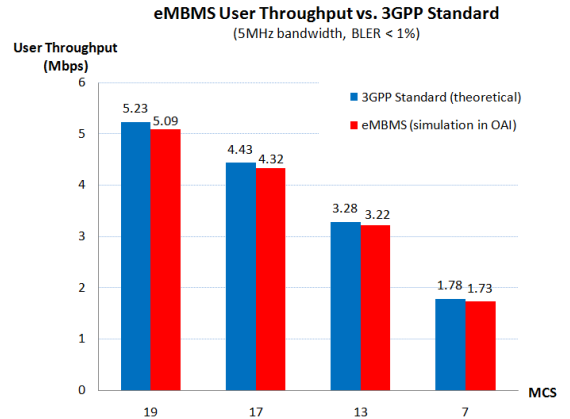

Fig. 8: eMBMS User Throughput

by OTG at receiver side while the blue bars represent the maximum transmission throughput for eMBMS calculated from specifications [5].

There is a slightly difference between these two values in each MCS configuration which can be explained as follow: firstly, the theoretical throughput is the transmission capability in physical layer while the user throughput is calculated after data is sent to OTG from PDCP. Hence, a small amount of resource is used for the headers at layer 2. Secondly, packet loss during the propagation over air interface (modeled channel) also effects the user throughput.

V. CONCLUSION

In this paper, we presented the implementation of eMBMS in LTE network based on release 10 of 3GPP standard on our real-time OAI platform. We also use OAI as a emulation tool for performance evaluating the eMBMS system. The BLER result better than the minimum requirement about 3dB together with the result in user throughput with different MCS very closed to the theoretical value has proved that our eMBMS implementation in OAI is correct and reflexes the standard.

For the future works, more realistic scenarios (consist of several eNBs providing multiple eMBMS services for a large number of UEs) would be tested using different network settings. The mobility management for eMBMS or the service continuity in mobile, heterogeneous environment should be investigated as well. Although eMBMS in OAI works with TDD frame configuration only in mode 3 at this moment, we are trying to make it work in all modes so that we can have a complete set for testing the LTE eMBMS service in real environment.

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