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Abstract

Recently, the evolution of wireless access technologies and mobile devices has created an explosion in the Internet mobile traffic. The popular of services like Netflix and YouTube has made the video streaming dominate the mobile data traffic. With video streaming service, in many cases, the same media content might be requested by a large number of users (e.g. new-released movies or a live sport event), which may lead to network overload because a dedicated radio resource is used for each mobile terminal. In response to tremendous demand for multimedia data and avoid the burden for network operators when the same service is sent simultaneously to numerous users, the Third Generation Partnership Project (3GPP) has defined the Multimedia Broadcast Multicast Service (MBMS) as an efficient and low cost solution for multimedia delivery.

Built on top of the 3GPP cellular network, the MBMS and its evolved version, the eMBMS, have great advantages over the conventional broadcast systems : It requires only minor adjustments in the existing network architecture. Therefore, eMBMS does not need a separate infrastructure or specific receiver like Digital Video Broadcasting (DVB) or MediaFLO. Further more, it can reuse the frequency spectrum of the 4G/LTE network and all subscribers of mobile network are the potential customers for broadcast services. As a consequence, eMBMS service is very promising and attracts a lot of attention from telecoms industry. However, the eMBMS is still at the standardization stage and some important features are very limited including the mobility support. In this thesis, we focus on the mobility-related issues of eMBMS service in LTE/LTE-Advanced network.

The thesis firstly introduces the broadcast/multicast service in cellular network and then addresses the problems of eMBMS in such a high mobility environment. Later, based on the standard analysis as well as the existing solutions in the research community, we propose a complete solution to guarantee the service reception for the moving eMBMS users. The continuity of media stream during the handover procedure is also mentioned in this thesis and followed by the presentation of a novel mechanism to reduce the service interruption time. For the validation purpose, the experiment in a real-time system is desired to see how much our proposal can improve the service quality of eMBMS. Due to lack of a simulator/emulator for eMBMS, we have implemented this broadcast service in an open-source, real-time radio system that is developed in our laboratory, the OpenAirInterface (OAI) platform. With this implementation, realistic results for eMBMS service performance can be obtained through the link level and system level emulation. Regarding the quality evaluation, it has been proved that the Quality of Experiment (QoE) is the most appropriate metric to indicate the satisfaction of the human users, particularly in video services. Thereby, we use the QoE metric to evaluate the performance of our proposed mobility support solution for eMBMS.

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Acronyms

Here are the main abbreviations used in this document. The meaning of an abbreviation is usually indicated once, when it first appears in the text.

3G	Third Generation
3GP-DASH	3GPP Dynamic Adaptive Streaming over HTTP
3GPP	Third Generation Partnership Project
4G	Fourth Generation
ALC	Asynchronous Layered Coding
ARP	Allocation and Retention Priority
BCCH	Broadcast Control Channel
BCH	Broadcast Channel
BLER	Block Error Rate
BM-SC	Broadcast/Multicast-Service Center
C-TEID	Common Tunnel Endpoint IDentity
CA	Carrier Aggregation
CBS	Cell Broadcast Services
CC	Component Carrier
CDMA	Code Division Multiple Access
CRC	Cyclic Redundancy Code
CSA	Common Subframe Allocation
DASH	Dynamic Adaptive Streaming over HTTP
DL-SCH	Downlink Shared Channel
DMB	Digital Multimedia Broadcasting
DVB	Digital Video Broadcast
DVB-NGH	Digital Video Broadcast - Next Generation Handheld
DVB-T2	Digital Video Broadcasting - 2nd Generation Terrestrial
E-MBMS	Evolved Multimedia Broadcast/Multicast Service
E-NB	Evolved Node B
E-RAB	E-UTRAN Radio Access Bearer
E-UTRAN	Evolved Universal Terrestrial Radio Access Network
EPS	Evolved Packet System
FDD	Frequency Division Duplex
FEC	Forward Error Correction
FLUTE	File Delivery over Unidirectional Transport

FTP	File Transfer Protocol
GERAN	GSM EDGE Radio Access Network
GGSN	Gateway GPRS Support Node
GPRS	General Packet Radio Service
GTP	GPRS Tunneling Protocol
GTP-C	GTP for Control plane
GTP-U	GTP for User plane
HARQ	Hybrid Automatic Repeat Query
HO	Handover
HTTP	Hyper-Text Transfer Protocol
IGMP	Internet Group Management Protocol
IP	Internet Protocol
ITU	International Telecommunication Union
LCT	Layered Coding Transport
LTE	Long Term Evolution
LTE-A	Long Term Evolution Advanced
LTE-B	Long Term Evolution Broadcast
M2-AP	M2 Application Protocol
M3-AP	M3 Application Protocol
MAC	Medium Access Control
MBMS	Multimedia Broadcast Multicast Service
MBMS-GW	MBMS Gateway
MBSFN	MBMS over Single Frequency Network
MCCH	Multicast Control Channel
MCE	Multi-cell/multicast Coordination Entity
MCH	Multicast Channel
MCS	Modulation and Coding Scheme
MIMO	Multiple Input Multiple Output
MISO	Multiple Input Single Output
MPEG	Moving Picture Experts Group
MLD	Multicast Listener Discovery
MME	Mobility Management Entity
MOS	Mean Opinion Score
MSI	MCH Scheduling Information
MSP	MCH Scheduling Period
MTCH	Multicast Traffic Channel
NBAP	Node B Application Part
OAM	Operation,Administration and Maintenance
OFDM	Orthogonal Frequency-Division Multiplexing
P-t-M	Point to Multipoint
P-t-P	Point to Point
PDCCH	Physical Downlink Control Channel
PDCP	Packet Data Convergence Protocol
PDU	Protocol Data Unit
PHY	Physical Layer
PMCH	Physical Multicast Channel

PSNR	Peak signal-to-noise ratio
QoS	Quality of Service
QoE	Quality of Experience
RAN	Radio Access Network
RANAP	Radio Access Network Application Part
RAT	Radio Access Technology
RLC	Radio Link Control
RNC	Radio Network Controller
RRC	Radio Resource Control
RTCP	RTP Control Protocol
RTP	Real-time Transport Protocol
SAI	Service Area IDentity
SDP	Session Description Protocol
SDU	Service Data Unit
SFN	Single Frequency Network
SGSN	Serving GPRS Support Node
SIB	System Information Block
SRTP	Secure Real-time Transport Protocol
SNR	Signal-to-Noise Ratio
SYNC	Synchronization Protocol
TCP	Transmission Control Protocol
TDD	Time Division Duplex
TMGI	Temporary Mobile Group Identity
UDP	User Datagram Protocol
UE	User Equipment
UMTS	Universal Mobile Telecommunications System
USD	User service description
UTRAN	Universal Terrestrial Radio Access Network
WAP	Wireless Access Protocol
WCDMA	Wideband Code Division Multiple Access

Chapter 1

Introduction

1.1 Motivation and Problem Statement

The evolution of wireless technologies and the mobility trend of customers have made the mobile device market continue to evolve and grow rapidly. The global mobile devices and connections at the end of 2013 is about 7 billion, approximately the world population, and expected to reach 10 billion in 2018 [6]. This tremendous growth in mobile device leads to the explosion of mobile data traffic in the last few years. According to the annual survey from Cisco [6], the worldwide mobile data traffic was equal to 18 times the size of the entire global Internet in 2000 and reached the amount of 18 exabytes in 2013 (81-percent growth). Cisco also forecasts the global mobile data traffic will grow nearly 11-fold between 2013 and 2018, which is similar to the figures in the study done by Ericsson [7]. In this massive volume of data, the mobile video traffic dominates over other data types with 53 percent last year and it is predicted to increase to 69 percent in 2018.

Nowadays, high capacity telecommunication network and mobile devices equipped with powerful processor and large screen such as tablets and phablets allow the users to access high definition (HD) video services in the Internet easier than ever. These mobile video services may be a live streaming or video on-demand streaming and their media content can be offered by the network operators or by a third party provider, i.e. Over-the-Top (OTT) services. The term OTT is referred to the service that is delivered to the end-users 'over the top' of the telecom operators' infrastructure but they do not control the content of these services. OTT is now become more and more popular in the mobile world and can be seen under the form of an application in a tablet or a smartphone. Skype, Whatsapp, Youtube or Viber are among the most common OTT services at the moment. Although OTT services involved with voice call or text message can affect the revenue of telephony operators, they create an opportunity in video streaming service for operators due to the diversity of the media content.

Traditionally, the video service in cellular networks is provided in unicast model, meaning that a dedicated part of network resource will be used for each user even if the same media content is simultaneously requested by different mobile users in the same area. This may lead to the overload in the network. To overcome this issue and response to the massive demand for mobile multimedia services from the customers, the Third Generation Partnership Project (3GPP) has defined the Multimedia Broadcast Multicast Service (MBMS) [1] as a solution for delivery multimedia content to numerous users at the same time. The idea of MBMS is multicasting the multimedia data to all users on the network rather than sending video streams individually to each of them in the area where every user wants to get the same content, which would quickly overwhelm the network.

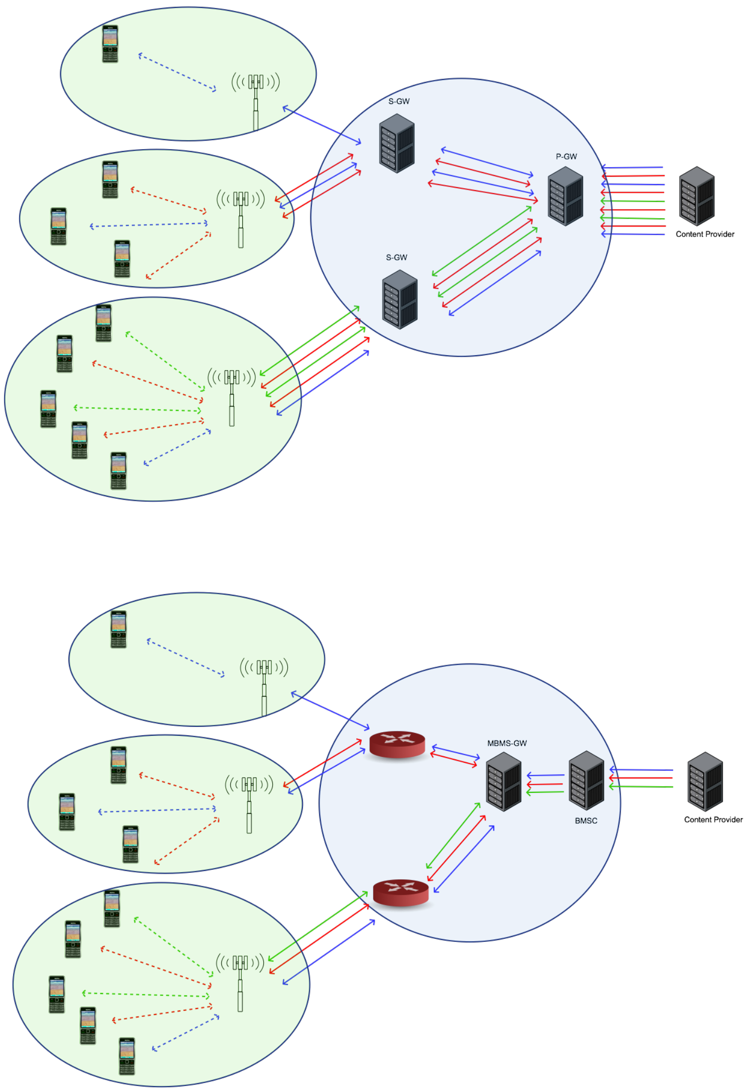


FIGURE 1.1 – Broadcast/Multicast over Unicast

Built on top of 3GPP cellular network, MBMS does not require a dedicated spectrum or a special receiver, which made the failure of MediaFLO [8] technology from Qualcomm. MBMS allows the operators to deploy the system with small modification in the structure (mainly for upgrading the software of their network entities) and permits the client to access the service in minimum cost. However, it did not get success in the Universal Mobile Telecommunications System (UMTS) networks and was supported by very few mobile operators. One reason is because of the limited bit rates and the capacity of 3G network which does not allow high quality video service in mobile devices. That would not be the case of the fourth generation (4G) network. In Long Term Evolution (LTE) networks, MBMS has been enhanced to evolved-MBMS (eMBMS) and become a very prospective broadcast technology. Thanks to the advanced performance of Orthogonal Frequency-Division Multiplexing (OFDM) and Single Frequency Network (SFN) technology in LTE, the eMBMS (also known as LTE-Broadcast) is now considered as the main competitor to the well-known Digital Video Broadcasting (DVB) technology (including DVB-T2 and DVB-NGH standard).

The ability of reusing the LTE cellular infrastructure for broadcasting together with flexible and high data rates has persuaded many telecommunication companies decide to adopt eMBMS as an efficient and low-cost solution to deliver multimedia content. Qualcomm Incorporated, the world leader in wireless telecommunications products and services, is one of the pioneers who promote eMBMS to the market. In 2012, collaborating with Ericsson, Qualcomm demonstrated the evolved Multimedia Broadcast Multicast Services platform at Mobile World Congress (MWC) 2012 in Barcelona with the scenario of live broadcasting a football match around the stadium area [9]. One year later, Qualcomm and Verizon Wireless, a top mobile carrier in North America, presented their first commercial demonstration of LTE Broadcast service at the international Consumer Electronics Show (CES 2013) [10]. And recently, in January 2014, Qualcomm participated in a five-day live demo of eMBMS at Bryant Park in New York with its Snapdragon 800 chipset on the latest Samsung's tablet Galaxy Note 3 over the Verizon's LTE network [11]. This is an important field trial before the commercialization of eMBMS in US market.

Aiming to bring the mobile TV to cross-platform devices anytime, anywhere, Ericsson has introduced the LTE broadcast solution based on three technologies : eMBMS, HEVC (High Efficiency Video Coding) and MPEG-DASH (Dynamic Adaptive Streaming over HTTP). The solution supports live streaming service for sport events or concerts where the venue is a high density environment. With this solution, a series of trial and demonstration is done in cooperation with other 4G/LTE network operators in many countries [12] : in October 2013 and January 2014, in Melbourne, Australia, live trial were carried out by the Telstra at a stadium for baseball and cricket match ; in February, they had a demonstration with Singtel in Singapore and with Vodafone India. The KPN Netherlands and Vodafone Germany were also testing the LTE-Broadcast solution from Ericsson.

As one of the largest telecom companies, Samsung cannot stand out the race for the hottest trend in broadcast technology. In an effort to commercialize the LTE broadcast, Samsung has worked for several years with partners to develop network entities, mobile devices and end-to-end solution for eMBMS. After the first demonstration with test-equipment manufacturer, Anritsu in 2012 [13], Samsung showcased its eMBMS service at the MWC 2013 in cooperation with Qualcomm and Korean Telecom (KT Corporation) [14]. These successes have allowed the Korea's telco giant to announce, in early 2014, that the world's first commercial eMBMS, namely the 'Olleh LTE Play', will be available for KT's LTE subscribers using the Galaxy Note 3 tablet [15].

Huawei, the largest telecommunication equipment maker in the world, has also joined the market by launching the innovation center to develop eMBMS in Shenzhen, China [16]. The Chinese infrastructure vendor has done many demonstrations in 2013 [17–19] : with China Mobile and other partners for the LTE TDD platform to transfer mobile HD video at the Mobile World Congress ; with the Filipino operator Smart Communications for the first video multicast over LTE is in Southeast Asia and with the 4G chipmaker Sequans Communications for successful tests of eMBMS technology in France using Sequans' eMBMS-capable LTE semiconductor solution. In Europe, Vodafone Germany is the first carrier to conduct a live trial for video broadcast a football match at Borussia Monchengladbach's stadium in collaboration with communications technology and services provider Ericsson, Qualcomm and Samsung in February this year [20].

The list of companies joining LTE broadcast market can continue endlessly with Telstra, Alcatel-Lucent, Expway, Altair, Orange... All the attention from the industry clearly shows that LTE broadcast is a key component to address the exponential growth in mobile multimedia traffic and it will become vitally important to Mobile Network Operators (MNOs). Not only MNOs, the third parties with their OTTs are also interested in eMBMS. Imagining that the HBO or StarMovies channel pay an operator for broadcasting their movies or episodes of a series over the LTE network to the their subscribers. The users can watch these movies live when they are on air or download them for watching later. Since the data is broadcasted, little resource is needed and thus the OTT service providers do not have to pay much but still can deliver their services to the subscribers. The versatile cooperation among chip-makers, mobile & network device manufacturers and MNOs all over the world as well as the interest from media service providers has pointed out the huge potential of eMBMS over LTE network in the coming years.

As a video streaming service in the modern wireless networks, eMBMS faces two main challenges :

- Assure the service continuity in a high mobility environment.
- Guarantee the best quality for the end-users.

At the beginning of this PhD program, the eMBMS was still in the standardization phase and the service continuity was not supported. Due to the characteristic of eMBMS, a particular service is available only in certain areas that contain a limited number of base stations. These base stations are synchronized to perform the Single Frequency Network transmission. For that reason, not all base station in the network transfer eMBMS service which may cause the disruption of the service. Thereby, when moving in the network, a mobile terminal may enter a base station that does not participate in the eMBMS transmission and it cannot continue receiving the service any more. This limitation in the 3GPP standard together with the important role of LTE Broadcast in the video streaming market have motivated us in the research for supporting the service continuity in eMBMS.

Like in any other services, the satisfaction of end-users is the ultimate goal of the operators and service/content providers. They always want to give the best eMBMS service in their ability to the costumer. On one hand, the 3GPP standardization body continues doing the research in transmission techniques, transport protocols or the characteristic of the media format in order to give a better eMBMS service to the end users. On the other hand, the research community also does its best to study the methodologies in measuring the quality of service perceived by the human users. In the last decade, the term Quality of

Experience (QoE) has been defined and become the most important metric for evaluating the quality of media service, especially for video. Following the trend, in this thesis, our objective is to tackle the service continuity issues in eMBMS and through that, improving the quality perceived by the eMBMS users.

1.2 Outline and Contributions

The principle objectives of this PhD thesis are to propose a solution for supporting service continuity and to manage the quality of the evolved Multimedia Broadcast Multicast Service in LTE/LTE-Advanced networks. More precisely, we aim to address these following problems :

— *The lack of a real-time simulator/emulator for eMBMS.* In our best knowledge, there are few real eMBMS implementations at the moment in the research community. Therefore, we have integrated the eMBMS system into an open-source, real-time radio platform - the OpenAirInterface [21]. Our eMBMS implementation provides a simulation/emulation tool for evaluating the service performance with a high degree of confidence in comparison with normal simulation tools. It allows other researchers to benchmark their studies related to the eMBMS service such as new allocation resource algorithm or multiple-input and multiple-output (MIMO) transmission. This work has been validated and published in the paper below :
  — Nguyen, N.D, Knopp, R., Nikaein, N. & Bonnet, C. (2013). Implementation and Validation of Multimedia Broadcast Multicast Service for LTE/LTE-Advanced in OpenAirInterface Platform. Workshop P2MNET, collocated with LCN conference. Sydney, Australia.

— *The discontinuity of eMBMS service when the users move around in the network.* The service continuity is always a crucial problem in wireless communication. To solve this problem in eMBMS, a novel method is proposed to maintain the service for the clients in a mobility context. Our method covers all the mobility scenarios and assures the eMBMS reception for the users across different cells, through different MBSFN Areas and on different frequencies. Further more, using our technique, the mobile terminals also have the ability to connect to other broadcast systems to receive the interested eMBMS service (of course with the constraint of device's capability). As the mobility support for eMBMS is very limited in the standard, our solution is an essential supplement to guarantee the quality of LTE-Broadcast in a heterogeneous wireless network nowadays. This method is a part of the conference paper presented at :
  — Nguyen, N.D. & Bonnet, C. (2014). Service Continuity for eMBMS in LTE/LTE-advanced network : standard analysis and supplement. IEEE Consumer Communication and Network Conference. Las Vegas, USA.

— *The service interruption during the handover procedure.* A discontinuous media stream may cause the annoyance to the customers, particularly in live streaming services. In the context that eMBMS is going to be commercialized very soon in the global size and the explosion of eMBMS is expected in the next few years, we design a mechanism to further improve the performance of LTE-Broadcast service in a high mobility environment. The target of this mechanism is to minimize the service interruption time when a mobile user moves from one cell to another. Taking advantage of the information exchange between the serving cell and its neighbors or network entities, some eMBMS controlling messages will be sent to the mobile equipment during the handover period so that, it does not need to collect them after connecting to the new cell. This is an efficient way to reduce the acquiring time for necessary signaling information and allow the users to access the real media data quicker. This work is submitted in the journal :

— Nguyen,N.D & Bonnet,C. "Mobility Support for eMBMS - LTE-Broadcast : State of the Art and Standard Supplement". Submitted to Wireless Networks, The Journal of Mobile Communication, Computation and Information, Springer.

Apart from the introduction and conclusion in the first and last chapter, the rest of this thesis is mainly divided into two parts : Theory and Practice. The main content of each part is given as follows :

1. The Theory part includes three first chapters and describes all concepts and information related to LTE-Broadcast service. The mobility problems in cellular wireless network and theirs solutions for eMBMS service are also mentioned in this part.

   A thorough study of the evolved Multimedia Broadcast Multicast Service (eMBMS) is presented in Chapter 2. Because of the fact that eMBMS is still at the very final stage before going to be commercialized, understanding the features and functions of every eMBMS entity is very essential to continue any further research in a proper way. Furthermore, this chapter also gives an introduction to the Quality of Experience concept. The metrics used for QoE assessment and methods to estimate QoE based on the normal quality indicators are mentioned as well.

   In Chapter 3, we analyze the issues that an eMBMS user is facing in the mobility context. Realizing the limitation of eMBMS service continuity in the 3GPP standard and the existing solutions, we propose a complete method to support the mobility for LTE-Broadcast service. Not only allows the service continuity for eMBMS, our suggestion also provides the information of the services which are supported by other broadcast technologies such as DVB or Satellite. Such information can help the capable terminal to switch to a suitable system and continue to receive its interested service when getting out the cellular coverage.

   One key feature of LTE network is supporting the seamless mobility for users across the network. A mobile terminal certainly expects to receive a continuous video service, and eMBMS is not an exception. However, at this moment, the 3GPP standard does not suggest any specific mechanism in order to moderate the stream disruption time. That means the user will probably witness the quality degradation during the handover when crossing cells. The work in Chapter 4 tackles this problem and designs a new mechanism that allows reducing considerably the service interruption time in the transition period. Also in this chapter, the dynamic resource allocation method for eMBMS is unveiled to get a whole picture about this prospective broadcast technology.

2. The second part covers the practical aspects of eMBMS in LTE network. In this part, we present firstly the implementation and performance of eMBMS in a real-time platform. Then a method to evaluate the quality of a video stream perceived by eMBMS users during the handover period is illustrated.

With its advanced features and huge potential in the market, eMBMS attracts a great deal of attention from the telecoms companies and device manufacturers. The research community also puts a lot of efforts into the study of different eMBMS's aspects, however, until now, except from the industrial demonstrations, we cannot find any work related to the eMBMS implementation in a real-time system. Chapter 5 will describe the implementation of the eMBMS service in the OpenAirInterface [21], an open-source SDR-based hardware/software development platform. Doing the experiment in a real-time system like OAI will allow us to evaluate the performance of eMBMS more accurately than normal simulation tools.

Based on the result of Chapter 5, some in-lab emulations have been carried out to study the performance of our solution for eMBMS service continuity. Chapter 6 describes the scenarios for link level and system level emulations. A handover field-test in a real telecom network has also conducted to evaluate the performance of our solution in eMBMS mobility support. From the emulation and real experiment result, the performance of the proposed handover method for eMBMS service is estimated in term of QoE.

Première partie

LTE Broadcast - Theory

Overview of Part I

The Theory part brings you an overall picture of the broadcast service in 4G/LTE networks. We will take a glance at the history of eMBMS from the time it was defined by the 3GPP standardization body. Then the system architecture and specific entities for eMBMS together with their functions will be introduced. Following the study on two operation modes of eMBMS, we go deeper into the protocol stack allowing the eMBMS transmission and the user services supported in LTE-Broadcast. New standards applied to eMBMS service in the latest release from 3GPP organization such as Dynamic Adaptive Streaming over HTTP (DASH) are also mentioned in Chapter 2.

Regarding the quality of service, the satisfaction of end-users (QoE) has become the most important indicator. In this part, we also introduce the concept of QoE in evaluating the service quality, especially for video services in which eMBMS is concerned. More than that, the methodologies used to derive the QoE and their corresponding tools will be presented as well.

From the fundamental background, some researches have been conducted to address the issues in LTE-Broadcast service. Mobility is always the hot topic in wireless network and it gets more involved in real-time services like video streaming. As a result, mobility is certainly a problem which cannot be ignored when studying the eMBMS. Due to the limitation in LTE standard and in the literature works, in Chapter 3, after introducing the state of the art, we present a complete solution that guarantees the continuity for the eMBMS service in a mobility context. Some extra information and modification in the standard are suggested in company with our method to allow the service continuity in all moving situations.

Besides the service continuity, receiving the media stream continuously when moving is also a key factor that affects the satisfaction of mobile users on video services, particularly during the change from one base station to another one. With the objective of giving a better service to eMBMS customer in LTE network, we have proposed a mechanism to reduce the interruption of the media stream and thus, moderating the impact of the mobility on service quality received by the eMBMS customer. This mechanism includes some adjustment in the conventional handover procedures (both X2-based and S1-based handover) and will be discussed in detail in Chapter 4.

Chapter 2

Fundamental Background

2.1 Introduction

Although being introduced since the 3GPP specifications release 6, the Multimedia Broadcast Multicast Service is still under development (release 12). This chapter will give the readers a global view on the broadcast service in modern cellular networks. Firstly, a brief history of the MBMS service in 3GPP networks and its specific terminologies are presented. Then we will take a look at the architecture as well as the operation mode of MBMS service before going in detail on our main subject : the eMBMS service in LTE networks.

Furthermore, this chapter contains an introduction to the concept of Quality of Experience (QoE) which indicates the satisfaction level of a human user on the video/audio services. From the definition, QoE is obtained from the end-users' assessment, however, to have an evaluation involved with human in some situations such as in a real-time streaming service is challenging. Therefore, the research community has turned to other directions in measuring QoE. One principal of these new techniques is to find out the relation between the quality perceived by human and the conventional network parameters ; and then use this relationship to determine the QoE value without the involvement of human users. We will mention some of these methods and associated tools for measuring the QoE at the end of the chapter.

2.2 Overview of Broadcast Service in Wireless Cellular Network

2.2.1 The brief history of Multimedia Broadcast Multicast Service

The story of MBMS started in 2004 when 3GPP defined a new point-to-multipoint communication in its specifications release 6 (Rel-6). Similarly to MBMS of 3GPP which is based on Wideband Code Division Multiple Access (WCDMA) technology, the 3GPP2 standard body also introduced BroadCast and MultiCast Service (BCMCS) for CDMA2000. MBMS and BCMCS allow the delivery of multimedia data from a single source to multiple users over the cellular networks and aim to replace the existing mobile TV service which is based on point-to-point connection at the moment. They both provide broadcast and multicast services in 3G network

With the evolution of WCDMA in release 7, the Single Frequency Network (SFN) technique is used for MBMS in both TDD and FDD that produces the term MBSFN or MBMS over a Single Frequency Network. In MBSFN, the same signal is transmitted by multiple cells over a wide area that permits eliminating the intercell interference for broadcast/multicast services. This thus provides a great improvement in the quality of received signal and spectral efficiency, especially for the mobile terminals at the cell edge. In UMTS network, MBMS requires minimum modification in the general architecture of cellular network (only one new entity is added) making the implementation very convenient in compared with other broadcast service such as Digital Video Broadcasting (DVB) or Digital Multimedia Broadcasting (DMB). However, the fact that WCDMA technology is not well suited for broadcast (all traditional broadcast technologies use OFDM) together with the limitation in bitrate (16 channels at 64Kbps in 5MHz bandwidth) and other factors lead to the failure of MBMS in UMTS.

Later in 2008, the 3GPP standardized the Long Term Evolution (LTE) network with the usage of OFDM as the access technology. Using OFDM with good spectral efficiency and high bitrate are among the reasons to bring the unsuccessful MBMS to LTE network (5MHz bandwidth can offer up to 20 video/audio channels, each has data rate of 256Kbps). But in Rel-8, only the physical layer was defined for MBMS and the 3GPP officially introduced the complete MBMS service for LTE in its specifications Rel-9 under the name evolved MBMS or eMBMS. To support the MBSFN operation in LTE, more entities are put in the network architecture as well as the definition of new channels for transport the MBMS data.

Continue with the evolution, Rel-10 provides some extra features for eMBMS including the Counting procedure, which allows the network to know the number of User Equipment (UE) interested in the MBMS services, and the support of HTTP streaming over eMBMS bearer. In Rel-11 (2012), an important feature was supplemented into the standard to support the mobility of eMBMS users. This procedure aims at providing the continuity of service by switching the mobile terminal to neighboring frequency in case where carrier aggregation is deployed in the network. eMBMS keeps evolving in the Rel-12 and beyond where many aspects are expected to be enhanced for a better performance such as the transmission in Multiple Input Multiple Output (MIMO), switching between broadcast and unicast or uplink report in eMBMS and much more.

2.2.2 MBMS Terminologies

When a new service appears, usually it comes with many new terms and MBMS is not an exception. In this section, we will explain some new definitions and terms to help the readers understand better the MBMS service and the content of the thesis.

Broadcast/Multicast service area : The area in which a specific broadcast or multicast service is available. The broadcast/multicast service area may represent the coverage area of the entire PLMN, or part(s) of the PLMN's coverage area. It is the sum of all local broadcast/multicast areas offering the same service.

MBMS Service Area : The geographical area within which data of a specific MBMS session (or service) are sent. Each individual MBMS session of an MBMS Service may be sent to a different MBMS Service Area (i.e. MBMS Service Areas are independent of each other and may overlap). This MBMS Service Area is the same or a subset of the Broadcast or Multicast Service Area.

Multicast Subscription Group : A group of users who are subscribed to a certain MBMS in multicast mode and therefore authorized to join and receive multicast services associated with this group.

Multicast group : A group of users that have an activated MBMS in multicast mode and therefore are ready to or are receiving data transmitted by this service. The multicast group is a subset of the Multicast subscription group. Multicast subscription group members may join the corresponding multicast group.

Broadcast/Multicast or MBMS service : A unidirectional point-to-multipoint service in which data is efficiently transmitted from a single source to multiple users in the associated broadcast/Multicast service area.

Broadcast/Multicast or MBMS session : A continuous and time-bounded reception of a broadcast/multicast or MBMS service. An MBMS service can only have one session at any time and it might consist of multiple successive sessions. For not mistaken between service and session, we can consider an MBMS service is a TV channel while the MBMS session is a program in this channel.

MBMS User Service : The MBMS service provided to the end user by means of the MBMS Bearer Service and possibly other capabilities. This term targets to the MBMS protocols and procedures in service layer.

MBMS Bearer Service : A transmission bearer provided by the PS Domain to deliver IP multicast datagrams to multiple receivers using common radio resources (broadcast or multicast).

MBMS over a Single Frequency Network (MBSFN) : A technique that allows multiple cells to transmit the same content simultaneously using an identical waveform. Cells participating in MBSFN transmission should be synchronized tightly in time. An MBSFN transmission from multiple cells within an MBSFN Area is seen as a single transmission in mobile users' point of view.

MBSFN Synchronization Area : An area where all eNodeBs (eNBs) can be synchronized and perform MBSFN transmissions. The MBSFN Synchronization Areas are independent from the definition of MBMS Service Areas.

MBSFN Area : An MBSFN Area consists of a group of cells within an MBSFN Synchronization Area of a network, which are coordinated to achieve an MBSFN Transmission. Except for the MBSFN Area Reserved Cells, all cells within an MBSFN Area contribute to the MBSFN Transmission and advertise its availability. One MBSFN Synchronization Area is capable of supporting one or more MBSFN Areas. There could be up to 256 different MBSFN Areas distinguished by their Identity and they are static configured by the network. MBSFN Areas can overlap each other, in this case, one base station belongs to multiple MBSFN Areas. The maximum number of MBSFN Area one base station could support in LTE network is eight.

MBSFN Area Reserved Cell : A cell within a MBSFN Area but it does not contribute to the MBSFN Transmission. To avoid the interference, the cells in this type are allowed to use the resource reserved for MBSFN transmission for other services but only with restricted power.

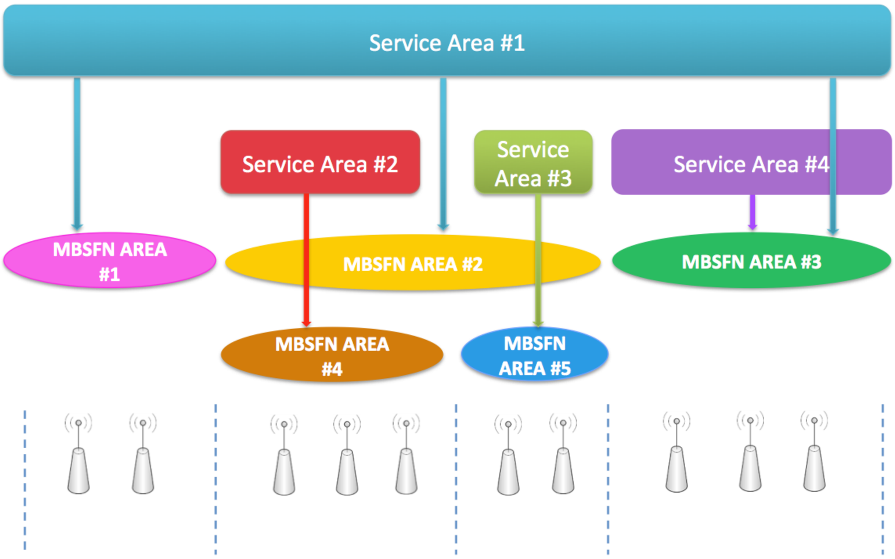


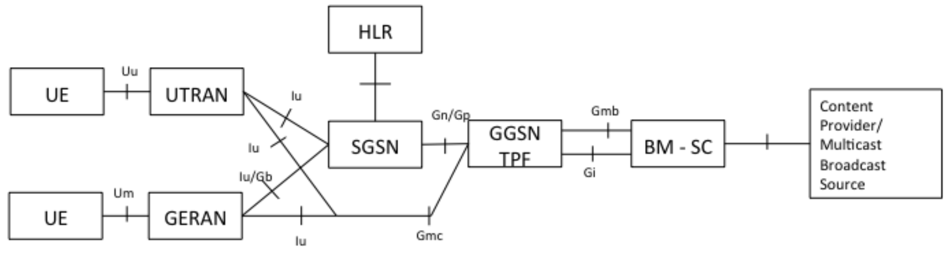
FIGURE 2.1 – Relation between Service Area and MBSFN Area.

The relation between MBMS Service Area and MBSFN Area is illustrated in Fig. 2.1. In this example, we suppose that the MBMS Service Area #1 provides the National News, Service Area #2 and #4 offers the Local News in two different districts while the Service Area #3 has a Sports channel. As described in the figure, MBSFN Area #1, #2 and #3 transfer the services of MBMS Service Area #1, whereas the MBSFN Area #4 and #5 transmit the content in MBMS Service #2 and #3, respectively. In addition, the MBSFN Area #3 also conveys the services provided by the Service Area #4. With this configuration, the cells belong to MBSFN Area #1 only broadcasts the National News channel. The eNBs belong to MBSFN Area #2 and #4 will provide both National News and Local News service while theirs neighbors offer National News and Sports channel. Finally, the base stations in MBSFN Area #3 gives to the users the Local and National News service.

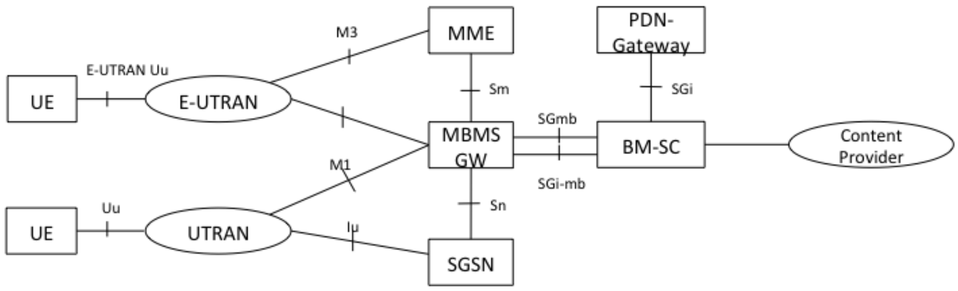
2.2.3 Architecture of MBMS system in Cellular Network

One advantage that MBMS has over the other broadcast technologies is the ability of using the existing infrastructure of the current cellular network. Fig. 2.2 describes how the MBMS system is integrated in the General Packet Radio Service (GPRS) and Evolved Packet System (EPS) network architecture.

Although the overall architecture is basically not changed, some extensions are required in existing network entities to support the MBMS framework. Some new functional nodes were also introduced for doing the MBMS specific features and new interfaces (or reference points) were added into the cellular network to connect these new entities with the traditional ones.



(a) The MBMS structure for GPRS network



(b) The MBMS structure for EPS netowrk

FIGURE 2.2 – Cellular network architecture with MBMS-supported capability.

In Fig. 2.2, we may notice that the major change in the network architecture for MBMS purpose is the appearance of a new entity called Broadcast/Multicast-Service Center (BM-SC). It plays the role of traffic shaper and authorizing the content providers/user terminals request. The BM-SC is the principal node in the MBMS system which connects the Service/Content Provider and the cellular core network. The interface between BM-SC and the content server can be located either within the mobile communication network or outside of it. The BM-SC functions detail will be described shortly in this section.

New functions are integrated into the Gateway GPRS Support Node (GGSN) in the core network so that it can establish, manage and release the MBMS bearer. This bearer is used to distribute the MBMS traffic from the BM-SC to the downstream nodes, i.e. the Serving GPRS Support Node (SGSN), using the GPRS Tunneling Protocol (GTP). The GGSN node gets from BM-SC a notification containing a list of the SGSN nodes to which it should transfer the MBMS content to in a broadcast/multicast transmission. Similarly to the GGSN in GPRS, a new functional element namely MBMS Gateway (MBMS-GW) is created in EPS to transfer the MBMS data and signaling information from BM-SC to UTRAN/E-UTRAN and SGSNs, respectively.

Being modified to adapt the MBMS structure, the main role of SGSN is to perform the functions in control plane between the UTRAN/GERAN and GGSN or MBMS-GW. Within the Radio Access Networks (RANs) supporting MBMS including GERAN (GSM/EDGE Radio Access Network), UTRAN (UMTS Radio Access Network) and E-

UTRAN (Evolved UMTS Radio Access Network), the modification are made for the efficient delivery multimedia content to the users. We will mention detail about these changes later in this manuscript.

In E-UTRAN, the Mobility Management Entity (MME) node is also upgraded to support the MBMS control plane function. MME provides the function related to the session control of MBMS bearers which guarantees the delivery of Session Start/Session Stop from MBMS-GW to E-UTRAN. It transfers these session control messages towards multiple E-UTRAN nodes.

2.2.3.1 The Broadcast Multicast-Service Center (BM-SC)

The Broadcast/Multicast-Service Centre provides a group of new functionalities to offer the MBMS capabilities to the mobile operators and multimedia service providers. It can also serve as an entry point for IP MBMS data traffic from the MBMS service providers, i.e the content providers only need to send their services to the BM-SC rather than delivery them to the individual customers. The BM-SC will take care of the MBMS data distribution inside the mobile network. Fig. 2.3 gives a description of all functions supported by the BM-SC.

The main functions of the BM-SC are listed as below :

— **Service Discovery and Announcement** function : The Service Discovery provides all the information a user terminal needs in order to receive the MBMS service distributed by the BM-SC. This information includes the description of the media files that are delivered in the MBMS user service (for example the encoding type of video or audio files) and the attributes of the MBMS session being transferred such as the duration and transmission time, the MBMS service identification or the IP multicast address for the end user to join that service. The Service Announcement information is sent to the MBMS user in form of information units after being encoded in Extensible Markup Language (XML) or Session Description Protocol (SDP) format. The Service Announcement might be delivered by a Short Message Service (SMS), through an HTTP connection or an MBMS bearer. One thing to be noticed is that although the BM-SC will trigger the function, the Service Announcement itself may be sent by another entity.

— **Session and Transmission function** : The main task of Session and Transmission function is to transport the MBMS session data to the MBMS users using MBMS bearer services or unicast bearer services. This function decides the schedule for transmitting MBMS sessions and gives a unique identification for each session. Further, it also allocates the Temporary Mobile Group Identity (TMGI [22], a unique value per MBMS bearer service) for MBMS notification purpose. The TMGI is then can be obtained by the user through Service Announcement procedure. The MBMS Session and Transmission function interacts with the GGSN in GPRS via the Gmb interface and with the MBMS-GW in EPS via the SGmb interface to activate and release the MBMS transmission resources. When IP multicast is used for transmitting the MBMS data from GGSN to UTRAN/GERAN or from MBMS-GW to UTRAN/E-UTRAN, this function can add the information related to the synchronization to the MBMS payload. The Session and Transmission function has two sub-functions : the MBMS Delivery Function and Associated Delivery Function. The first sub-function decides the way to deliver MBMS data in user service layer : Streaming or Download ; while the latter sub-function controls the file repair or reception report procedure.

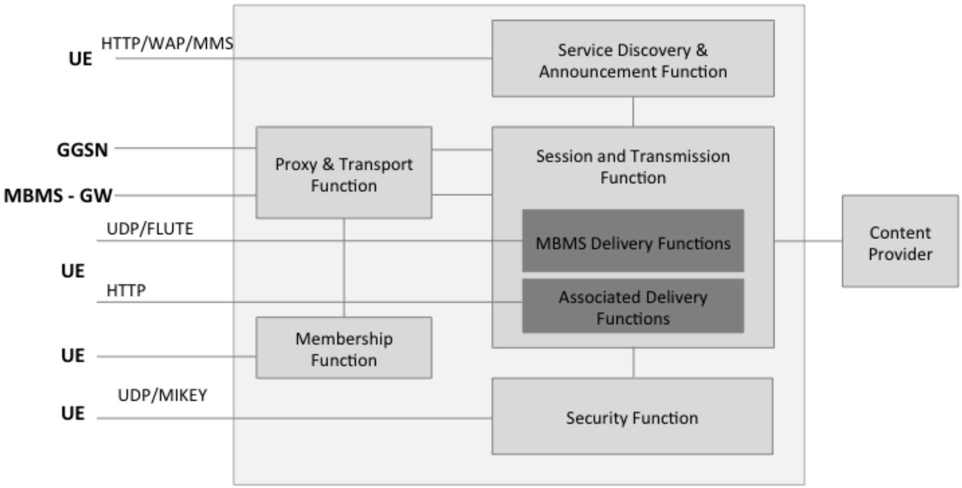


FIGURE 2.3 – Broadcast Multicast-Service Center Function.

- **Proxy and Transport function** : The Proxy and Transport function of the BM-SC acts as a proxy agent between the Session and Transmission function and the GGSN or MBMS-GW in control plane via SGmb/Gmb interface. It is responsible for generating the charging information for the Service Provider. Besides, this function is in charge in case more than one physical network entities are used to control the BM-SC functions for different MBMS services.
- **Security function** : For the secure purpose, the MBMS data are optionally confidentiality and/or integrity protected and the Security function provides the protection for the MBMS user data transfered between the BM-SC and user terminals if needed. More specific, this function gives a series of MBMS keys to an authorized user terminal so that it can decrypt the received messages and MBMS files. In order to receive the MBMS keys for the protected service, a user has to register to the Key Request function. After the registration, the user can request MBMS keys and their updates from the BM-SC by indicating the specific MBMS key identification. If the MBMS User Service does not require any protection, then no registration is required. A bootstrapping procedure is triggered in BM-SC and user terminal to generate the so-called MBMS User Key (MUK). This MUK key is then used to decrypt the MBMS Service Key (MSK) which is conveyed in Multimedia Internet KEYing message (MIKEY). Once MSK is decoded, the user terminal will use it to derive the MBMS Traffic Key (MTK) which is the key used to secure the MBMS data.
- **Membership function** : The Membership function check whether a user has the authorization to request and receive MBMS keys or activate an MBMS service. The function has the subscription data of all the users that have registered to a multicast service and is able to use these information for charging purpose. For that reason,

the Membership function is only defined in the MBMS Multicast Mode.

2.2.3.2 MBMS Gateway

The MBMS Gateway is a new logical entity created in EPS dedicated for MBMS service. MBMS-GW could be either a stand-alone network entity connecting the BM-SC and RAN or be a part of other network entity (e.g. the BM-SC or Service/Packet Data Network Gateway). It is involved in both signaling and data delivering part for the MBMS service. In the user plane, the MBMS-GW sends/broadcasts the MBMS data packet directly to the UTRAN/E-UTRAN by means of IP Multicast through M1 interface.

In the control plane, the MBMS-GW performs the Service Announcement as well as the MBMS Session Control Signaling (Session Start/Update/Stop) procedure toward UTRAN via SGSN and toward E-UTRAN via MME. When an MBMS session arrives, its function is to allocate the IP multicast address to which the base stations participating in MBMS service should join to receive the MBMS content. This IP Multicast address together with the IP address of the MBMS service source and a Common Tunnel Endpoint IDentity (C-TEID) is provided to the evolved Node B (eNBs) or Radio Network Controller (RNC). In case there are more than one MBMS-GWs in the network, the generating of C-TEIDs in different MBMS-GWs should be managed to avoid the collision in the value for different MBMS services.

2.2.3.3 Multi-cell/multicast Coordination Entity

In E-UTRAN, one new logical entity is defined dedicatedly for the Control plane of the MBMS transmission, it is the Multi-cell/multicast Coordination Entity. In some documents it is referred to as the MBMS Coordination Entity. The network can deploy MCE in a single physical node or integrate it as a part of another network node. MCE is considered as the key element for MBMS in LTE networks whose task is to organize the resource allocation of all eNBs within one MBSFN area. It ensures the proper configuration at MAC layer of these eNBs so that the same radio resource blocks are allocated to the specific MBMS services to realized the MBSFN operation.

Another job of MCE is doing the admission control for MBMS sessions, i.e. it decides to establish the radio bearer for a new MBMS session or not create the bearer for a session that requires more radio resources than those are available. It may pre-empt the resource from other bearers of coming MBMS services according to the ARP (Allocation and Retention Priority - an integer from 1 to 15 that indicates the priority order of a bearer).

In addition to coordinate the time/frequency resources for MBMS service, choosing the radio configuration (e.g. the modulation and coding scheme) is also done at the MCE. Furthermore, it controls the scheduling for MBMS transport channels in an MBSFN area. From 3GPP specification release 10, an advance feature known as the Counting procedure which reports the number of connected LTE terminal receiving MBMS service is at the responsibility of MCE as well. Based on the ARP or the result of Couting procedure of an MBMS service, the suspension or resumption of that corresponding service in an MBSFN area is done at MCE.

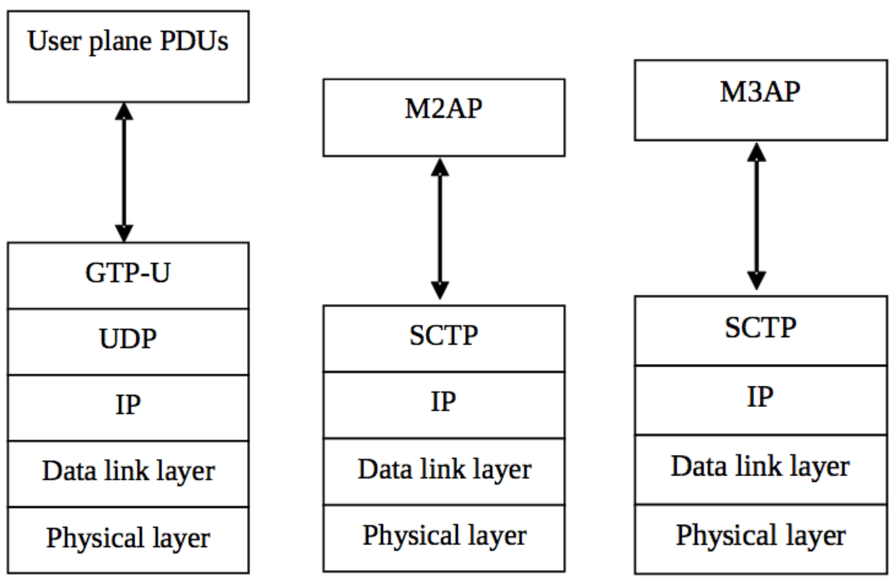
2.2.3.4 MBMS Functional Interfaces (Reference Points)

Together with the functional extension in existing network entities (e.g. SGSN and GGSN) and the appearance of new MBMS specific nodes (e.g. BM-SC and MBMS-GW), the 3GPP standardization body has defined new associated functional interfaces or reference points (as called in the some standard documents) to support the MBMS transmission.

In GPRS, the BM-SC transfers the MBMS signaling message and broadcast the MBMS user data to the GGSN across the interface Gmb and Gi, respectively. The corresponding interfaces between the BM-SC and MBMS-GW in EPS are SGmb for control information and SGi-mb for broadcast/multicast payload. The SGmb supports all the signaling procedure for MBMS including user authorization, setting up/releasing MBMS bearer and session start/update/stop while the SGi-mb supports the MBMS user traffic plane. The Sm/Sn interface are also defined to allow the transmission of the MBMS service control messages and the IP Multicast address from MBMS-GW to MME/SGSN in EPS.

Besides these modification, the following interfaces are defined dedicated for the information exchange of the MBMS services.

— The **M1 interface** is a pure user plane interface connecting MBMS-GW and eNBs or RNCs, hence there is no control information transmitted over this interface. IP multicast is used to deliver point-to-multipoint MBMS data packets over the User Datagram Protocol (UDP) without guarantee on the M1 interface. SYNC protocol is used over the M1 interface to keep the content synchronization in MBMS data transmission. In LTE network, the GPRS Tunneling Protocol for user data (GTP-U) is used on top of the transport layer in the protocol stack for the M1 interface as shown in the Fig. 2.4(a)



(a) M1 U-plane interface (b) M2 C-plane interface (c) M3 C-plane interface

FIGURE 2.4 – Protocol stack for new interface in MBMS [1].

— The **M2 interface** is the logical link between the MCE and the base station (i.e. the evolved Node B) in E-UTRAN. This interface only conveys the control information related to the MBMS. It is used to coordinate the setup of MBMS service in the evolved Node Bs (eNBs) for the MBSFN operation. Through this interface, the MCE plays the role of the coordinator while the eNBs will provide feedback about the MBMS service to the MCE.
  The M2 interface provides a means to transfer the MBMS session handling function including Session Start, Session Stop and Session Update messages from the MCE to the base stations. This interface transfers the scheduling and control information of a specific MBSFN area to all the eNBs belonging to that area. The M2 interface also supports timing and synchronization management functions that assure the control information related to the corresponding MBSFN area to be transmitted at all eNBs simultaneously. When this MBMS information is updated, the synchronization signaling is conveyed on the M2 interface.

— The **M3 interface** is the logical interface between the Mobility Management Entity (MME) and E-UTRAN introduced for the MBMS control plane. Different from the MBMS user plane interface, the M3 interface uses the reliable transport protocol SRTP (Secure Real-time Transport Protocol) for a guaranteed delivery of MBMS signaling messages. The M3 Application Part (M3-AP) protocol allows the transport of MBMS session control signaling on E-RAB level (i.e. it does not convey radio configuration data). It is responsible for providing the list of MBMS service areas served by the MCE to the MME. This interface supports the MBMS session initiation and termination (the MBMS Session Start, Session Stop procedure and Session Update procedure).

2.2.4 Broadcast and Multicast Operation Mode

As the name says itself, the Multimedia Broadcast Multicast Service has two different operation modes for delivering IP packets in the bearer service layer : Multicast mode and Broadcast mode.

2.2.4.1 Multicast mode

The MBMS multicast is a point-to-multipoint, unidirectional transmission of a multimedia content from a single source to many recipients in a certain area. The multicast mode is designed to use the radio resources in an efficient way, for example, using a common radio channel to transmit data to multiple end users. The MBMS multicast operation should not be confused with the IETF IP multicast [23] Diffusion of stock market information or sport event results to some interested users are among the popular examples for the service using multicast operation.

In the multicast operation mode, a MBMS service is solely transmitted to the users which have the interest and already registered to receive that service. In other words, the receivers have to inform the network their interest for data reception and the network will then decide whether the users may receive the multicast content or not. Therefore, the subscription to a multicast group is required for a user terminal that wants to get particular services. Once joined an appropriated group, the user can access to the desired service provided in that group. Furthermore, due to the subscription and the selective content transmission within a group, the data charging is usually made for the subscribers in this operation mode. The charging information could be the duration of the MBMS session, duration of the membership in the multicast group or the amount of the media content. The billing method can be based on this charging info and done during the security phases. One point to be noticed is that the Multicast operation mode is only supported for GPRS whereas the Broadcast mode is able to deployed in both GPRS and EPS. To access the MBMS services in multicast mode, certain procedures need to be performed as the following flow :

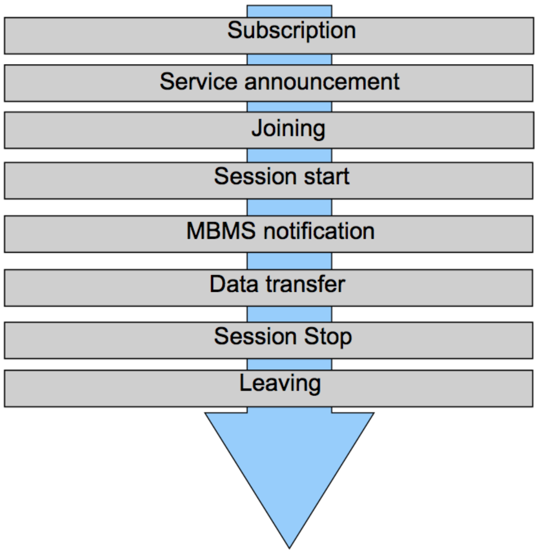


Figure 2.5 – MBMS Multicast Procedures.

Among the phases described in Fig. 2.5, some are related to the service activation/deactivation and done for each individual user including Subscription, Joining and Leaving procedure while the other processes in the flow are concerned with particular MBMS user service.

Subscription is the procedure in which a user subscribes to a multicast subscription group. In this phase, the relationship between the user and the service provider is established. It is the agreement that allows the user to join certain multicast groups and receive the concerned MBMS services when they are available. The subscription information could be stored in the BM-SC (and could be used for charging purpose). The multicast subscription process is usually performed by the terminals/clients and they are able to subscribe or unsubscribe as their wish.

The Joining procedure authorizes a subscriber in multicast subscription group to join into a specific multicast group in order to receive his interested services. The information about the services provided by a multicast group will be informed to the members in the Service Announcement procedure. If the user figures out its favorite services are available due to the information in service announcement message, it will trigger the Joining process to become a member of that group. To join the group, the users have to send out an Internet Group Management Protocol (IGMP) message for IPv4 or a Multicast Listener Discovery

(MLD) message in case IPv6 is deployed. The network will store the 'connect' state of the members of the multicast groups in network entities (SGSN, GGSN and RNC) for mobility management purpose.

When a MBMS services provided in a multicast group are ready to start, the network will send a request to downstream nodes and notify the member of the corresponding multicast group about the upcoming session. These jobs will be done during the Session Start and MBMS Notification phase. After getting the notification, the user terminals can actual receive MBMS data, which corresponding to the Data Transfer procedure in Fig. 2.5. Finally, when the MBMS session/service terminates, the network will stop the transmission and release the resource of that MBMS bearer by doing the Session Stop procedure. The users will then start the Leaving phase to leave the multicast group. During the Data Transfer phase, whenever a user wants to stop receiving a service, it sends to the network an IGMP/MLD leaving message and it will be removed from the group.

2.2.4.2 Broadcast mode

The MBMS broadcast operation mode is an unidirectional point-to-multipoint transmission of multimedia content from a single source to all the users in a broadcast service area. A broadcast service may contain one single session or several intermittent sessions in a period of time. Unlike in the multicast mode, a user terminal that would like to receive an MBMS service does not need to register to the network. As a result, there is no subscription or 'joining' required in broadcast mode. That is the distinction between broadcast and multicast mode and it explains why the processes related to the membership registration such as : Subscription, Joining and Leaving procedure are disappeared in the broadcast service provision flow in Fig. 2.6. In the multicast mode, due to the membership subscription, the network is aware of the MBMS subscribers ; while in the broadcast mode, without the uplink direction, the network has no knowledge about the users that are currently receiving the service inside an MBMS Service Area. It thus has to deliver the service data to all cells belonging to the broadcast area to make sure that all the users in this area can get the service if they want.

The Cell Broadcast Services (CBS), which is introduced in GSM and in Release 99 of UMTS, also provides the broadcast service. This service allowed to transmit short text messages with the length from one up to fifteen pages (each has maximum 93 charaters or 1395 characters in total [24]). We should not be confused the CBS with the MBMS broadcast operation mode. In CBS, although IP multicast protocol is used for diffusing the messages within the core network, they are then tunneled to the users with point-to-point connections. In that way, one replicate of a message needs to be transferred to each interested user, that make the CBS different from the broadcast mode where high bit rate multimedia services are sent on one common channel to all the users in a service area.

In general, the service provision steps in broadcast operation mode are the same with those in multicast mode except the service activation procedures, so we will describe clearer the Service Announcement and Session Start procedure.

Service Announcement procedure

Before a user can receive the actual data of its interesting MBMS services, it needs to know which services are available in the network as well as when and how it can get them. This type of information, which is given in a metadata format, is advertised by

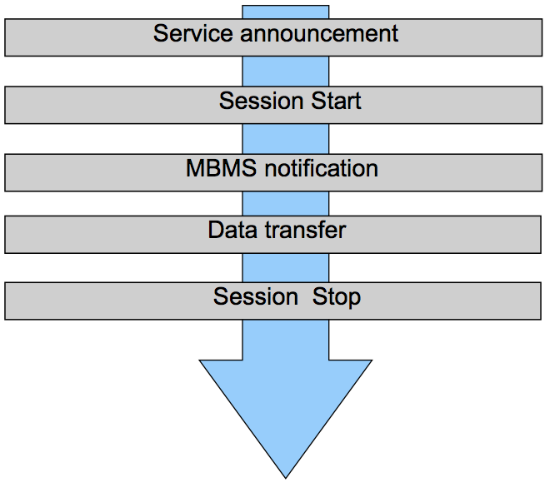


FIGURE 2.6 – MBMS Broadcast Procedures.

the service provider in the Service Announcement procedure. Through this procedure, all characteristics of the service (service name, time of transmission, duration, media codec...) are distributed to the users.

Several mechanisms can be used to deliver the service announcements to the MBMS users. A standard method is pushing the service announcement by an SMS-PP (Short Message Service Point-to-Point), MMS (Multimedia Message Service) or using cell broadcast service. An alternative way, which is referred as the pull method, is storing the service announcement on a web server and the users can download it through the HyperText Transfer Protocol (HTTP), File Transfer Protocol (FTP) or Wireless Access Protocol (WAP). The users can also get the metadata of service announcement broadcasted in the network via a MBMS bearer. After getting and extracting the information in the service announcement, the mobile terminals operating in multicast mode have to send a request to join the multicast group while the recipients in broadcast mode just listen to the channel with the parameters described in the service announcement. The Session Description Protocol (SDP) is usually used in the service announcement procedure.

Session Start procedure

The purpose of Session Start procedure is to establish the MBMS bearer (for both control and data plane) and prepare the resource for the MBMS service transmission. The BM-SC will be the entity that triggers this procedure by sending a request to the network when a session of the MBMS service is ready to transfer. All the attributes of such as service/session identity, duration of the session, MBMS service area identity or quality of service class are given to the entities in core network (MBMS-GWs, GGSNs, SGSNs and MMEs) and entities in UTRAN/E-UTRAN (RNCs and MCEs) which participate in that MBMS transmission. Also, during this procedure, the MBMS bearer context which contains all information of the MBMS bearer service is created in every MBMS-concerned nodes in the network. The mobile users also get the notification about the session that is about to start in Session Start procedure. In case the distribution of user data from core network to the UTRAN/E-UTRAN is done by the IP multicast, the media source

IP address, IP multicast address and the C-TEID are sent to eNBs or RNC via MME or SGSN correspondingly.

To ensure that all network entities and users have enough time to establish the bearer and configure the resources for the MBMS service, the BM-SC only sends the media content after sending the Session Start procedure a certain amount of time. This time could vary from few to tens of seconds depending on the nature of the networks (2G, 3G or LTE...).

The Fig. 2.7 illustrates step by step the Session Start procedure with all messages exchanged among entities in EPS. A similar procedure for GPRS can be found in [2]

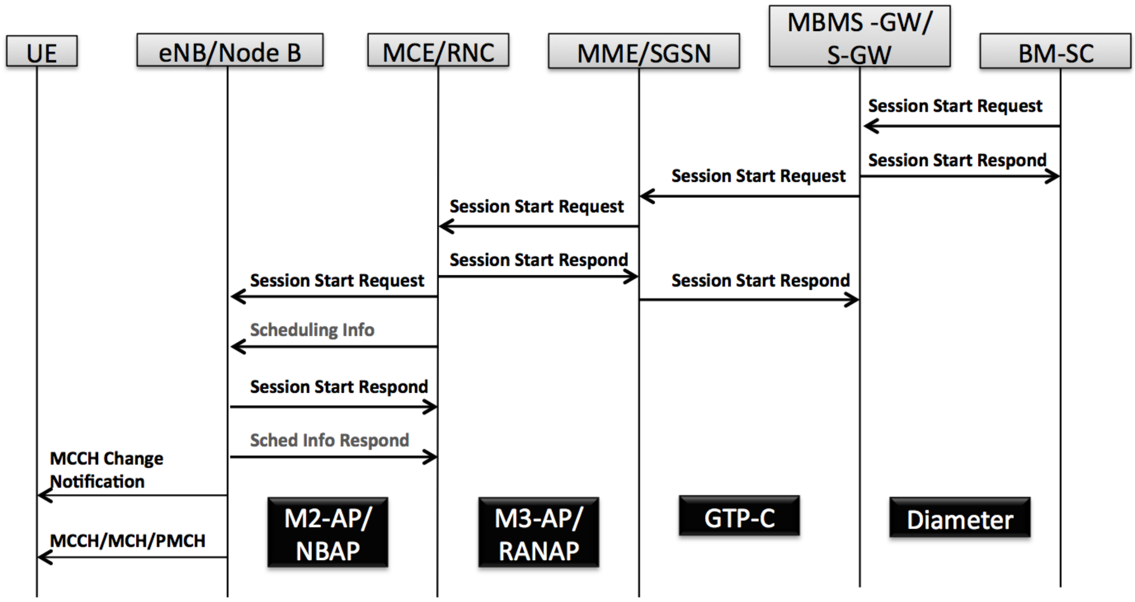


Figure 2.7 – MBMS Session Start Procedure in EPS.

- When data for a particular MBMS session is ready, the BM-SC will send to the MBMS-GW a Session Start Request message (Re-Auth-Request RAR command) including all features of that session (service/session ID (TMGI), MBMS service Area, session duration, MBMS data transfer start, time to MBMS data transfer...). In case the MBSFN transmission is applied, the MBMS data transfer start will be used instead of the time to MBMS data transfer to guarantee the synchronization MBMS contain between BM-SC and RANs. If the MBMS service has more than one session with different content or quality, the Flow identifier is transmitted to distinguish these sessions. A list indicates all the downstream nodes that the MBMS-GWs have to forward MBMS signaling information (SGSNs and/or MMEs) is enclosed in this request message. Moreover, the radio access technologies in which the service is transferred are also specified for the MBMS-GW.
- A Session Start Response message (in Re-Auth-Answer command) is sent back to BM-SC in response for the request with the information that allows the BM-SC to send the MBMS user data to the MBMS-GW. In parallel, the MBMS-GW creates an MBMS bearer context to save all information received from BM-SC. It also adds the IP multicast address and C-TEID to the bearer context of that MBMS session

. An example of the MBMS bearer context in EPS is depicted in the Fig. 2.8. The connection between BM-SC and MBMS-GW is based on the Diameter protocol.

Parameter	Description	RAN	MME/ SGSN	MBMS-GW	BM-SC
MBMS GW TEID-C	Tunnel Endpoint Identifier of MBMS GW for control plane.		X		
TMGI	Temporary Mobile Group Identity allocated to the MBMS bearer service.	X	X	X	X
Flow Identifier	Location dependent subflow of the MBMS bearer service. When present, the Flow Identifier together with the TMGI uniquely identify the MBMS Bearer Context.		X (note 1)	X (note 1)	X (note 1)
MBMS GW IP Address for Control Plane in use	The IP address of the MBMS GW used for the control plane.		X (note 2)		
MBMS GW IP Address for User Plane in use	The IP address of the MBMS GW used for the user plane.		X (note 2)		
C-TEID	Common Tunnel Endpoint Identifier of MBMS GW for user plane	X		X	
QoS parameters	Quality of Service required for the MBMS bearer service.	X	X	X	X
MBMS Service Area	Area over which the MBMS bearer service has to be distributed.	X	X	X	X
List of downstream nodes	List of downstream nodes that have requested the MBMS bearer service and to which notifications have to be forwarded.		X (note 3)	X (note 4)	X
IP multicast address and IP Source address for distribution	IP addresses identifying the SSM channel used for user plane distribution on the backbone network.	X	X	X	
MBMS HC indicator	Flag set by BM-SC if it is using compressed header for the payload.		X (note 5)		X (note 5)
SGSN IP Address and TEID for User Plane over Sn-U	The IP address and TEID of SGSN used for the user plane over Sn-U when some RNCs have not accepted IP multicast distribution.			X	

NOTE 1: It is an optional parameter.
NOTE 2: MBMS GW that supports both IPv4 and IPv6 address types, stores only the IP address in use.
NOTE 3: For SGSN, the list includes the registered DRNC.
NOTE 4: For MBMS GW, the list includes the couples of the SGSNs and MMEs IP addresses and TEIDs for control plane.
NOTE 5: Header Compression is only supported for UTRAN for this Release.

FIGURE 2.8 – MBMS Bearer Context for Broadcast operation mode in EPS [2].

— In this step, the MBMS-GW sends a Session Start Request message with the elements of the MBMS bearer context to its downstream nodes listed in the message from BM-SC. This signaling info passes by the MME over Sm interface to reach E-TRAN or goes through UTRAN via SGSN on the Sn interface. In both cases, the GPRS Tunneling Protocol for Control plane (GTPv2-C) is used to transport the messages between MBMS-GW and MMEs/SGSNs.

— At their turn, the MMEs or SGSNs store the MBMS session attributes, transport network IP Multicast Address, IP address of the multicast source and the C-TEID which are included in the message from MBMS-GW into their own MBMS bearer context. They also send a Session Start Request toward the MCEs in E-UTRAN or RNCs in UTRAN with the restriction that these entities belong to the MBMS service area supporting that particular MBMS service/session.

— After receiving the request from MMEs/SGSNs, like other network entities, the MCE/RNC creates an MBMS bearer context and stores the information related to the session attributes. In addition, the MCEs/RNCs verify if the radio resources are enough for the coming MBMS bearer. If the answer is yes, they will establish the radio bearer for MBMS service and send the Session Start Request together with the scheduling info to the eNBs/NodeBs in appropriate service area. The M2-AP or Node B Application Part protocol (NBAP) will be used for the communication between MCE/RNC and eNBs/NBs. If there is not enough radio resource, MCEs/RNCs decide not to establish the radio bear. The MCEs/RNCs also have to response to the MME/SGSN the reception and their decision by means of a Session Start Response message over the M3-Application Protocol(M3-AP) and the Radio Access Network Application Part protocol (RANAP), respectively, on top of reliable tranport protocol SCTP. As soon as received a positive response from a MCE/RNC, the MME/SGSN will reply a Session Start Response to the MBMS-GW using the GTPv2-C protocol

— The eNB/NB will then indicate the MBMS session start to the users inside its control area by the MCCH change notification and MCCH message which convey all the information of the MBMS session. It joins the IP multicast group to receive the MBMS data from MBMS-GW and finally transfer to the end-users.

2.2.5 MBMS User Services and Delivery Methods

When the MBMS data is transmitted from a service provider to a mobile user, two methods could be used at the user service layer : Streaming delivery method or Download delivery method. The selection between two methods does not depend on the choice at bearer service layer (either broadcast or multicast). For distinction sake, the MBMS user service layer involves the protocol above IP layer while the MBMS bearer service relate to the procedures below the IP layer. Different applications will apply different methods to deliver the content depending on the nature of the application, for instance, the mobile TV uses streaming method while software updating uses download method. The protocol stack for MBMS user service is illustrated in Fig. 2.9.

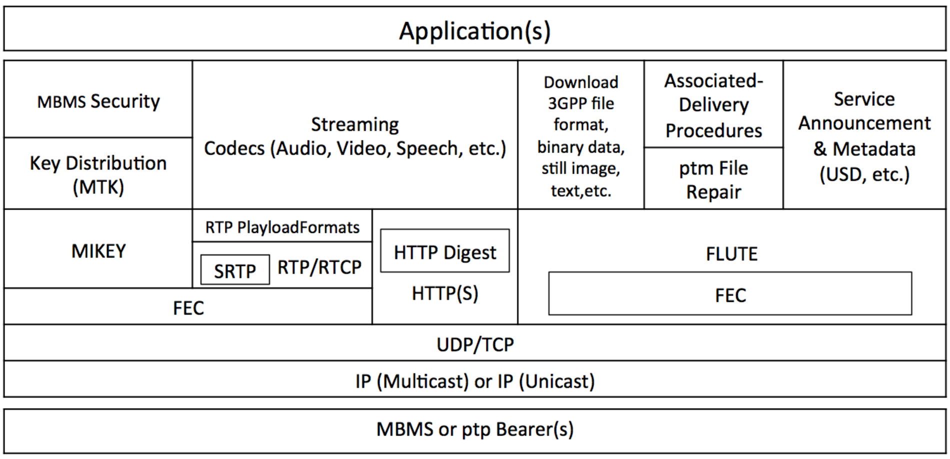


FIGURE 2.9 – Protocol Stack of MBMS User Service [3].

2.2.5.1 Streaming Delivery Method

The main objective of streaming delivery method is to deliver the continuous multimedia data including speech, audio and video on an MBMS bearer. Examples for streaming service could be the reception of near-real-time services such as a live sport event or a concert, video on demand, live traffic information, news or the most typical service : mobile

TV. Although usually deployed with the broadcast bearer, the MBMS Streaming delivery method can be used on unicast bearer as well [3].

The streaming method uses Realtime Transport Protocol (RTP) which sends the real-time data over the UDP as the transport protocol. Because of the nature of UDP, packet loss might occur during the transmission and effect the quality of the streaming service, therefore, the Forward Error Correction (FEC) mechanism is used as a protection solution. The protocol stack for FEC mechanism in MBMS streaming service is described in Fig. 2.10

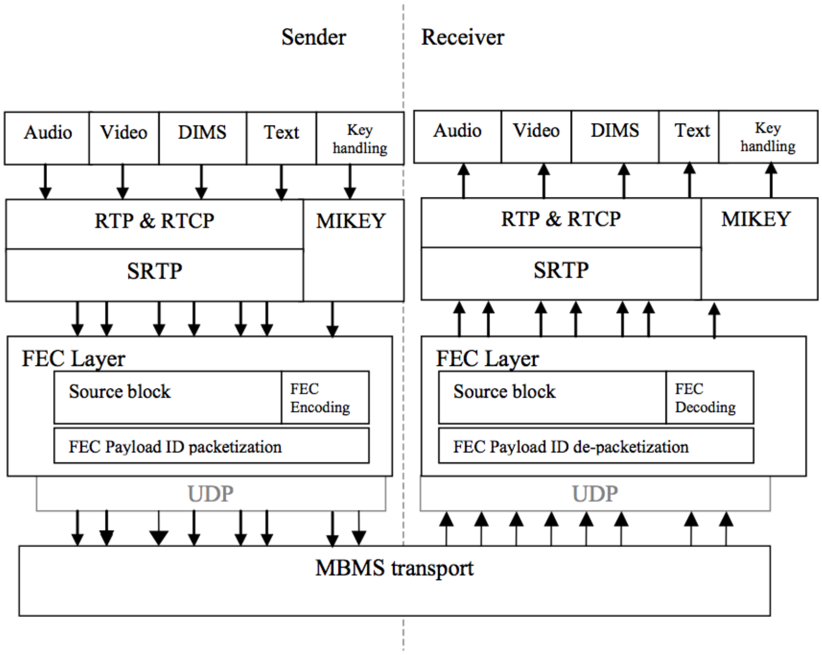


FIGURE 2.10 – Protocol Stack for FEC Mechanism in Streaming Delivery Method [3].

In MBMS streaming, the media data including speech, audio and video should encoded in a suitable format for being transported over RTP. The following RTP payload formats are eligible :

- AMR narrow-band speech codec ;
- AMR wideband speech codec ;
- Extended AMR-WB codec ;
- Enhanced aacPlus codec ;
- H.264 (AVC) video codec ;
- H.265 (HEVC) video codec ;

2.2.5.2 Download Delivery Method

The MBMS download delivery method aims to file distribution services with a near-error-free transmission. With this delivering method, the users can download and store in their devices arbitrary files at their interest such as music, movie trailer, news highlight, even games or software updates. Besides the common media types like video, audio or speech, the MBMS download method also supports still images, vector graphics, bitmap graphic or text. The traditional MMS service which transfers short videos over unicast connection can now take advantage of this feature to deliver the same content to multiple users.

The MBMS download delivery method may use the Push Over-The-Air (OTA) protocol to deliver data over normal unicast bearers (e.g. for the delivery of service announcement). That explains the HTTP(S) and TCP part in Fig. 2.9. To deliver the MBMS data over MBMS bearer, it uses the File Delivery over Unidirectional Transport (FLUTE [25]) protocol. FLUTE is a protocol for the unidirectional delivery of files over the Internet with both multicast and unicast but it is particularly suitable for multicast network. Initially, it was designed for transmission over UDP/IP and it is compatible with both IPv4 and IPv6. Built on top of the Asynchronous Layered Coding (ALC) protocol, FLUTE inherits the ability of massively scalable multicast distribution. The ALC is a protocol instantiation of Layered Coding Transport (LCT) which provides in-band session management functionality. The most important functionality for download service is the reliability and due to the nature of UDP protocol, ALC has to combine the LCT building block with the FEC building block. This combination allows error-correction and improves the reliability of the transmission. Raptor code is chosen as the basis for FEC scheme in MBMS download delivery method. ALC originally uses the Congestion Control building block, however, the congestion control feature is not appropriated with MBMS download environment [26] and hence it is eliminated in MBMS. Fig. 2.11 shows the structure of FLUTE for MBMS. Besides FEC coding, two more file repair procedures are applied in MBMS download service using the normal p-t-p bearer or MBMS bearer.

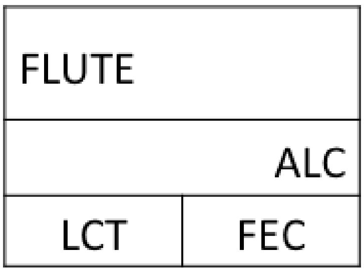


FIGURE 2.11 – FLUTE Building Block Structure for MBMS Download Delivery Method.

In a delivery over FLUTE protocol, a file to be transfered is called a transport object. This object will be sliced into many source blocks whose size are pre-calculated by FLUTE. These source blocks are then divided to multiple source symbols which are the input of the encoding procedure if FEC is applied. Finally, the encoded symbols are added headers to form the FLUTE packets for sending over UDP protocol. It uses a special object called File Description Table (FDT) to provide the index of files within a session as well as their identification and other associated attributes (location, name...).

Another application of the Download delivery method is delivering the data of a streaming service based on Dynamic Adaptive Streaming over HTTP (DASH) technology. How the Download mode can be used to transport a streaming service will be explained in the

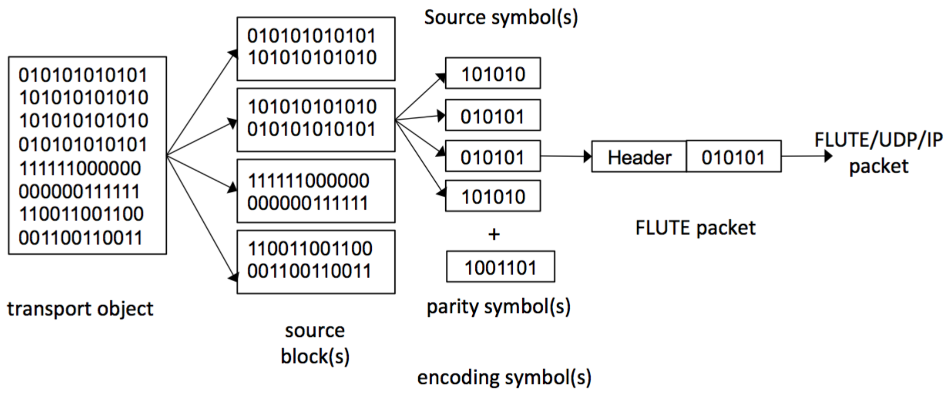


FIGURE 2.12 – Construction of FLUTE packet.

next section together with the introduction to DASH.

2.2.6 LTE Broadcast or Evolved MBMS in LTE Networks

One key feature introduced in the release 9 of 3GPP specifications is the MBMS service for LTE network under the name of evolved MBMS or eMBMs. The Orthogonal Frequency Division Multiplexing (OFDM) technology in LTE network allows using the single frequency network and less interference at the receiver, which is very suitable for broadcast. Not only changing from CDMA to OFDM, the MBMS service in LTE network or eMBMS has also other difference in comparison with MBMS in UMTS network. For example, in UTRAN, there are three modes of MBMS including point-to-point, single cell p-t-m and multicell p-t-m connection while the eMBMS only supports the multicell p-t-m mode. Also, in the eMBMS, multicast operation mode is omitted, only the broadcast operation mode is supported. The multicast in LTE eMBMS is used within the network to deliver the MBMS data from MBMS-GW to the eNBs in E-UTRAN.

In the specifications prior to release 9 (Rel-9), the UMTS network can deploy an entire frequency for MBMS transmission, however, in LTE network, with MBSFN operation mode, eMBMS can be used on the frequency that carries both broadcast and unicast traffic. It means that the eMBMS services are transferred by the base stations referred to as MBMS/unicast-mixed base stations. In these base stations, the radio resource allocation for eMBMS and unicast services is done using the time division multiplexing manner such that each subframe carries either broadcast traffic or unicast traffic on their dedicated physical channel.

Compared to the unicast transmission, the Home-eNB (HeNB) and the Robust Header Compression are not supported in eMBMS. The Hybrid Automatic Repeat Request (Hybrid ARQ or HARQ) and the Radio Link Control (RLC) retransmission mechanism are neither used in eMBMS, i.e. the eMBMS channels are transported in single transmission. In LTE network, one user can be in either RRC-connected mode or RRC-idle mode and in both states, it can receive the eMBMS data and get the notification for unicast service such as an incoming call.

The eMBMS architecture is evolved to support the MBSFN operation with high flexibility in bandwidth usage and scheduling for a particular eMBMS service. Concerned the deployment of eMBMS architecture with the newly defined entity MCE, there are two possibilities as depicted in Fig. 2.13

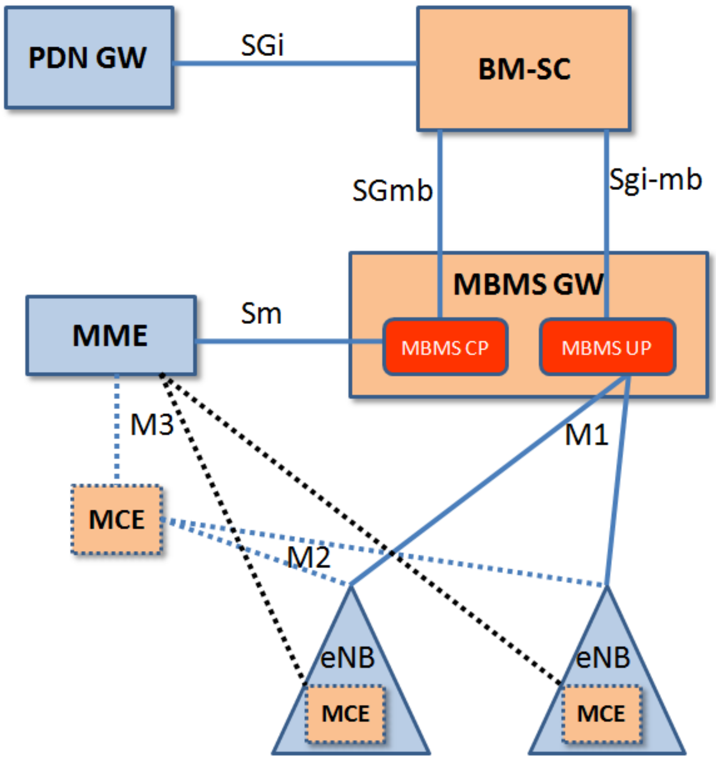


FIGURE 2.13 – eMBMS Network Architecture with 2 MCE deployments.

The first way to integrate the MCE into the LTE network is building it inside the eNBs which is referred to as the “distributed MCE structure". With this deployment, the network operators just need to upgrade software part of their base stations and therefore, it is very good in terms of cost efficiency. Because the MCE resides in the eNB, the M3 interface will terminate at the eNB and M2 interface would not be necessary anymore. In an alternative way, the MCE is implemented as a stand-alone network node, as know as the “centralized MCE structure". In this case, one MCE can connect to all eNBs that belong to one MBSFN area whereas the “distributed MCE" only control MBMS function of cells inside one base station in which it is attached. That makes the centralized MCE structure have an advantage for the coordination in MBSFn transmission.

2.2.6.1 eMBMS Subframe

In LTE network, the eMBMS is time multiplexed with unicast service meaning that one radio resource can either conveys eMBMS traffic (signaling or user data) or unicast traffic. In one LTE frame, maximum six out of ten subframes might be used for delivering eMBMS data (60% the capacity of the network) while in GERAN, MBMS may use up to 5 timeslots in downlink for a single transport channel. Once a subframe is allocated, all resources in that subframe are used for eMBMS services. The position of resource reserved for each traffic type is given to the users in the System Information Block type 2 (SIB2). Which subframe can be allocated for eMBMS service is depending on whether Time Division Duplex (TDD) or Frequency Devision Duplex (FDD) is used in the network. The eMBMS services coud be transported in both TDD and FDD mode, however, there is a difference in the subframe allocation between TDD and FDD. Maximum six subframes can be allocated for broadcast service in FDD and they are subframe 1, 2, 3, 6, 7 and 8 as appeared in Fig. 2.14.

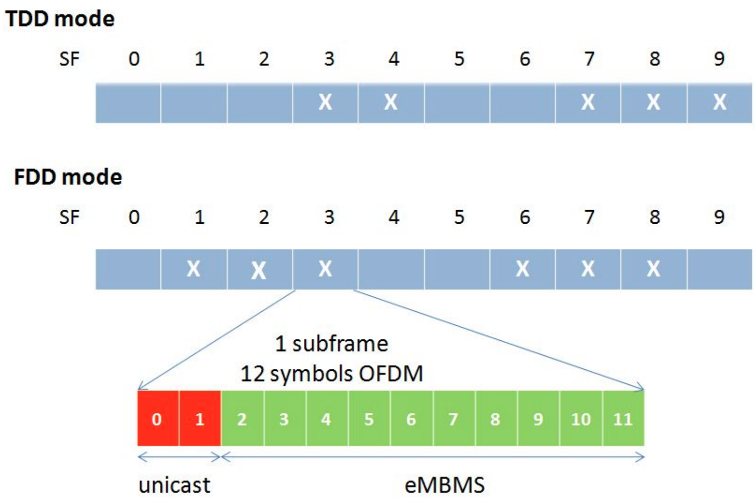


FIGURE 2.14 – Subframe Allocation for eMBMS.

The situation is a bit different for TDD mode, only five subframes are able to carry the eMBMS services including subframe 3, 4, 7, 8 and 9. Another constraint is that this allocation depends on the TDD uplink/downlink configuration.

UPLINK-DOWNLINK CONFIGURATION	DOWNLINK TO UPLINK SWITCH PERIODICITY	SUBFRAME NUMBER									
		0	1	2	3	4	5	6	7	8	9
0	5 ms	D	S	U	U	U	D	S	U	U	U
1	5 ms	D	S	U	U	D	D	S	U	U	D
2	5 ms	D	S	U	D	D	D	S	U	D	D
3	10 ms	D	S	U	U	U	D	D	D	D	D
4	10 ms	D	S	U	U	D	D	D	D	D	D
5	10 ms	D	S	U	D	D	D	D	D	D	D
6	5 ms	D	S	U	U	U	D	S	U	U	D

FIGURE 2.15 – Uplink/Downlink Configuration in LTE TDD.

As we can see in Fig. 2.15, only in the configuration mode 5, all five possible subframes can be reserved for eMBMS while in other configuration, it is impossible because the subframes for eMBMS and those for downlink are not matched. For example, in TDD configuration mode 3, only subframe 7, 8 and 9 can be used for eMBMS, subframe 3 and 4 are reserved for uplink ; or in configuration mode 1, only subframe 4 and 9 are able to contain eMBMS because subframe 3, 7 and 8 are for uplink purpose.

One more thing needs to be noticed : there is a small part for unicast traffic inside each eMBMS subframe. The reason for the appearance of unicast traffic in eMBMS subframe is that the mobile users still require the information about the scheduling and power control command for uplink direction in unicast transmission. This unicast control part takes one or two first symbol OFDM in eMBMS subframe and is informed to the terminals in common broadcast information (in System Information Block type 13).

2.2.6.2 eMBMS Channels

To support the eMBMS transmission in LTE network, two new logical channels are introduced : the MBMS Control Channel (MCCH) for eMBMS signaling informatioin and the MBMS traffic channel (MTCH) for the eMBMS user data. In one MBSFN area, all control information related to the eMBMS services provided in that MBSFNA area is given in a message that is carried on the MCCH channel. This information is created at Radio Resource Control (RRC) level and guides the terminal how to receive a specific eMBMS service. Contrary to the MCCH, in one MBSFN area, there could be many MTCH channels and each of them corresponds to one service/session. The MBMS point-to-multipoint Scheduling Channel (MSCH) in UMTS is eliminated in eMBMS.

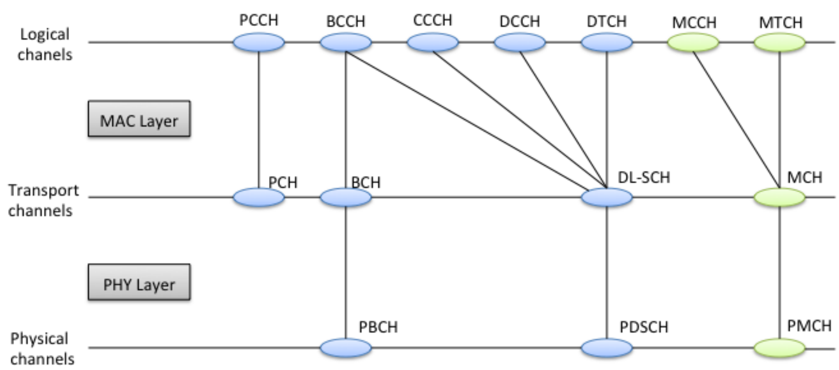


FIGURE 2.16 – Channel Mapping for eMBMS.

Different from UMTS network, the MCCH and MTCH channels in LTE eMBMS are mapped on a transport channel called Multicast Channel (MCH) instead of the Forward Access Channel (FACH) or the Downlink Shared Channel (DL-SCH). One MCH transport channel transfer the MBMS data (including one or more MTCHs and maybe the MCCH) from MAC to PHY layer. The MCH is mapped to the Physical Multicast Channel (PMCH) before the eMBMS data are transported over the air interface to the mobile terminals. Fig. 2.16 illustrates the mapping among logical, transport and physical channels in eMBMS.

2.2.6.3 eMBMS Content Synchronization

To realize the MBSFN operation with higher spectrum efficiency, all the eNBs belonging to one MBSFN area need to be tightly synchronized in time for transferring the eMBMS content. In order to ensure that all the eNBs broadcast exactly the same MBMS content, a protocol namely Synchronization protocol (SYNC) is applied in the User plane (U-Plane) over the M1 interface.

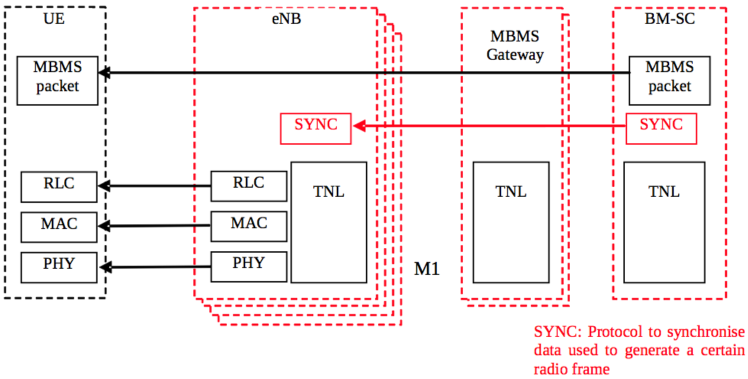


FIGURE 2.17 – eMBMS User-plane Protocol Architecture [1].

The MBMS-GW sends to all the LTE base stations participating to the eMBMS transmission the eMBMS data packet with SYNC protocol information. The information in SYNC protocol helps the eNB to determine the timing for transmitting radio frames as well as to detect the packet loss. One SYNC protocol instance is associated to one and only one bearer between MBMS-GW and eNB or the E-UTRAN Radio Access Bearer (E-RAB). This SYNC instance contains a “time stamp" field indicating the moment at which eNBs should do the transmission and other fields with packet number and packet size for the packet loss detecting purpose. There are three types of SYNC Protocol Data Unit (PDU), each has different format and may consist of the control information and/or payload data [27].

2.2.6.4 DASH for eMBMS

For the last few years, an evolution has been taken placed in the video streaming industry : the Hypertext Transfer Protocol (HTTP) based streaming protocols such as Apple HTTP Live Streaming (HLS) [28], Adobe's HTTP Dynamic Streaming (HDS) or Microsoft SmoothStreaming have dominated the traditional Real Time Transport Protocol (RTP) based streaming protocol. The 3GPP standardization body also introduced in Rel-9 the protocol called Adaptive HTTP Streaming (AHS) to allow the media streaming via eMBMS. Based on the AHS, 3GPP in cooperated with Moving Picture Experts Group (MPEG) has defined the Dynamic Adaptive Streaming over HTTP (DASH or MPEG-DASH) standard in 2012. Later in the specifications Rel-10, a compatible version of MPEG-DASH is defined with the name of 3GP-DASH for delivering streaming services to DASH clients from HTTP servers. Both MPEG-DASH and 3GP-DASH content can be streamed over eMBMS.

There are two concepts need to be understood in DASH : the Media Presentation Description (MPD) and Segment. A segment is a small piece of media content and the MPD is a manifest file in XML form giving the information of these segments. This information consists of media characteristic (video resolution, duration and bitrate, the address or Uniform Resource Locator (URL) to get the segment and corresponding timing.

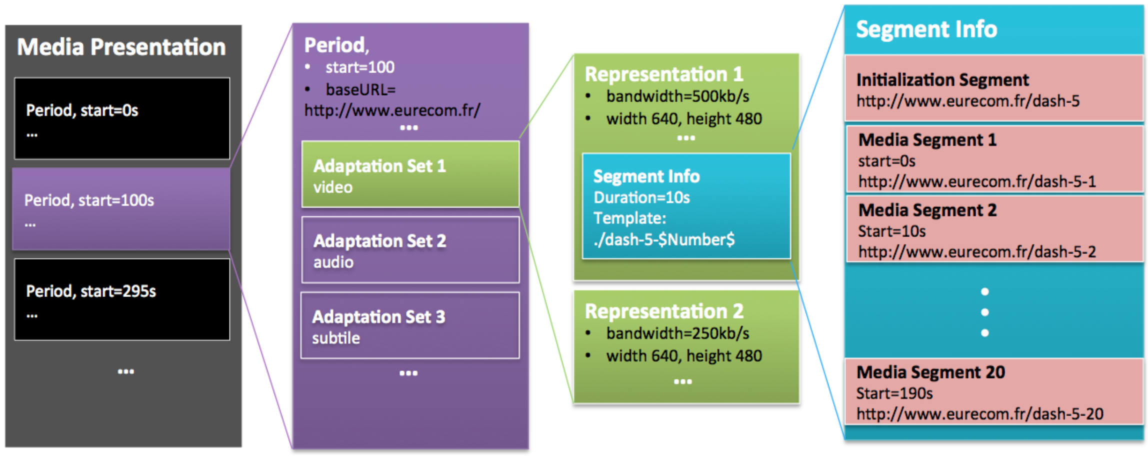


FIGURE 2.18 – DASH Data Model.

The detail of DASH data model is explained in Fig. 2.18 An original media content or a Media Presentation is divided into small parts call Periods. Each Period consist of one or more Adaptation Sets which represent media content components. For instance, in the figure above, one Adaptation Set contains the video part and the one represents the audio part and the last one for subtitle. As its turn, each Adaption Set may contain multiple Representations that have different characteristic (different bitrate for example). Despite the difference, these Representations are interchangeable, i.e. the client can get any Representation to render the media content. Finally, each Representation is sliced into Segments which are then delivered to the clients. Depending on the connection quality and maybe other factors, a client can demand for the Representation that fits their need. And the MPD will guide them to get the appropriate Segments in the suitable Representations.

For video streaming, DASH allows the continuous segments of the media content transmitted from source to users over HTTP while eMBMS uses a unidirectional to distribute files. How could DASH be used with eMBMS ? As we know, the MBMS Download Delivery Method is designed to deliver one or more objects via MBMS bearer to multiple receivers. Further, DASH formats are not obligated to transferred over HTTP/TCP protocol. We can take advantage of the download method to deliver the DASH segments and MPD file to the clients using FLUTE protocol.

The MPD, which provides the information to obtain the Segments in DASH, plays the same role with the File Delivery Table (FDT) in FLUTE that describes the attributes of the objects being transported in a session. To adapt the DASH in eMBMS, the URL address corresponding to a Segment in MPD file is associated with a delivered object in the FDT. The MPD could be sent to the users via the User Service Description (USD) while the DASH Segments are transferred as FLUTE files (objects) using UDP/IP protocol. At the receiver side (i.e. the terminal), FLUTE is able to map the received objects into the

HTTP caches. In such way, the DASH client part in the mobile terminal will consider these objects/files are delivered over HTTP protocol and it can retrieve these files using the MPD file. This point leads to the idea of combining the DASH in eMBMS and traditional DASH over HTTP to allow a seamless switch between broadcast and unicast connection.

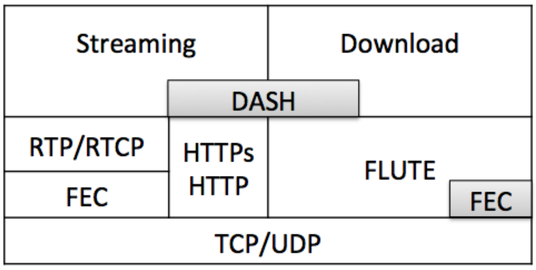


Figure 2.19 – Protocol Stack for eMBMS with DASH.

In the original design, DASH client can choose one suitable instant among a set of representations, however in eMBMS, the user has no choice, only one representation is delivered via the MBMS bearer, i.e. the MPD file describes only one representation of the media content. As a trade-off, using DASH in eMBMS has some advantages :

- The reliability in FLUTE transmission is increased thanks to the FEC mechanism and the ability of using file-repair function in unicast.
- The same DASH encoder can be used to serve a large number of clients in both unicast and broadcast streaming service.
- It allows the use of the same protocol stack for file delivery and streaming system.

2.3 Quality of Experience

Besides the familiar concept Quality of Service (QoS), the term Quality of Experience (QoE) which has been introduced recently attracts many attentions from researchers. There have been quite a lot of studies concerned with QoE in the last few years. But what is QoE, why it now becomes more and more popular in video assessment and how can we measure it ? This section will first give the definition of QoE and then approach the measurement methods for QoE.

2.3.1 Definitions

The International Telecommunication Union (ITU) Focus Group on IPTV defines QoE as "the overall acceptability of an application or service, as perceived subjectively by the end-user". In the definition, we can see obviously that QoE is measured by the human, in other words, it is a subjective measurement. The human quality assessment is usually given on a scale called Mean Opinion Score (MOS) [29] that consists of five levels from 1 (worst) to 5 (best) as in the table below :

Table 2.1 – Mean Opinion Score

Scale	Quality	Impairment
5	Excellent	Imperceptible
4	Good	Perceptible, but not annoying
3	Fair	Slightly annoying
2	Poor	Annoying
1	Bad	Very annoying

2.3.2 Measurement Methodologies and Tools

In general, there are two principal ways to measure the Quality of Experience : subjective and objective. The first method requires the assessment directly from the human user while the latter one decides the QoE based on technical parameters. Recently, there have been some studies on another approach, referred to as Pseudo-subjective technique, which combines the advantages of both methods. We will introduce in this section these QoE estimation methodologies and their tools.

2.3.2.1 Subjective measuring technique

The subjective measuring is based on the evaluation of the real end-users who use the service ; hence this kind of technique gives us the true perceptive quality. In [30], C.Schaefer et al. has published his research in measuring the subjective quality of a multiplayer Real-time games. The paper gave the true subjective quality assessment for the performance of an end-to-end service and proved that human perception did have the relation with the objective quality (the System Response Time-SRT in this case). However, the drawback of this process is the requirement of great number of human subjects to get the reliable result, therefore it is very costly and time consuming. Besides that, it cannot be done automated, so somehow it is not really suitable for the real-time application. For these reasons, people prefer using the objective measuring techniques in order to have the reasonable accuracy compared to subjective one. In fact, these objective methods measure technical parameters of the system (QoS parameters : the transmission network or quality of the media source) and then try to generate the value of QoE from these parameters (QoE = f(QoS)). Usually, this relationship is expressed in form of a formula and the goal of researchers is finding out the most suitable components for this formula. There are a lot of studies have been done in this subject and we will list some of them in the next section.

2.3.2.2 Objective measuring techniques

The objective methods were developed in order to emulate the quality assessment of the human users based on the Quality of Service (QoS) parameters. The International Telecommunication Union, Telecommunication Standardization Sector (ITU-T) introduced in [31] a method so-called E-model to predict the QoE of voice conversation. In this method, the rating factor R is first calculated in the following equation :

$$R = R_o - I_s - I_d - I_{e-eff} + A \tag{2.1}$$

in which, Ro is the basic signal-to-noise ratio (SNR), Is is related to the impairments occurs simultaneously with voice signal, I_d is concerned with the delay and I_{e-eff} represents for media codec or packet loss.

From the rating factor R, an estimated MOS for the conversational situation is given using the equation :

$$MOS = 1 + 0.035 * R + R(R - 60)(100 - R) * 7.10^{-6} \quad (2.2)$$

Based on the E-Model, ITU also defines in [32] the similar way to calculate the QoE for video-telephony service where the MOS for audio and video are estimated separately. With audio part, the quality index Q is calculated following the equation below :

$$Q = 93.193 - I_{dte} - I_{e-eff} \quad (2.3)$$

The speech quality S_q is then determined from factor Q exactly the same way as the previous method for voice conversation from factor R while the video quality V_q is calculated using the parameter I_{coding} related to coding distortion, the loss robustness D_{PplV} and the packet loss rate Ppl_V.

$$Vq = 1 + I_{coding}\ exp(-\frac{Ppl_V}{D_{PplV}}) \quad (2.4)$$

There are many types of parameters that may involve to the quality evaluation of the video transmission including packet loss, delay and jitter. The other metrics such as Peek-SNR (PSNR), ITS's Video Quality Metric (VQM) or EPFL's Moving Picture Quality Metric (MPQM) are also used. EvalVid is a framework using PSNR to calculate the MOS for video transmission. It compares the maximum possible signal energy to the noise energy, which was shown having a higher correlation with the subjective quality evaluation than the original SNR. PSNR calculates the difference in every single frame between the video source and the destination one as described in the following equation :

$$PSNR(n)_{db} = 20log_{10}(\frac{Vpeak}{RMSE}) \quad (2.5)$$

where $Vpeak = 2k - 1$; k is the number of bits per pixel ; $RMSE$ is the mean square error of the N^{th} column and N^{th} row of sent and received video frame n. After finishing the calculation, we need a mapping between $PSNR$ value and the MOS score to get the quality assessment. Jirka Klaue et al. used the mapping given in 2.2 to get the MOS from PSNR [33].

Table 2.2 – PSNR and MOS

PSNR(dB)	MOS
>37	5 (Excellent)
31-37	4 (Good)
25-31	3 (Fair)
20-25	2 (Poor)
<20	1 (Bad)

This kind of technique can be considered as a full-reference model because it requires the knowledge about both sender and receiver side, so it needs time to get the reconstructed video sequence as well as much intension in calculation. Moreover, PSNR metric does not take into account the delay and jitter, which have a big effect in the perceived quality of a video stream. The content of media source is also a factor that makes result in PSNR technique unstable, this point was proved clearly in the context of video transmission [34] ; therefore it is obviously not suitable for an online media QoE evaluation.

Video Streaming Quality Index (VSQI)

Contrary to full-reference model, no-reference method only judges the quality of the service based on the received signal. It can be less accurate than full-reference technique but no need the synchronization between source and received signal that make it more practical (less complex in the computation) and suitable for real-time service, especially in live video streaming. One representation for this technique is the Video Streaming Quality Index (VSQI) [35] which is integrated in TEMS Investigations tool [36]. VSQI method is a part of the P.NAMS project in ITU-T with the objective to imitate the quality estimation of a user in both video and audio part of a streaming service. The output of VSQI is a value varies from 1 to 5, i.e. corresponds to the MOS scale while the input of VSQI includes following factors :

— Attributes of the media file such as : codec type and bit rate (both video and audio).
— Duration of initial delay, number and duration of interruptions during playback.
— Number of packet loss at the application level of the receiver.

There are two versions : static VSQI used to estimate the QoE of the whole video stream and dynamic VSQI which evaluate the QoE of the streaming service in realtime at consecutive intervals of 1 second. The static method takes the input parameters of the entire streaming session into account and calculates the result by the simplified equation below :

$$VSQI_{static} = VSQI_{clean} - (buffering\ penalty) - (packet\ loss\ penalty) \tag{2.6}$$

where the $VSQI_{clean}$ is the value calculated from the parameters related to the nature of the encoded media file before the transmission.

The dynamic method gives the QoE value for each interval based on the recent packet loss as well as buffering event of the received stream. Because the dynamic VSQI mechanism is suitable for real-time streaming services and its input parameters (interruption time + packet loss) are related to the service quality perceived by the human users during the handover period, we decide to use VSQI as the tool for estimating the QoE of eMBMS service during the handover in our experiment (will be presented in Chapter 6).

Besides the method calculate QoE for general audio or video streaming service, some specific services like video streaming over HTTP or Internet Protocol Television (IPTV) are also the objective for QoE evaluation method. For assess the HTTP video streaming, the authors in [37] have provided a function to calculate the MOS based on the initial buffering time, rebuffering time and the rebuffering frequency :

$$MOS = 4.23 - 0.0672 * T_{init} - 0.742 * f_{rebuf} - 0.106 * T_{rebuf} \tag{2.7}$$

For IPTV, one important element is the time for a user changes from one channel to another one, often known as channel zapping time. The authors in [38] have proposed a model for mapping between the zapping time and service quality received by human users and validated their model by conducting a test with the evaluation of real human users. The mapping is given in following formula :

$$MOS = max\{min\{2.65 - 1.02 * ln(Zapping\ Time), 5\}, 1\} \tag{2.8}$$

The $Zapping\,Time$ (in second) is very similar to the interruption time of a media stream in eMBMS when the handover happens, therefore, we also use this formula to calculate the QoE of eMBMS during the handover period to demonstrate the out-performance of our proposed solution in Chapter 4.

2.3.2.3 Pseudo-subjective or hybrid methods

Although taking into account the QoS parameters that affect the quality perceived by end-users, the objective methods still have some drawbacks : the result is not always correlate with the human perception, high requirement in calculation power and difficulty in adaptation with real-time service. That is the motivation for researchers working on a new type of technique which combines both subjective and objective one.

One representation for hybrid technique was proposed by S.Mohamed and G.Rubino in [39]. The study is based on the Random Neural Network (RNN), an enhancement of their previous work that used another member in Neural Network family. As a hybrid technique, this method consists two factors : the evaluation of end-user and the automatic quality assessment from the values of objective parameters measured online. It is also called Pseudo-Subjective Quality Assessment (PSQA) method.

The first step in this technique is choosing the most effective quality-affecting parameters (will be mentioned later) corresponding to the nature of media source and of course the characteristics of the transmission network. From each chosen parameter, we consider its values which appear most frequently in order to identify its range. A set of many parameters with certain values in their range is called a configuration. For one configuration, a distorted video sequence is produced along with network condition thanks to a simulation environment. Doing this process for all configurations we have a distorted database and it is the time for carrying out a subjective quality assessment with the presence of end-users. Next step is collecting the scores given by human subjects and storing them with their corresponding parameters. In this study, the authors used a slightly different MOS scale with nine levels from 1 to 9 instead of the 5-level-scale as usual. These MOS scores will be used as the input of an RNN architecture. Now we have MOS scores with their associated configuration $f(v_1, v_2, ..., v_P)$ (P is the number of parameters ; v_i is the value of parameter i^{th}) and the goal of RNN is to identify the function f containing P variable such that :

- $f(v_1s, v_2s, ..., v_Ps) = \mu_s$($\mu_s$ is an MOS score)
- $f(v_1, v_2, ..., v_P)$ is close to the MOS would be received by human evaluation from a video sequence having specific values $v_1, v_2, ..., v_P$.

The final step of this method is validating the result by another set of video sequence database. In the paper, these following parameters were used regarding their impact to video quality : the Bit rate of the encoder's output, the Frame Rate of the video sequence, Loss Rate, the number of Consecutively Lost Packets (CLP) and the ratio of the encoded intra macro-blocks to inter macro-blocks. Their effects on video quality were compared very detail in [4]. Not only applying RNN technique for video transmission, the authors also studied its impact in speech/audio quality through a packet network in [5], and in both cases, the results are very promising. These studies showed a good correlation with the subjective evaluation from the real-time measuring objective parameters.

In another work, Prasad Calyam et al. presented a novel framework that provides online QoE estimation without any reference about the sources and end-user involvement. His study, the GAP-model, is also a hybrid technique for measuring the perceptual quality of an end-user. Like PSQA method, this methodology requires the human opinion at first. Human subjects are asked to rank their subjective perceptual QoE from a set of videos produced in different network conditions. These network conditions were configured by the NISTnet WAN emulator based on the network parameters. Four factors considered in this research were : bandwidth, loss, delay and jitter. These parameters are classified in three levels, namely "Good", "Acceptable" and "Poor" which create the model's name GAP. The detail values of these factors within their ranges can be found in [40]. The human assessments for these media sources are given in term of MOS, i.e. in the mark from 1 to 5 and these results are collected in order to establish the relation between the network parameters and end-user perceptual QoE (q_{mos}). Not like in the previous method, a multiple-regression technique was used to generate the formula of q_{mos} instead of an RNN model. The QoE value is described in the below equation :

$$q_{mos} = C_0 + C_1 b_{net} + C_2 d_{net} + C_3 l_{net} + C_4 j_{net} + C_5 l_{net}^2 + C_6 j_{net}^2 + C_7 d_{net} l_{net} + C_8 l_{net} j_{net} \tag{2.9}$$

where $b_{net}, d_{net}, l_{net}$ and j_{net} are bandwidth, delay, loss and jitter of the network, respectively. The coefficients $C_0..C_8$ depend on the specific experiments and are determined due to the results given by the human subject. Once these coefficients are obtained, we can retrieve the QoE metric value from the network parameters which are measured in the real-time. The authors have studied this method in the context of streaming (one way) and interactive (two ways) Voice and Video over IP (VVoIP) service. The study in [40] focused on H.263 video codec at 768Kbps speed but it can be applied for other video codecs such as MPEG-2 or H.264 with higher speeds. Furthermore, he also proposed another QoE metric other than MOS in order to evaluate the perceive quality of VVoIP service, especially in video conferencing. All the simulations in his work were done with the help of Vperf tool. Although giving the result very closed to the human assessment with an automatic and in real-time measuring process, the pseudo- subjective techniques still have a common disadvantage ; that is the narrow in applying for a specific case. For example, with RNN-based method, we have to choose appropriated parameters that have strong impact to the quality of service in order to get the good RNN model ; while in GAP-model method, we have to recalculate the coefficients each time the type of service (streaming or interactive video) changes.

Chapter 3

Service Continuity for LTE Broadcast Service

3.1 Introduction

Nowadays, providing a smooth service in a high mobility environment is a crucial task for the wireless network operators and service providers. With LTE-Broadcast, the situation is more critical because popular sport events such as a match of Super Bowl or World Cup, which are the target of eMBMS, would attract many spectators who are on the move (in a car, a bus or on a train, etc.). As the result, supporting the mobility for eMBMS users becomes a need in LTE/LTE-Advanced networks. Because not all base stations in the network transfer the same set of eMBMS service, the users may change to a target cell that does not transfer the eMBMS service they want. And in that case, if there is no special mobility support mechanism, the service will be stopped.

Due to the attribute of MBSFN transmission, there could be following types of handover for an eMBMS user :

1. Intra MBSFN Area handover : the user moves to a new cell that belongs to the same MBSFN Area with the current cell.
2. Inter MBSFN Area handover : the MBSFN Areas supported in the source and target cell are different.
3. Inter frequency/carrier handover : the user switches to another frequency or component carrier (maybe in the same or different eNB).
4. Inter Radio Access Technology (RAT) handover : the user changes to another broadcast system to continue receiving the service.

Although the 3GPP standard has just introduced a supplement in the specification release 11 (2012), the mobility support for eMBMS is still very limited. This supplement only provides the service continuity for eMBMS in the case of inter frequency/carrier handover. This chapter aims to address the service continuity for all cases listed above.

The content in this chapter is organized as follows : we begin with the mobility issue in each case, then the support from LTE standard and solutions from research community will be mentioned. Finally, we will present our solution to support the service continuity for eMBMS service in LTE networks.

3.2 Mobility Issues

Fig. 3.1 illustrates a part of an LTE network in which several eNBs are contributing to eMBMS transmission within four MBSFN areas. Each cell/eNB is represented by a hexagon shape in the figure while the MBSFN Areas are the eclipse areas in different colors. The cells in one eclipse belong to the corresponding MBSFN area. For example, cell 1 and 2 belong to MBSFN Area 1 ; cell 7 and 8 are part of MBSFN Area 2 and so on. Cell 3 and 10 are two MBSFN Area reserved cells and do not participate in the eMBMS transmission. Cell 6 is in the overlap zone of MBSFN area 2 and 3 so it supports both areas.

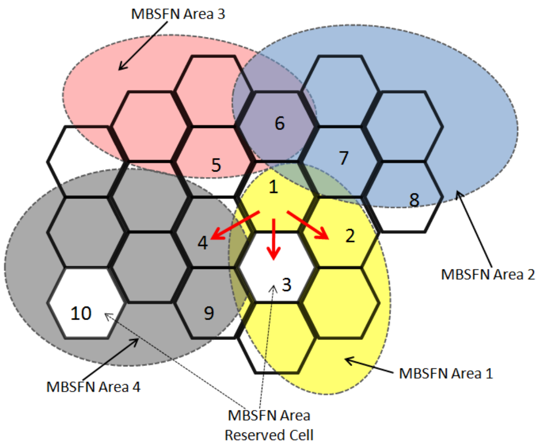


FIGURE 3.1 – MBSFN Area and eNB example

With this simple network configuration, when an LTE mobile terminal is receiving eMBMS and moving in the area, several basic mobility scenarios can happen as follows.

Case 1 When a UE leaves Cell 1 to Cell 2 (in MBSFN area 1) or from Cell 4 to Cell 9 (in MBSFN Area 4), it does not get out the current MBSFN Area. In this case, the intra-MBSFN Area handover will occur.

Case 2 The UE is receiving an eMBMS service and moving to an MBSFN Area reserved cell which is a cell that does not participate to the eMBMS transmission (for example, it moves from Cell 1 to Cell 3 in the Fig. 3.1). Changing to unicast connection or an inter RAT handover is envisioned in this situation.

Case 3 If the UE moves to a target eNB that does not belong to the same MBSFN Area with the serving eNB. (cell 1 to cell 4 for example), the inter MBSFN Area handover will take place

Case 4 The mobile terminal switches to another component carrier in the serving cell or to a new cell that operates in other frequency.

In the first scenario, even though the UE has to do the Handover or cell re-selection procedure to maintain the unicast connection, it does not need to do anything for eMBMS transmission. In fact, thanks to the MBSFN operation, all signals from the eNBs in the same MBSFN area will be considered as a signal from one transmitter under the multi-path effect at the receiver side. Thereby, the UE will act as if there is no eMBMS mobility with the moving within one MBSFN area. This is the biggest difference between the mobility for unicast and broadcast service in LTE.

In the case where the mobile user enters an MBSFN Area reserved cell, the broadcast service reception will be terminated unless the data flow is guided to go through an unicast transmission. The switching from broadcast to unicast can be done due to the use of DASH technology for eMBMS. However, the mechanism to do this is not specified in the standard. In this thesis, we will focus on the solutions that help the user receive the eMBMS service through eMBMS bearer. The detail of changing to unicast connection (e.g. buffering, redirect traffic or using DASH, etc.) will be considered in the future research. If the UE has no choice but connecting to the MBSFN Area reserved cell, then the inter RAT handover might solve the problem. There are many requirements needed for this type of handover and in the method that will be presented at the end of the chapter, we provide one of these requirements to allow network to inform the UE information about the other RATs' capability.

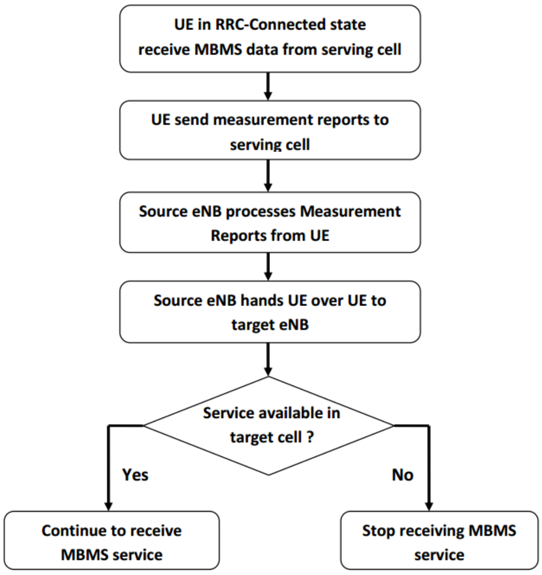
The mobility from one MBSFN area to another in the third scenario is currently not support in the 3GPP standard and it is a key feature in our solution to complete the mobility support for LTE-Broadcast. The last scenario is not really visible in the above figure but it happens quite commonly in modern cellular networks where the multi-frequency or Carrier Aggregation (CA) is deployed. The continuity support for eMBMS user in this case is mentioned in the LTE standard, which will be discussed in the next section.

Above are some basic scenarios could happen to an eMBMS capable LTE terminal in a mobility context. The following analysis will show what happen to the user's service reception of a user if there is no mobility support for eMBMS.

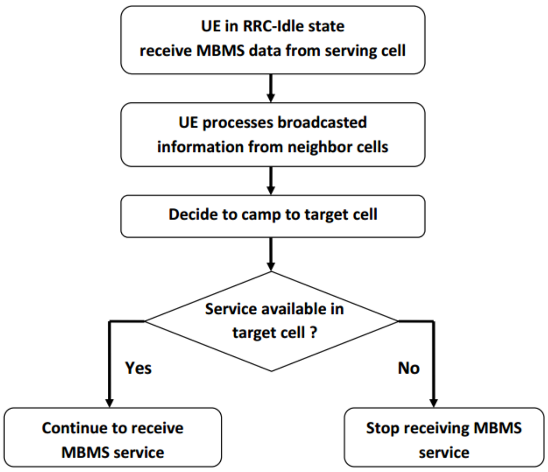
According to the 3GPP document release 10 (Rel-10) and previous specifications, there is no specific mechanism supporting the mobility for UEs that are receiving an eMBMS service [1]. That means, when moving, the UEs would perform normal procedures as it should do for unicast transmission in order to stay connect with the network at the new cell. Once connected, users will start to get the control information of eMBMS services if they are available.

As we all know, when one LTE mobile terminal is switched on, connect to the network, it is either in RRC-Connected state or RRC-Idle state and in both cases, it can receive the eMBMS services. Consequently, when studying the mobility of a user who is utilizing eMBMS services, we usually consider two situations : when that user is in the connected mode and when it is in the idle mode.

In connected mode, the mobile terminal detects, measures the attributes of neighboring cells while moving and it will send the measurement results to the serving cell if certain predefined conditions were met. Based on these reports, the serving cell will decide to make handover if necessary. The source eNB shall trigger the procedure by sending a Handover Request to the target eNB. If radio resources are allocated, UE can connect to a new cell and listen to eMBMS control information, which is conveyed in System Information Block Type 13 (SIB13), in order to know the MBSFN Area information. If the new cell is in



(a) Handover procedure



(b) Cell Re-selection procedure

FIGURE 3.2 – eMBMS without Service Continuity Support.

the same MBSFN Area with the old one, UE continues to receive the eMBMS service using the configuration in old cell. If they belong to different MBSFN Areas, the UE has to listen to the MCCH message which gives the detail information of a particular service (ID, position of radio resource allocated for that service) in the new cell. If the service that UE is receiving or interested in, is available, then it will continue receiving eMBMS data. Otherwise, UE cannot receive MBMS data anymore and the service is disrupted. Fig. 3.2(a) describes the standard procedure for the devices receiving eMBMS service in RRC-Connected state.

In idle mode, UE performs cell re-selection to support the mobility. During an eMBMS reception, UE obtains the broadcast information from neighbor cells and uses this information in evaluating process for cell re-selection decision. If there is no addition information provided concerned the eMBMS service, UE will choose the eNB with the highest priority and camp to that eNB (signal strength is usually used as the main factor for determining the priority order). Then, similar to the connected mode, the UE will check SIB13 and MCCH message in the new cell to get the desired service if available as given in Fig. 3.2(b).

We can realize that the service continuity can be surely maintained only if the source and target cell are in the same MBSFN Area. With the other cases, there is a possibility that the eMBMS service could be dropped. The reason is that the source eNB (or UE) decides to hand UE over (or to camp to) a target eNB without knowing which eMBMS services are available in that eNB. As a consequence, the chosen target cell (may be the one with maximum signal strength among neighbor cells) might not provide the eMBMS services that UE is interested in.

3.3 Mobility Support for LTE Broadcast Service in 3GPP Standard

Carrier Aggregation (CA) is a feature of LTE-Advanced that allows the aggregation of multiple component carriers to attain maximum transmission bandwidth (up to 100 MHz, corresponding to five 20 MHz carriers in the current LTE network). CA combines carriers at the mobile device to increase the user data rate, giving a better quality for high-bitrate services such as HD video streaming application. In case of eMBMS service, CA can offer the same service over multiple carriers/frequencies in order to increase the service's coverage. Another possibility is one service may be diffused on different component carriers in different quality (resolution of the video) to provide the diversity of media content and adapt to the need of the mobile users.

In the high mobility environment nowadays, a circumstance most likely happen is thats when receiving eMBMS service, a client moves out of the coverage of serving cell or frequency. Realizing the need of supporting the mobility for eMBMS user in LTE-Advanced network, especially with CA deployment, the 3GPP standardization body has introduced a supplement to provide the service continuity for broadcast services in the release 11 of its specifications [1]. With this supplement, the mobile terminals can achieve the service continuity when changing cell within one MBSFN area. Thanks to the guidance of the serving eNB, the UEs are able to switch to the frequency that supports their interested eMBMS services.

According to the 3GPP standard, the network is responsible for informing LTE terminals (in both RRC-Connected and RRC-Idle mode) about the eMBMS services that are supported in the current frequency as well as in the neighboring frequencies. This information is given in the User Service Description (USD) and an MBMS specific System Information Block - SIB15 [41]. In the USD, each service will be associated with its own Service Identity which is a part of the Temporary Mobile Group Identity (TMGI), the frequencies on which it is transferred and the MBMS Service Area Identities (SAIs). The SIB15 contains two elements :

— A list of all MBMS Service Area Identifications (SAIs) that are supported in the current cell/frequency.

— A list of neighboring carrier frequencies together with the corresponding SAIs they are supporting.

In order to get the SAIs of neighboring frequencies/cells, the serving cell can demand directly from its neighbors over the X2 interface or from the Operations, Administration, Maintenance (OAM).

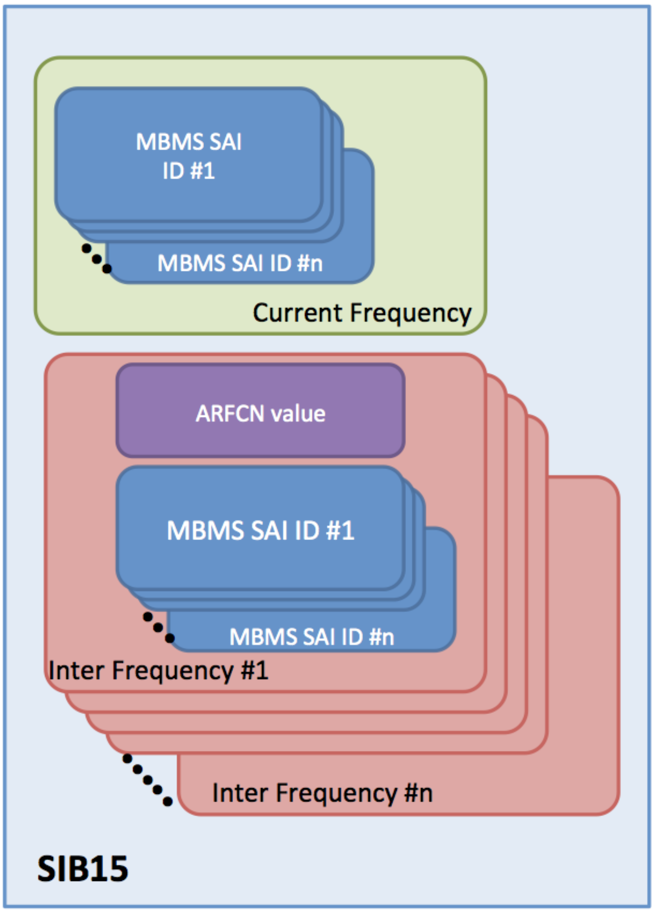


FIGURE 3.3 – System Information Block Type 15 Structure.

Combining the information of the SAIs listed in SIB15 and the SAI of the MBMS service indicated in USD, the mobile terminal can determine which frequency provides the services it is receiving or interested in receiving. For LTE terminals in RRC-Idle state, identifying the appropriate frequency is very important because it could help them to prioritize candidates for the cell re-selection procedure in a right order. If an eMBMS UE is looking for a cell to camp and interested in eMBMS services, it would assign a higher priority order to the frequencies that offer its services. With this mechanism, the eMBMS users can choose the right candidate to camp and receive their desired broadcast services. As the result, the eMBMS reception will be maintained for the idle UEs if at least one neighbor frequency provides the required services.

If none of neighboring frequencies provides the appropriate eMBMS services, the UE

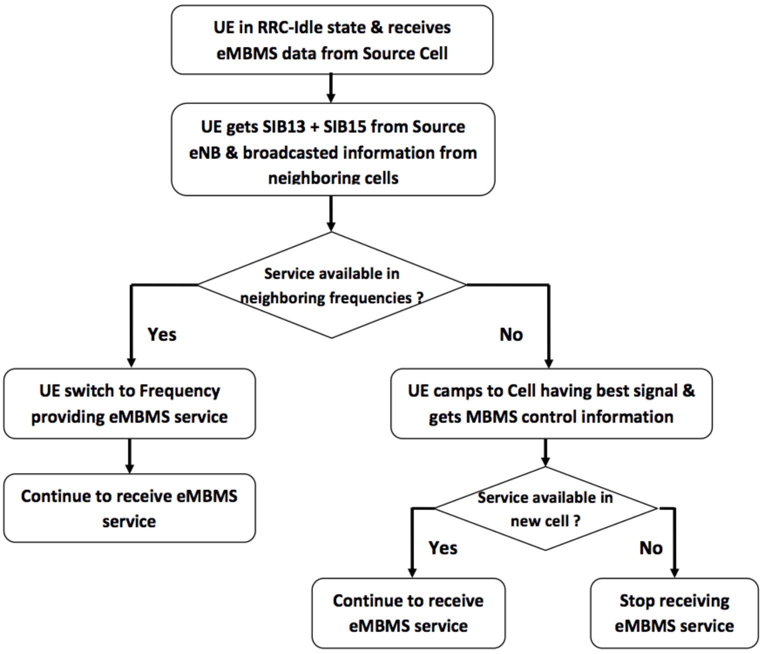


FIGURE 3.4 – eMBMS Mobility Support for Idle Users in LTE standard.

will choose the candidate with the best signal as usual. After camping to the new cell, the terminal will listen to the control information related to eMBMS service in SIB13 and MCCH message. Fig. 3.4 illustrates how the eMBMS service continuity is done for RRC-Idle users in LTE network.

Unlike in the idle mode, the serving cell will choose the target cell to hand the RRC-connected users over. The mobile users who are getting or wish to get eMBMS service will assist the current cell in handover procedure by giving the information regarding the eMBMS interest besides the normal measurement report. This extra information is enclosed in one RRC message and is sent to the serving cell as a response to the SIB15. The message is called *MBMS Interest Indicator* and it consists of the frequencies on which the UE is receiving or interested in receiving eMBMS services. The user may send the MBMS Interest Indicator message as soon as the RRC connection is established or when it changes the interest. And this information can be sent by the serving cell to the target cell during the Handover procedure. In addition, this message also contains one bit to indicate whether the UE prefers the eMBMS reception to normal unicast reception. The current cell will use these informations in choosing the suitable cell for handover decision. The candidate on the frequency providing the required eMBMS services will be in first priority and when the UE switches to that frequency, it can continue to receive its interested service. The eMBMS mobility support procedures for RRC-Connected UE in 3GPP standard release 11 is depicted in Fig. 3.5.

With the enhancement in Rel-11, LTE standard is now supporting the service continuity for eMBMS. However, the mobility support is still restricted in changing among frequencies within one MBSFN area. There is no information provided to help the UE in case of switching from one MBSFN Area to another. Therefore, if none of neighbor frequencies

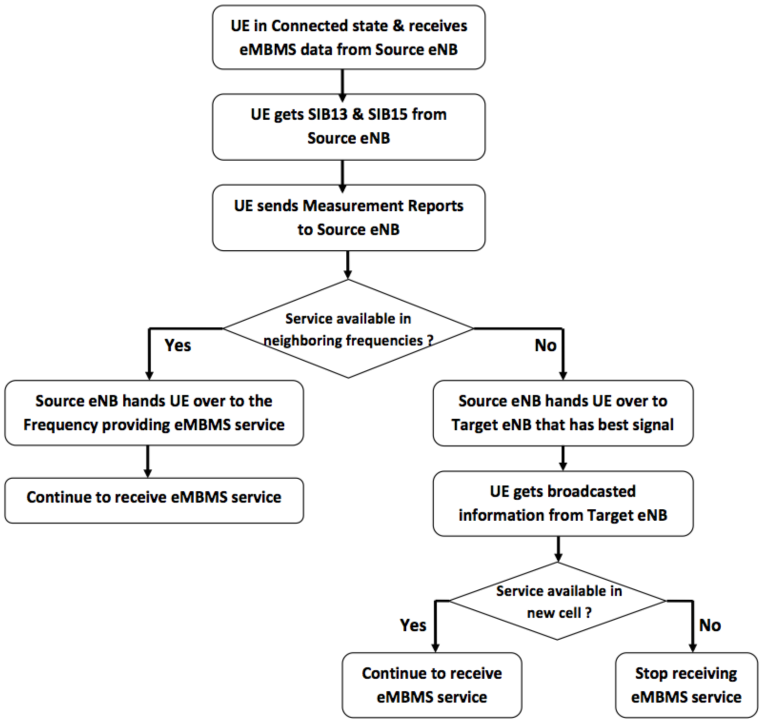


FIGURE 3.5 – eMBMS Mobility Support for Connected Users in LTE standard.

provides the desired broadcast service or there is no CA deployment in the network, the eMBMS users may not get the interested services in target cell (even though it is available in another MBSFN area and the UE should have connected to the neighboring cell belongs to that MBSFN area).

3.4 Related Works

Being introduced in UMTS network since 2004, eMBMS has just got popular and become a prospective broadcast technology for LTE network in the recent years. For the best of our knowledge, although many aspects in eMBMS standard are considered, there is no academic publication concerning the mobility support for eMBMS service. Some papers that mention about the MBMS handover can be found in [42–46], however, this term is referred to the change between p-t-p and p-t-m transmission of the MBMS service in 3G networks. The main objective of these researches is to identify the right moment/distance to trigger the switching from one transmission mode to the other, which is not related to the eMBMS handover we are studying. Opposite to the shortage in academic world, this topic attracts a lot of attention from the telecoms industry and some studies have been published in the form of commercial patents. This section will introduce some of the solutions from the industrial patents.

3.4.1 Patent from Electronics and Telecommunication Research Institute (ETRI)

Jee Hyeon et al. has presented in [47] a method to support the continuity of service among MBMS areas. In this patent, the mobility of users using MBMS service is classified into 3 different cases : when a UE moves from an MBSFN area to a non MBSFN area, from non MBSFN area to an MBSFN area and when it moves between two MBSFN areas. It is worth noting that in non MBSFN area, the cell can still provide MBMS service in single cell transmission mode.

The serving cell helps the UEs to continue receiving the MBMS service by providing the *broadcast area information* of the neighboring cells through a system information block (SIB). This information should be attached in the *neighboring cell information* field as shown in Fig. 3.6. According to [47], the following information may be included in *broad-*

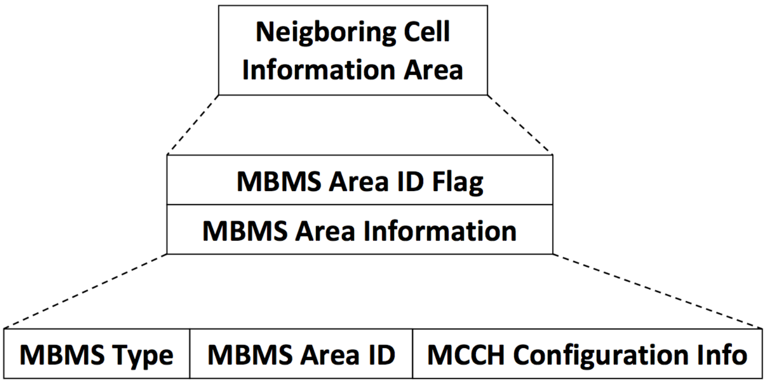


FIGURE 3.6 – MBMS Area Information structure.

cast area information : *i)* Service transmission scheme supported in a broadcasting area of neighboring cell (multi-cell or single cell transmission) ; *ii)* Identification of the broadcasting area of the neighboring cell ; and *iii)* Configuration information of a logical channel transmitting contents which could be the shape information about MCCH and lower protocol settings (PDCP, RLC, MAC and PHY layer setting). A flag indicating whether broadcasting areas in the serving cell and the neighboring cell have the same type, is also added to the *neighboring cell information area.*

Using the information in the SIB received from the serving cell together with the ID of neighboring cell, the UE may verify whether the serving and neighboring cell have the same broadcasting area or not. If the answer is yes, UE can access the MBMS data using the same configuration as in the serving cell. Otherwise, if UE finds out that it is moving to a new cell with different broadcasting area (either another MBSFN area or MBMS single cell transmission area), it may obtain the MCCH message of new MBSFN area using the logical channel configuration info attached in the SIB. Based on the information included in MCCH message, UE will then figure out if its interest service is provided in the new cell and may continue to receive or terminate the MBMS service.

This method allows the UE to continue receiving MBMS service while moving to another MBSFN area or to different MBMS transmission scheme (multi-cell to single cell or vice versa). Thanks to the *broadcasting area information* of the neighboring cell received at the time of handover, the UE can access to the MCCH message without acquiring the SIB from the new cell and thus, the disruption time may be reduced. However, the continuity of service is not guaranteed in this method because UE does not know about the MBMS service supported in new cell prior to Handover decision, the information of MBMS service can be obtained only after the UE connects to new a base station. Moreover, from 3GPP standard release 10, the single cell transmission mode was no longer supported, i.e. non-MBSFN area is now referred to cell that does not participate to transmit MBMS service or the MBSFN Area reserved cell. Thereby, if UE moves to a non-MBSFN area, the MBMS service will be terminated. Changing to unicast with the same content from service provider is the only way to continue getting the desired service but it requires complicated procedures with a considerable disruption.

3.4.2 Patent from MediaTek Inc.

One good research in the continuity for MBMS service was published early 2013 by Chia-Chun Hsu. In [48], the author provides a network-assisted solution to maintain ongoing service for mobile user using : *i)* the *MBMS service continuity (SC) indication* which is broadcasted by the serving cell ; and *ii)* the *MBMS reception status* sent by the RRC-Connected UE to the serving eNB. The *MBMS SC indication* as introduced in the patent contains lists of MBMS Service Area IDentities (SAIs) supported by current cell and neighboring frequencies. Similarly, the *MBMS reception status* comprises carriers that support specific MBMS service the UE is interested in and UE's preference of MBMS over unicast transmission.

In Idle state, UE receives MBMS data, system information, detect incoming call and measures the signal from neighboring cells. The mobility is controlled by UE in this state, i.e. it will perform cell re-selection procedure when getting out of one cell's coverage. With the *MBMS SC indication* collected from the serving cell through a SIB, the UE gets to know about the MBMS service supported in other frequencies and decides to change to an appropriate cell (assuming that UE has a mapping between SAIs and Service IDs in order to know which frequency provide its required service). Another proposal of the author is replacing SAIs by MBSFN Area IDs or Service IDs to save UE's power on monitoring/acquiring MCCH message. The Fig. 3.7 illustrates the content of *MBMS SC indication* provided by the serving eNB.

Frequency	MBMS Service Area ID (SAI) {Grouped by MBSFN Area}
Current Frequency	MBSFN Area 1 {SAI #1…}, MBSFN Area 2 {SAI #2…} …
Neighboring Frequency #1	MBSFN Area 3 {SAI #3…}, MBSFN Area 4 {SAI #4…} …
Neighboring Frequency #2	MBSFN Area 5 {SAI # 5…}, MBSFN Area 6 {SAI #6…} …
⋮	⋮
Neighboring Frequency #8	MBSFN Area 7 {SAI # 7…}, MBSFN Area 8 {SAI #8…} …

FIGURE 3.7 – MBMS Service Continuity Indication.

To avoid the service discontinuity for moving terminal in RRC-Connected mode, the serving eNB guides it to connect to the frequency that provides its ongoing service by combining the information about MBMS service provided in neighboring frequencies and the interest of UE. The author suggests the serving cell to acquire the MBMS information of neighboring carriers via direct communication with its neighbors or via a network entity (e.g. the Operation, Administration and Maintenance server). In the user's site, its preference of MBMS data over normal unicast data as well as the interested service will be sent to the serving cell by means of a dedicated RRC message. With these informations, the serving base station can choose the right carrier or neighboring cell to hand the UE over.

The advantage of this method in comparison with the previous one is that it considers the MBMS service supportability of the neighboring cells/frequencies before giving the handover/cell re-selection decision. In such way, the continuity of MBMS service is surely guaranteed if at least one of neighboring frequencies provides the desired service. In addition, the necessary MBMS-related information to support the service continuity for both network (eNB) and user side (UE) are clearly defined. And in fact, these informations are corresponding to the System Information Block Type 15 and the *MBMS Interest Indicator* message, respectively, as appeared in 3GPP standard release 11. However, Chia-Chun Hsu's solution still has a better point than the standard when proposing to use the MBSFN area ID or Serice ID instead of the SAI. It could prevent UE from monitoring/decoding MCCH message in new cell/frequency and hence, reducing device's energy consuming as well as eliminating the need to store a mapping between SAI and service ID. The drawback of this work is that like in 3GPP standard, it focuses only on frequency, not on base station, so it may be not aware of cells that belong to other MBSFN areas that could provide the required service.

3.4.3 Patent from Research In Motion (RIM)

R.W Purnadi and his colleagues have introduced an efficient technique to support the service continuity for MBMS users in RRC-Connected state without broadcasting of MBMS-related information from serving cell to the users.

Lacking the knowledge of the MBMS services being received by the user, the serving eNB could hand UE over unappropriated target eNB and the service might be dropped. Understanding this point, in [49] the authors have suggested the UE to report the identification of its ongoing MBMS services to the serving eNB when leaving its coverage. The MBMS users can include in measurement reports the Temporary Multicast Group Identity (TMGI), which uniquely identifies an MBMS service, to inform the current cell about its MBMS interest. The UE may also send a new MBMS priority information element (IE) in the measurement report to indicate the priority of MBMS services it is using. If this IE does not show the MBMS priority, source eNB would choose candidate has strongest signal as the target cell. Otherwise, the handover decision made by source eNB would not be based only on the signal strength of neighbor cells but also on the MBMS interest of users.

In case the mobile user interests in MBMS service, the serving eNB needs to know about services supported by its neighbors before giving the handover decision. This task may be achieved by sending a query with the requiring TMGI value to neighbor cells or to a network component such as MCE or MME. The source eNB can send an M2 interface Application Protocol (M2AP) message or an M2AP/M3AP message to MCE or MME, respectively, to consult about their supported MBMS services. The X2 interface message is used when the current base station want to take this information from its neighbors. Upon receiving the query, the MCE or MME will response to the corresponding base station with a message containing the identification of cells that support the service required by the users. Similarly, neighboring cells reply the query by an X2 message indicating whether they support the service associated with the received TMGI. The query result can be stored locally in source eNB for later use or for exchanging with other neighbors. More detail on how the MCE or MME knows which eNB support which MBMS service can be found in [49].

Depending on the query response, two different scenarios may happen. When at least one neighboring cell supports the service requested by the UE, the serving cell will hand UE over that cell. If there are two or more qualified cells, the one with highest signal strength from measurement report will be chosen as target cell for handover procedure. Because there is no information about the service supported by the neighboring cell is broadcasted, the serving cell will inform the UE about TMGI value of MBMS service supported by the target cell in the Handover Command (RRC Connection Reconfiguration message) so that UE can continue to receive or initiate the MBMS service when needed.

In the other scenario, none of neighboring cell provides the service demanded by UE, the authors proposed several ways to help users continue receiving ongoing MBMS service in this situation. The first solution is changing the current point-to-multipoint transmission into unicast transmission. It means instead of making the handover decision, the serving cell will send a message asking the mobile to create a new dedicate bearer for transmitting MBMS data. After the unicast connection is successfully established, the UE gets the MBMS content via a regular unicast bearer and it can stop the MBMS transmission. The normal handover procedure can now be applied.

The second way is doing the handover from the source cell with MBSFN transmission to the target cell but with unicast transmission, i.e. the target eNB is demanded to obtain the MBMS content from MBMS gateway and transfer to UE through an unicast bearer. To do so, the serving cell should include the IP multicast address of the MBMS gateway and information of the specific MBMS service in the *Handover Request* message (in X2-based handover) or *Handover Required* message (in S1-based handover) and send to the target cell or MME, respectively. In such way, the target eNB can join the MBMS multicast to get data and be able to transfer the MBMS service via unicast transmission when the UE connects to it.

Based on two above solutions, a variant/combining one is also proposed, that is the source eNB adds unicast bearer to transfer the MBMS data to the UEs and in parallel, demands the target eNB to connect and get the media content from the MBMS gateway. With the simultaneous reception of multicast and unicast transmission, the UE combines the received data at layer two so that the performance of MBMS service can be improved. It also allows the target eNB get more time to finish the connecting procedure with MBMS gateway before the handover starts.

Different from two previous methods, in this patent, no information about the eMBMS services supported in neighboring cells is provided, thereby the UE could not choose the right candidate for cell re-selection procedure. As a result, this patent is designed only for users in RRC connected mode and can not be applied for idle mobile users. Besides this drawback, the work of the authors has given some value points including : to take use of the Handover Request or Handover Required message to transfer the MBMS-related info and to suggest & describe in detail the technique to change from multicast/broadcast to unicast for maintaining the eMBMS service continuity.

3.5 Proposed Solution for eMBMS Service Continuity

From the analysis of the LTE standard and the existing solutions, we present in this section a solution to guarantee the service continuity for the eMBMS users in LTE network. The main idea of our method is taking into account the information of the services broadcasted by neighboring cells when choosing candidates for handover or cell re-selection procedure. Knowing where the desired services are available will help the serving eNB to choose the right target eNB to hand the UE over or help the UE to camp to a suitable cell. Although the idea is in general similar to the one mentioned in 3GPP specifications, our method does have the difference : we focus on the neighboring cells and the eMBMS services they support instead of the services transmitted on other frequencies. Our proposed solution will lead the UE to the neighboring cells that have its interested services in the same frequency with the current cell before searching on the other frequencies.

Cell ID	Frequency (Carrier Component)	MBSFN Area ID	Service ID
Current Cell	Frequency #1	MBSFN Area #1	Service #1 (TMGI #1)
			Service #2 (TMGI #2)
	Frequency #2	MBSFN Area #2	Service #3 (TMGI #3)
			Service #4 (TMGI #4)
Neighbor Cell #1	Frequency #1	MBSFN Area #2	Service #3 (TMGI #3)
			Service #4 (TMGI #4)
Neighbor Cell #2	Frequency #2	MBSFN Area #3	Service #5 (TMGI #5)
Neighbor Cell #3	Frequency #1	MBSFN Area #1	Service #1 (TMGI #1)
			Service #2 (TMGI #2)
	Frequency #2	MBSFN Area #4	Service #6 (TMGI #6)

FIGURE 3.8 – eMBMS Mobility Support Information.

The SIB13 contains the information about MBSFN Areas (ID, location of the MCCH message) however, all details of the eMBMS services supported in each MBSFN Area are given in MCCH message which is only obtained when the UE connects to the cell. Although from the information in SIB15, a mobile terminal can determine on which frequency its required services are available, the lack of knowledge about the services supported by the neighbors on the same frequency and in other MBSFN Areas with serving cell might cause the discontinuity. It shows that the information in SIB13 and SIB15 is not enough to retain the eMBMS connection. Therefore, we propose that a base station will broadcast the identity of all MBSFN areas and eMBMS services (ServiceID or TMGI) it supports as well as those supported by its neighbors. This information is named as the *eMBMS Mobility Support Information* and it contains the mapping between neighboring cell ID, frequency, MBSFN area ID and MBMS Service ID or TMGI as depicted in Fig. 3.8. The current cell may collect this information either from a network entity or from its neighbors and then attach it to either SIB13 or SIB15 before broadcasting to the users.

If we choose to broadcast the eMBMS Mobility Support Information in the SIB13, a part related to neighboring cells will be added to the traditional SIB13. This part, as seen in Fig. 3.9, contains a list of the neighboring cells which operate on the same frequency with the serving cell and the all identification (TMGI value) of eMBMS service they support.

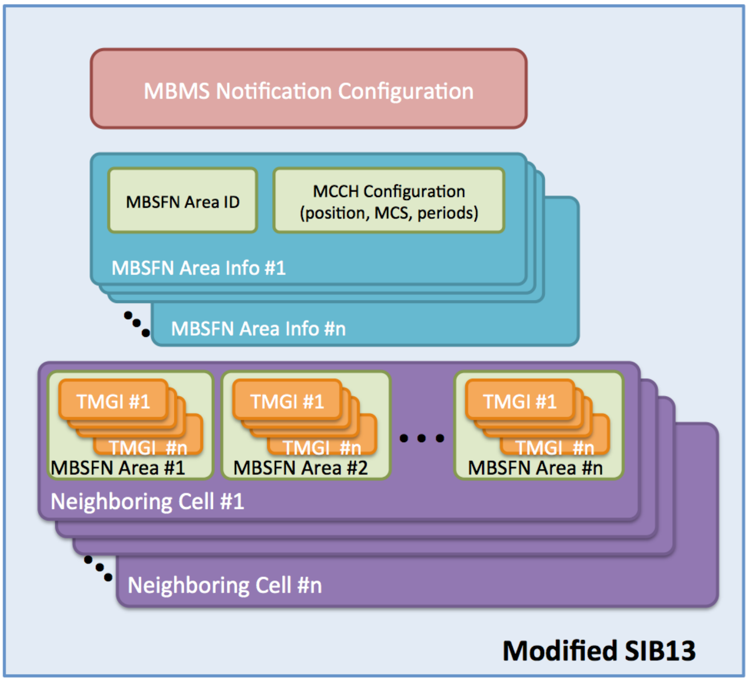


FIGURE 3.9 – SIB13 Modification for Service Continuity Support.

Receiving the modified SIB13, an Idle UE will compare the Service ID provided by the neighboring cells and the one of its interested service. If one or more neighboring cells support the service, the terminal then chooses the one with highest signal strength to camp to and continues getting eMBMS data. In case none of Service ID listed in SIB13 matches with the one of the user's service, the SIB15 will be used to identify the neighboring frequency that offers the required eMBMS service.

In alternative, the eMBMS Mobility Support Information can be embedded in the SIB15. In this case we suggest the modification in SIB15 so that it is now containing : *i)* The neighboring frequencies (on which the serving cell is operating) and their supported eMBMS service identifications (or the SAI as in the standard SIB15) ; and *ii)* The neighboring cells together with the MBSFN Area IDs and Service IDs of eMBMS services. Similarly to the first option, the LTE terminals which are interested in eMBMS service can extract information in SIB15 and look for the neighboring cell that are in the same frequency with the current cell. The neighbors working on different frequencies come after in the MBMS priority order.

For the mobility in connected mode, a network-controlled handover procedure is applied, i.e. the serving eNB will decide when and where to hand the mobile terminal over. If the serving cell wants to ensure the eMBMS continuity for a moving user, it has to pick the target cell that providing the eMBMS services being received by that user. In order to choose the right candidate in the handover decision, the current cell needs to know two

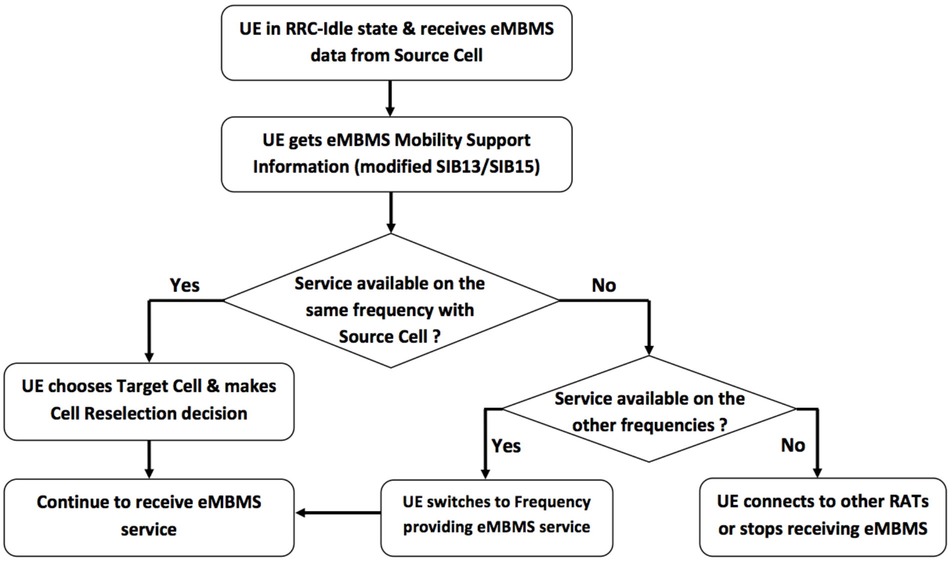


FIGURE 3.10 – eMBMS Mobility Procedure for RRC-Idle Users.

things :

1. The services supported by neighboring cells (*eMBMS Mobility Support Information*).
2. The eMBMS services UE is receiving or interested in receiving (referred as *eMBMS Service Interest*)

The serving cell already has the first element after acquiring from its neighbors through X2 interface or from another network entity as we proposed earlier. The latter one is still missing (the *MBMS Interest Indication* in the standard [41] only gives the list of frequencies not services) ; therefore the UE should provide it to the serving cell, may be in a RRC message like the MBMS Interest Indication. This *eMBMS Service Interest* simply conveys an identification list of the services that UE is receiving or interested in receiving and the corresponding MBSFN areas. It could be sent to the serving eNB together with the measurement reports when a trigger event occurs or when the UE changes its interest.

Using the *eMBMS Mobility Support Information*, the *eMBMS Service Interest* and the measurement reports from UE, the source eNB can choose the cell supporting the required services for the users. One point to notice in our method, the candidate working on the same frequency with the current cell has higher priority than those on different frequency. In the case that the target eNB is in a different MBSFN Area with the source, to avoid the need to read the MCCH message in the new eNB, the MCCH message can be sent from the target eNB to the UE via the serving eNB. This can be archived during the Handover procedure and will be explained in detail in Chapter 4.

Fig. 3.11 and 3.12 illustrate how our method works in a complex scenario in which the eMBMS is broadcasted over a heterogeneous network.

— A mobile user is moving in a network and receiving an eMBMS service. At step 1, it moves to another eNB in the same MBSFN Area 1, therefore, no special procedure needs to be done in this step.

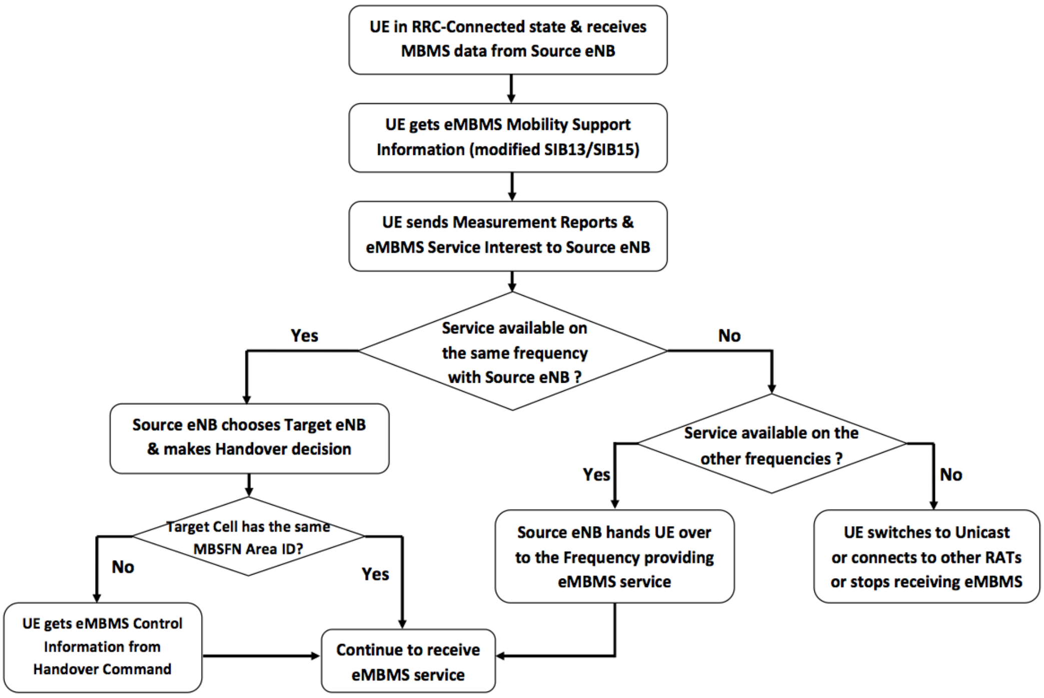


FIGURE 3.11 – eMBMS Mobility Procedure for RRC-Connected User.

— At step 2, the UE moves to another eNB, from the eMBMS mobility support information and eMBMS service interest, the serving eNB knows that its neighbor belongs to another MBMS Area but still provides the same eMBMS service, therefore, it makes the decision to hand UE over the target eNB belonging to MBSFN Area 2.
— The user keeps moving within the MBSFN Area 2 and receives its service at step 3.
— The UE once again gets out the coverage of the current cell in step 4, however, the serving eNB realizes that the neighbor in the same frequency belongs to MBSFN Area 3 and it does not support the service that UE is receiving. As the result, it has to look for the other neighbors on different frequency. Fortunately, one neighboring cell operating in the frequency 2 provides the required service, and thus, the serving cell make the decision in step 5 to switch the UE to frequency 2 to continue receiving the eMBMS service.
— In step 6, the UE continues its movement but this time, none of the neighboring cells broadcasts the its ongoing service and it is about to get in the remote area without the cellular signal. In this case, the best thing that the current cell can do is signaling the UE about the service supported in other broadcast technologies. And depending on its capacity, the UE could switch to other RAT for the broadcast service or stop receiving it.

To summarize, the solution we presented ensures the continuous service for eMBMS users through different cells, in different MBSFN Areas and on different frequencies. Moreover, our method also brings up the ability for eMBMS users to connect to other Radio

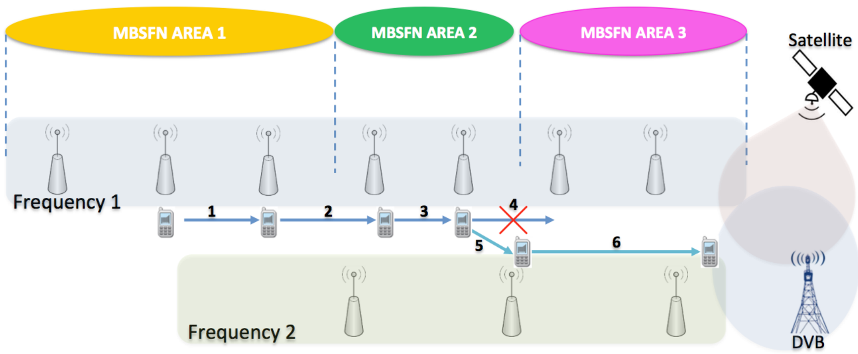


FIGURE 3.12 – Illustration for a Complex Scenario.

Access Technologies (RATs) such as DVB or satellite so that the users still can get the MBMS service even outside the coverage of the cellular network. Imagining a situation where an eMBMS service is broadcasted over the LTE network, satellite and DVB-NGH system at the same time, the mobile device also has the capability to receive media content from all of above technologies. In case this device is receiving the video data and moving to a remote area where there is no cellular signal available, it is going to lose the connection and the service will be stopped. Fortunately, the satellite signals have very good outdoor coverage and if the user somehow gets to know that the same service is also broadcasted through satellite, it can switch to the satellite transmission to continue watching its interested service. The issue here is how the users know which technology is capable to provide its required service ? With our method, the network can give this information to mobile devices when transmitting the eMBMS Mobility Support Information with a small adjustment : other broadcast technologies will be represented by a pre-defined "cell ID" value so that they are considered as "special" neighboring cells.

The most difficult part of this idea is the communication between two broadcast systems which is beyond the scope of this thesis and could be a direction for future work. Actually some researches on this subject have been done to handle the connection among technologies in a common/hybrid system. The authors in [50] have introduced an architecture to manage the handover between LTE/3G network and satellite system ; the Common Broadcast System proposed in [51] offers to eMBMS the capability of enlarging the coverage thank to satellite system and the convergence of eMBMS and DVB-NGH is also addressed [52] with the aim to understand clearer the ability in cooperating of two technologies. All of these studies have proved that the extension of eMBMS to other broadcast systems in a high mobility, heterogeneous environment, or in other words, the mobility support for eMBMS service, is a very potential research topic in the future.

3.6 Conclusion

In this chapter, we have analyzed the mobility issue for eMBMS users and the mobility support defined in 3GPP specifications. Apart from the standard, several solutions for service continuity in the related works are also presented. Based on these studies, we have proposed a novel method to assure the continuity of eMBMS service in the mobility context.

In order to realize our solution, these following modifications have been made in the LTE standard :

1. An extra information called *eMBMS Mobility Support Information* is defined and should be added to the system information block and broadcasted by the serving cell. We suggest to modify the SIB13 or SIB15 to convey this extra info.
2. A new message namely *eMBMS Service Interest* is transferred from the UE to the serving eNB to inform users' interest. It can be a stand-alone RRC message or be added to the MBMS Interest Indication.

With these supplements, before the handover decision is made, all neighboring cells belong to different MBSFN Areas and frequencies will be checked to find the candidates providing the users' interested services. In case the user gets in the non-MBMS area or reserved cell, the continuity can be only maintained by changing to an unicast transmission or to other broadcast technologies. In other words, our solution covers all the possible types of eMBMS handover and guarantees the service continuity for mobile users. A brief comparison between our proposed method and the existing solution including the LTE standard is given in Table 3.1.

Table 3.1 – eMBMS mobility support in different methods.

Mobility Support	**3GPP standard**	**Our Method**	**ETRI**	**MediaTek**	**RIM**
Intra-MBSFN Area	Yes	Yes	Yes	Yes	Yes
Inter-MBSFN Area	No	Yes	Yes	No	Yes
Inter-Frequency	Yes	Yes	No	Yes	No
Inter-Technology	No	Yes	No	No	No

As we can see in this table, our method assures the service continuity in all cases, but it only means that the service will not be dropped in the new cell. How about the continuity of the media stream ? How long after connecting to the new cell the UE can receive the eMBMS data ? We can have the answers for these questions in the next chapter.

Chapter 4

Media Stream Continuity

4.1 Introduction

The mobility support solution introduced in the previous chapter has helped the eMBMS-capable mobile devices to continue receiving their interested services while moving. As the continuity is guaranteed, another important aspect should be considered, that is the quality of service during the transition period. A common metric used to evaluate the performance of multimedia services during the transition is the interruption time. In unicast transmission, during the handover procedure, the serving eNB can forward the data to new target eNB so that the user can continue receiving the data right after connecting to the target eNB. However, there is no such mechanism in eMBMS transmission and the users have to listen to the control information after connecting to a new cell. The media stream is thus can be interrupted for a while when the UE changes to a new cell. The purpose of this chapter is to deal with the stream disruption issue during the handover through following steps :

— To identify the factors that affect the eMBMS stream interruption time during the handover. These factors here are the signaling messages a user needs to receive in order to access the real multimedia data.
— To analyze the time for retrieving all control information to get a specific eMBMS service. In this step, we firstly see how the eMBMS resources are allocated for a particular service/session and then the time to collect each signaling message is pointed out. Finally, the total time to acquire all the eMBMS signaling information is calculated with different parameter sets.
— To propose a method to reduce the time receiving eMBMS control information at the new cell. A mobile terminal needs less time to get control information also means that the stream disruption time is shorter and the quality of service is improved.

4.2 Service Interruption Time in eMBMS

The service interruption time is the interval between the moment the UE loses the connection (no signal or the received signal is below a pre-defined threshold) with the current cell/frequency and the point it starts receiving data in the target cell/frequency. Although the time for retrieving eMBMS control messages has a strong impact on the interruption time, it is not the only factor. Different mobility scenarios will be analyzed below to understand more about the interruption time of eMBMS service in mobility context.

If the source eNB and the target eNB are in the same MBSFN area and same frequency, because both eNBs are synchronized tightly in time and transmit exactly the same waveform, the UE will consider it is moving within one "large cell" in term of eMBMS. As a consequence, there is no disruption in eMBMS service even though the mobile terminal has to perform necessary procedure to continue the unicast transmission.

When the UE moves to a new base station which operates on the same frequency with the current one but belongs to a different MBSFN area, it needs to perform the cell re-selection (in the idle state) or handover procedure (in the RRC connected state). After that the control information for eMBMS service should be collected before the user can continue the service reception. Therefore, the interruption time is roughly equal to the cell re-selection/handover duration plus the time for retrieving eMBMS-related info. We say roughly because the cell re-selection or handover procedure may start before the eMBMS connection is completely lost.

In case the frequency of the target eNB is different from that of the source eNB or the UE changes to another component carrier, the synchronization must be done before any further acquisition. This scenario has two possibilities, either the new frequency/carrier provides a different MBSFN area from the one in the current frequency (but still has the eMBMS service required by UE) or supports the same MBSFN area. In the first case, it is clearly observed that the service interruption time is composed of the duration of synchronization process and the time for collecting eMBMS-related information. The latter one (which is supported by the LTE standard) is simple, a user can acquire the eMBMS service by using the same configuration as in previous frequency after finishing the synchronization procedure.

From the analysis, we can see that the eMBMS-related information acquisition time impacts the service interruption time in most of the mobility scenarios. In addition, to improve the performance of unicast procedures such as the Handover or Synchronization is not an easy task and it is not our priority because we are focusing on the eMBMS service. For these reasons, the only feasible way to have a shorter eMBMS service interruption in a new base station is to reduce the time to retrieve the eMBMS control information. Next section will give a quantity analysis on the time a user needs to obtain all the control information concerned with the eMBMS reception.

4.3 Quantitative Analysis on Acquisition Time for eMBMS Control Information

As the prerequisite to have a correct analysis on time for retrieving the eMBMS service, we should know exactly what piece of information a UE has to collect before it can actually receive the user data. More than that, where and when the user can get this information are also needed for the analysis. As the result, we divided this section into two parts : the first part will explain the way eMBMS system organizes the resources for a particular service (this answers the questions What and Where) ; and in the second part, the time to collect each piece of control information will be analyzed (which gives the answer for the question When)

4.3.1 eMBMS Resource Allocation

From the basic background, the MBSFN Area is the fundamental concept in eMBMS. It consists of several eNBs and provides (typically) many services. In the MBSFN operation, each eNB can belong to multiple MBSFN Areas (up to 8 areas), meaning that it will transfer the traffic for all services supported in these MBSFN Areas. The information about the services in each MBSFN Area is put in the MCCH message and transferred on MCCH channel. The network stores the information about the MCCH channel in the SIB13. Thus, if an eNB belongs to 5 MBSFN Areas, in the SIB13 it broadcasts over the air, there will be information of 5 MCCH messages. The content of SIB13 includes :

- Subframe allocated for the MCCH change notification (on Physical Downlink Control Channel - PDCCH).
- List of MBSFN Area(s) information
  - MBSFN Area Identification.
  - Subframe contains the MCCH and MCCH repetition period.
  - MCCH modification period.
  - Notification indicator.
  - Modulation and Coding Scheme (MCS value).

In the SIB13, there are two MCCH-related parameters which may make the misunderstanding : the repetition period and modification period. To be clear, the MCCH message is transmitted every repetition period. The content of MCCH message can be modified from time to time however, a modification period is defined for the change of this message. It means, the MCCH message stays the same during the modification period. Even the content is changed in middle of period boundary, the updated MCCH message could only be transferred at the beginning of the modification period. The relationship between these two parameters is described in Fig. 4.1 and it is not hard to realize that the modification period should be a multiple of the repetition period.

The MCCH change notification parameter is used to notify the terminals about the content change of the MCCH message. It is transferred on the PDCCH in form of a 8-bit bitmap. The number 8 here corresponds to 8 MCCH messages (of 8 MBSFN Areas) that one eNB can convey. The parameter Notification Indicator in MBSFN Area Information will help the UE know the position associated with that MBSFN area in the bitmap. When one bit in the bitmap is set to 1, the corresponding MCCH message will be updated in next modification period. In brief, SIB13 is the first piece of information a user needs to

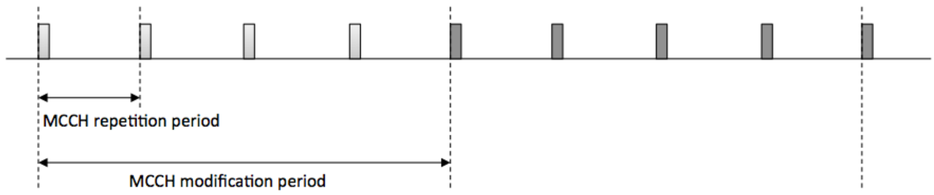


FIGURE 4.1 – MCCH Repetition Period and Modification Period.

acquire.

The content of SIB13 leads the UE to the position of MCCH message. So what is inside this message ? According to 3GPP document [41], the MCCH message contains either MBSFN Area Configuration message or MBMS Counting Request message. Because the counting feature is optional and only applied for RRC-Connected users and plus the configuration of MBSFN Area is much more important, the MBSFN Area Configuration message is usually considered as the MCCH message. In this manuscript, these two terms are interchangeable. The detail of MCCH message is given below :

- Common Subframe Allocation configuration
  - Pattern type.
  - Repetition Period.
- Common Subframe Allocation period.
- List of Physical Multicast Channel (PMCH) configuration
  - Modulation and Coding Scheme (MCS).
  - Multicast Channel Scheduling Period (MSP).
  - Last Subframe for this PMCH.
  - List of MBMS session information
    - Service ID (TMGI).
    - Logical Channel ID (LCID).
    - Session ID.

One MBSFN Area may support many eMBMS services and 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 by a specific transport channel for eMBMS so-called Multicast CHannel (MCH) using one Modulation and Coding Scheme (MCS) which is the parameter listed in the MCCH message. This design leads to the subsequence that one MBSFN area provides MBMS services in many MCHs and they can be multiplexed in time domain according to the 3GPP specifications. That is the reason why there is a list of PMCH configuration in MCCH message and each MCH has its own MCS (because the MCH is mapped on one and only one PMCH, two terms can also be used interchangeable and usually appears in 3GPP document as (P)MCH).

The parameter Common Subframe Allocation (CSA) pattern indicates the subframes that are reserved for this MBSFN Area (also called MBMS or MBSFN subframe) and the word Common here means that all the MCHs in this MBSFN Area use this pattern. The standard allows this pattern to occupy one radio frame or four radio frames. The one-frame pattern is represented by a 6-bit string corresponds to maximum 6 subframes eligible for eMBMS as we mention in Chapter 2. If a bit is set to 1, the corresponding subframe will be allocated for eMBMS transmission. With the same manner, a 24-bit string is applied for the four-frame pattern. This CSA pattern will repeat every Repetition Period.

The CSA period parameter indicates the period (in radio frame unit) in which the resources are shared by all MCHs. Subframes reserved for each MCH are allocated in the order that these MCHs are listed in MCCH message and the amount of resource is determined by the Last Subframe parameter. Looking inside the configuration of each (P)MCH, we will see the information of the eMBMS sessions which are basically eMBMS services and corresponding to the MTCHs. This information gives us the identification of each service/session and the logical channel identity associated with that service/session at MAC layer.

So far, with the MCCH message, the users are aware of the number of services groups (MCH) in that MBSFN Area (up to 15 per area) and the number of services/sessions in each group as well as the identities of these services. At this point, although knowing that its desired service is provided in this MBSFN Area, a terminal still cannot get the data due to the fact that it only knows the resource allocated for the whole service groups, not for the its specific service. Pointing out the scheduling information for a particular service is the job of the MCH Scheduling Information (MSI). That is the last piece of information a user device ought to require before it can actually access to the media content.

The MSI is a control element created at MAC layer where multiple MTCHs and maybe the MCCH are multiplexed into an MCH channel. The MAC layer provides MSI repeatedly and transmits it at the beginning of an MCH scheduling period (MSP-the parameter given in the MCCH message). The MSP is quite small in comparison with the period of MCCH message making the scheduling of MTCHs (i.e. eMBMS services) over a particular MCH more dynamic and then the smooth switch between services can be archived. This mechanism also allows the flexibility in scheduling eMBMS services, for example, the data of two services can be alternatively scheduled in one MSP.

As the review for this section, Fig. 4.2 shows an example configuration in resource allocation for eMBMS. In this figure, the horizontal axis represents ten subframes in 1 radio frame (RF) and the vertical axis represents radio frames. This example illustrates the MBSFN resource allocation in LTE system with FDD configuration mode (subframe 1,2,3,6,7 and 8 can be assigned). 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 in this example and they are time multiplexed in a period of 16 RFs (i.e. the CSA period is 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-Alloc-end* in the figure), it means the MCH 1 will take from subframes index 0 to 8 and subframes index 9 to 14 are reserved for MCH 2 (note 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). Continue with this example, the scheduling for each of three MCHs is depicted in Fig. 4.3

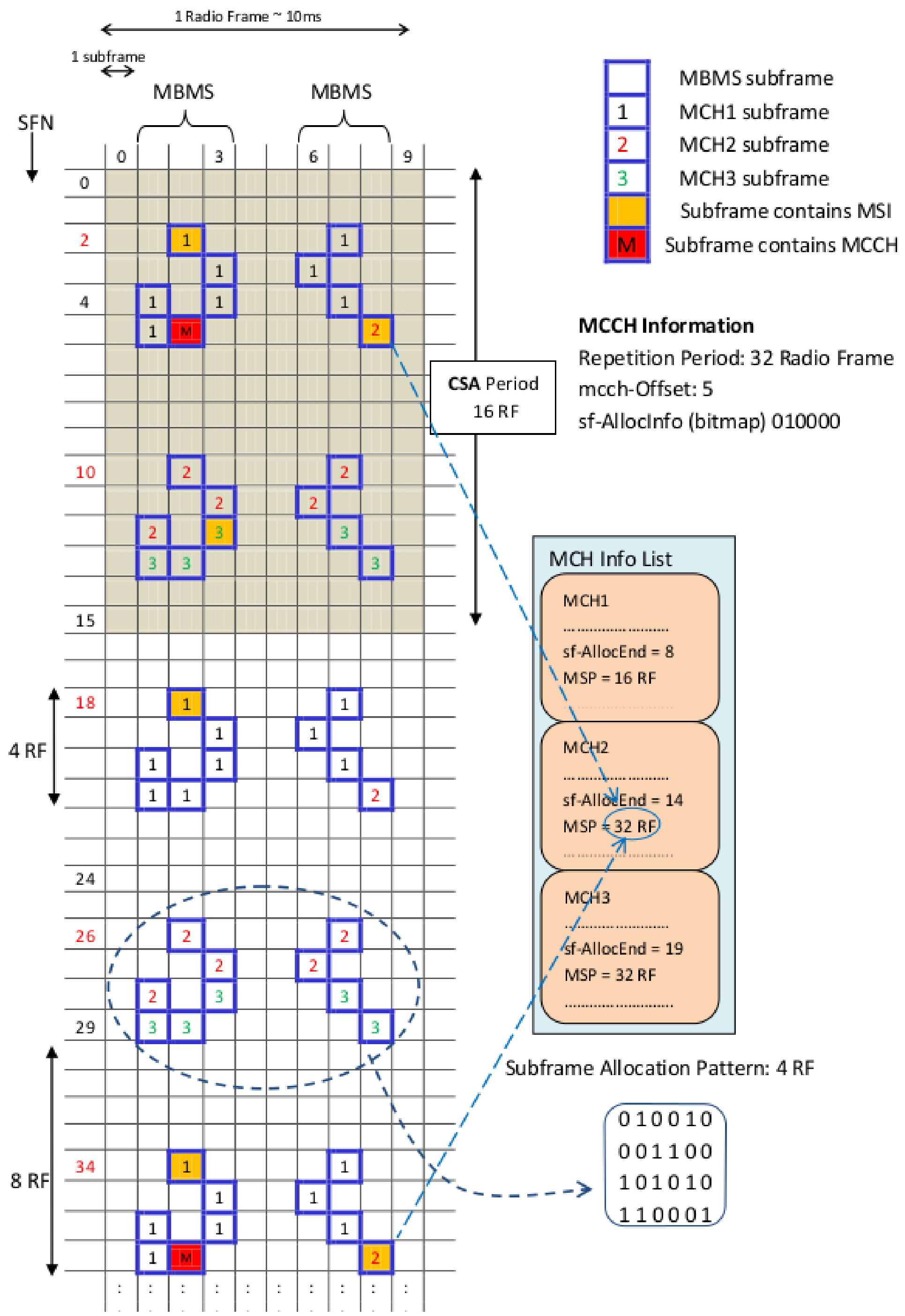


FIGURE 4.2 – eMBMS Resource Allocation Example.

In the above figure, we only illustrate the MBSFN subframes and all eMBMS resources in one CSA period are put in one row. As we can see, nine subframes allocated for MCH 1 are delivered for three MTCHs (corresponds to three different eMBMS services/sessions) and the MCCH. The resource reserved for each MTCH is limited by the last subframe of

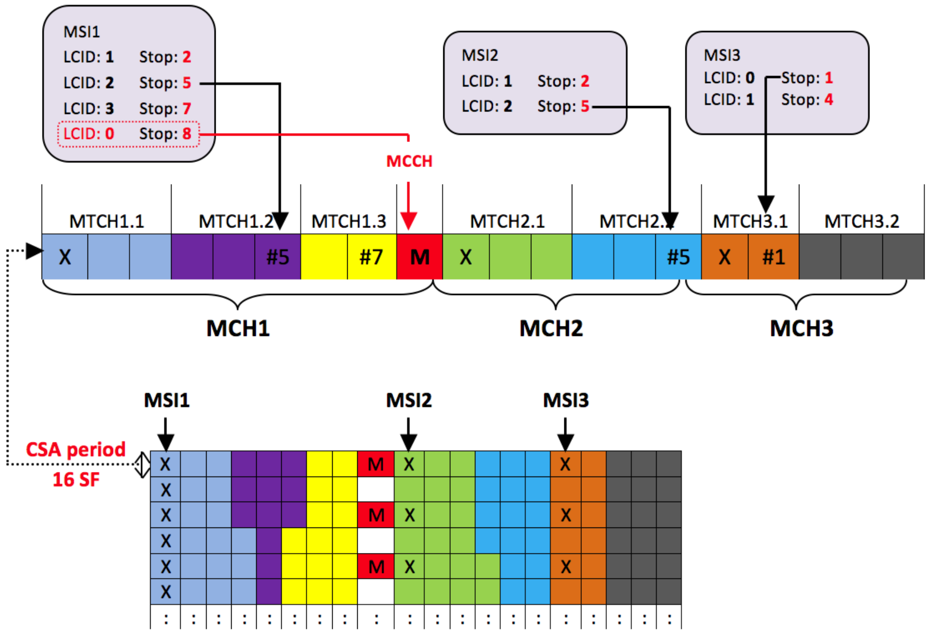


FIGURE 4.3 – MTCH Scheduling Example.

that MTCH which is given in the MSI control element. The MCH 2 and MCH 3 occupy six and five subframes, respectively, and both have two MTCHs. At the beginning of each MSP, the corresponding MSI is transmitted which is the position marked by an "X" in the figure. The scheduling for MTCHs inside an MCH could be changed after every MSP, for instance, in the MCH 2, after two MSPs, the MTCH 1 needs more resources and takes one subframe from the MTCH 2. Noting that, the scheduling for MTCHs can change every MSP while for MCHs, it only could be updated every MCCH Modification Period.

4.3.2 eMBMS Control Information Acquisition Time

From the previous section, we have learned that a user that is interested in eMBMS service has to obtain three types of information before it can access the real eMBMS user data. The service reception process in step by step is illustrated in Fig. 4.4. In this section, the amount of time for a terminal going through these steps are analyzed carefully.

4.3.2.1 System Information Block 13 Acquisition

In LTE networks, the system informations are divided into the Master Information Block (MIB) and a number of System Information Blocks (SIBs). MIB message contains most essential information of the network (downlink bandwidth, system frame number,etc.) and is transmitted with the periodicity of 40 milliseconds (duration of 4 Radio Frames) and repetitions every 10 ms. That means the transmission of MIB is done at subframe #0 of radio frame for which SFN mode $4 = 0$ and different copies (redundancy version) are transmitted in subframe #0 of every radio frame. Among SIBs, System Information Block Type 1 (SIB1) is a special one because it conveys the scheduling info of all other SIBs. The

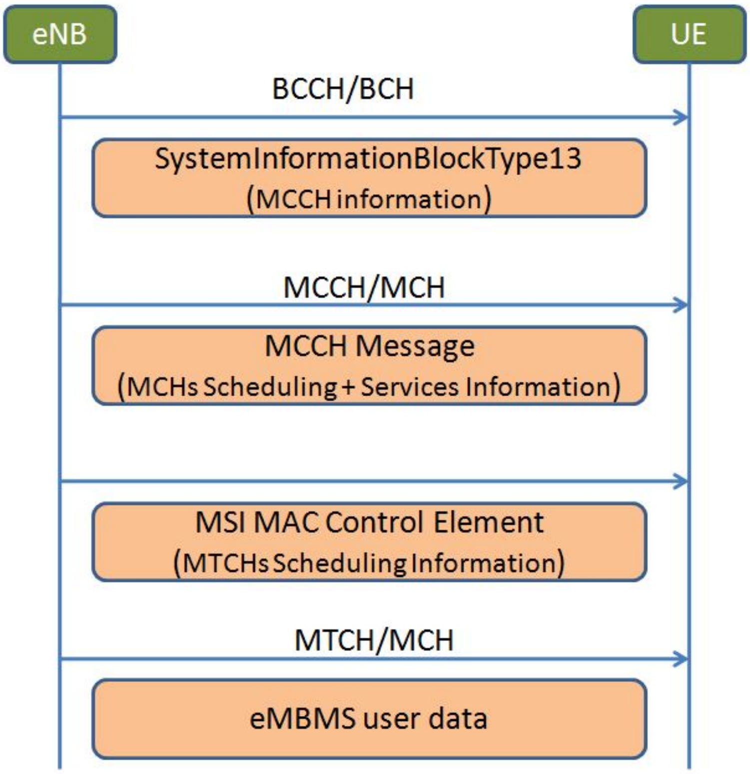


FIGURE 4.4 – eMBMS Service Reception.

SIB1 message is scheduled every 80 ms and similar to MIB, repetitions are made within 80 ms. It is transmitted on subframe #5 of radio frame for that System Frame Number or SFN mode 8 = 0 and repetitions can be found in subframe #5 of all other radio frames for which SFN mode 2 = 0.

All other SIBs are conveyed by SI messages which are transmitted periodically within time windows so-called SI-windows. Each SIB belongs to only one SI message and one or more SIBs that has the same periodicity can be mapped into a single SI message. One SI message is associated with one SI-window and these SI-windows are not overlapped. All SI-windows have the same length value (from 1ms up to 40ms) that is given in SIB1. Within a SI-window, the SI message can repeat a number of times in any subframe except for : MBMS subframes, subframe #5 and uplink TDD subframe. The scheduling and mapping between SI messages and SI-windows are indicated in SIB type 1. Different SI messages can have different periodicity varying among 8, 16, 32, 64, 128, 256, 512 radio frames, corresponding to a range from 80 ms to 5.12 seconds.

In order to get System Information Block Type 13, the UE needs to read the SIB1 first and practically, this message can be found every 20 ms (two radio frames). With the assumption that UE can decode the information immediately and the SI message containing SIB13 is transmitted once within one SI-window, the time to guarantee that we can get the SIB13 is then equal to 100 ms (20 ms for SIB1 and 80 ms for SI-window contains SIB13).

One thing worthy to notice is that in a real environment, when a UE is in the overlapped area between two cells, the signal from one eNB could be the interference to the others. For that reason, the UE usually needs more than one duplicate to decode the entire SIB message. Hence, in reality, the time for completely decoding SIB13 could be probably longer than 100 ms.

4.3.2.2 Multicast Control Message Acquisition

The information from SIB13 leads to the position of MCCH message and the UE is now trying to get the rest of the eMBMS control information. The MCCH message is transmitted every repetition period which is indicated in SIB13. According to the standard [41], this period takes the value of 32, 64, 128 or 256 radio frames, which means that in an ideal condition, the UE is assured to have the MCCH message within 320 ms after successful decoding the SIB13 (always with the assumption that the decoding time of mobile device is negligible).

4.3.2.3 Multicast Traffic Channel Scheduling Acquisition

Through the MCCH message, the UE knows its required service belongs to a particular group and where to find the resources for that group. However, it still cannot identify the data of its service because there could be up to 29 eMBMS services (or sessions) in a group. Therefore, the UE has to get MSI to access the user data of interested eMSMS services. The possible values for the MSP as specified in [41] are among 8, 16, 32, 64, 128, 256, 512, 1024 radio frames which is very short when compared to the MCCH (the minimum value for MCCH modification period is 5.12 seconds). In other words, the scheduling information MSI can be obtained within 80 ms after the acquisition of MCCH message.

So far, we have analyzed the time to receive every piece of information necessary for the eMBMS service reception. To summarize, the total time a user needs to retrieve all the control information required to access the data of a particular eMBMS service, denoted as T_{eMBMS}, is expressed as the following formula :

$$T_{eMBMS} = t_{SIB13} + t_{MCCH} + t_{MSI} \tag{4.1}$$

where t_{SIB13}, t_{MCCH} and t_{MSI} is the time to acquire the SIB13, the MCCH message and the MAC control element-MSI, respectively.

Fig. 4.5 shows how the T_{eMBMS} varies with different values of MCCH period and MSP while the SIB13 period is fixed at 80 ms.

In a different view, the theoretical time to collect each piece of eMBMS signaling information counting from the time the UE connect to the network is depicted in Fig. 4.6 where the repetition period of SIB13 is set to 80 ms, the MSP is 160 ms and the MCCH period is varied from 32 Radio Frames (RFs) to 256 RFs.

To summarize, with the hypothesis that all control messages are decoded successfully at the first receiving and the time for decoding messages is negligible, the UE may need 100 ms for acquiring the SIB13, 320 ms for MCCH message and another 80 ms for the MSI in the minimum configuration. In total, counting from the moment of listening to the broadcast information from the eNB, an LTE mobile terminal is assured to receive the

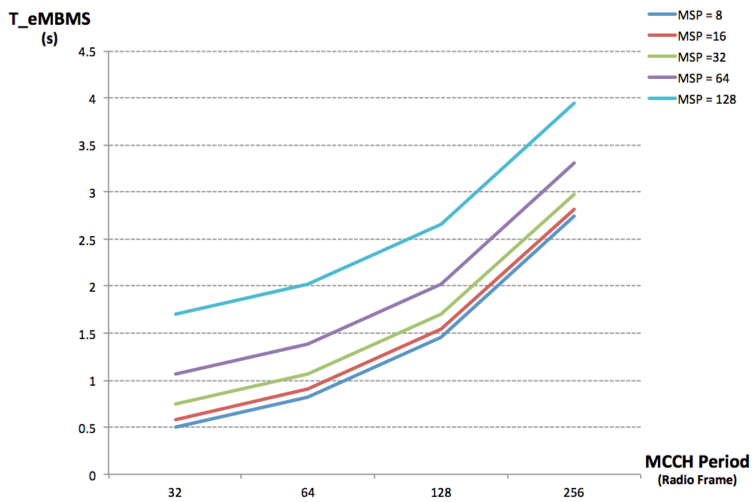


FIGURE 4.5 – Total Time for Retrieving all eMBMS Control Information.

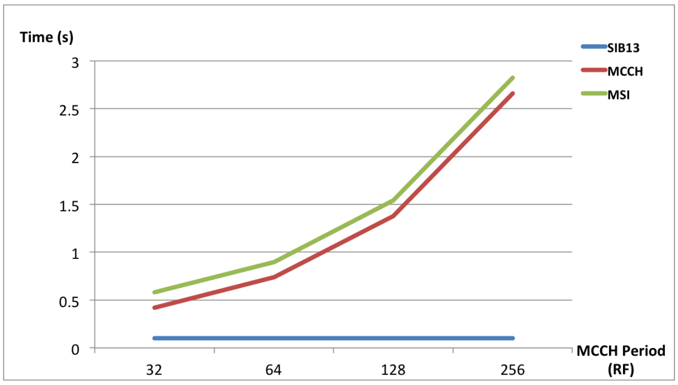


FIGURE 4.6 – Time to collect eMBMS Control Information.

eMBMS user data of its interest within 500 ms or half of a second. It is considerably large in comparison with the handover/cell re-selection or synchronization procedure (studies in [53, 54] prove that the intra-frequency handover duration in LTE network is less than 100 ms). Thereby, we can infer that the eMBMS service disruption time is mainly affected by the time collecting eMBMS signaling data.

It is worth noting that the time calculation for collecting MBMS-related information we are doing here is based on theoretical parameters indicated in the 3GPP specifications. Using the lowest value of these periodicity parameters will give us the minimum time to guarantee one user can collect all necessary information to access eMBMS data. However, this time amount is just an estimated number, most probably not equal to the result we get in a real system and it can also vary depending on the deployed configuration set.

4.4 Method to Reduce the eMBMS Service Interruption Time

From the analysis we have presented above, in order to minimize the impact of the eMBMS signaling retrieving time, choosing the configuration with minimum value for all periodic parameters is one solution. However, with this solution, the T_{eMBMS} is still long. An intuitive thought to reduce this amount even more is to eliminate one or more components that contribute to the sum. That is equivalent to somehow providing the essential information to the users so that they can have it before connecting to the new cell. Conventionally, these control messages are transferred by the target cell and the mobile users do not want to wait and collect them, so the solution is letting the serving cell do the job. Following this idea, we will present here the mechanism that allows the eMBMS users to receive a part of signaling information before connecting to the new cell.

When a trigger event occurs (depending on the policy of the network operator, but usually it happens when the signal received from neighboring cell exceeds the serving cell's signal by a predefined threshold and the situation lasts for a certain period), a mobile user in RRC-Connected mode will send measurement reports to the network. Based on these reports, the source eNB will start the handover (HO) procedure by sending the Handover Request message to the target eNB. The admission control is done at the target eNB and if the resource is sufficient, it responses to the source eNB with the Handover Request Acknowledgment including the Handover Command message. This message is then forwarded to the UE for establishing the connection with target eNB.

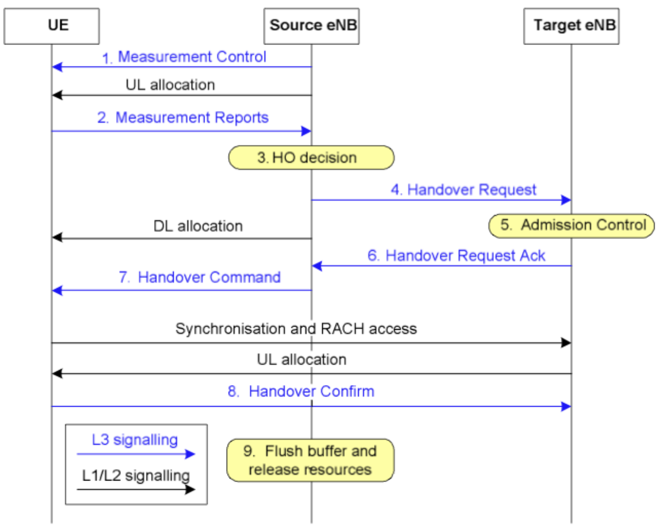


FIGURE 4.7 – Standard X2 Handover Procedure.

Noticing that there is a direct connection between source and target cell during the handover procedure, we can take advantage of this point to transfer the eMBMS info supported by target cell to the mobile terminal. To be more precise, when the current base station sends the Handover Request message to a target base station during an X2-based handover, it should indicate the identities of services which the UE is receiving or interested in receiving and the respective MBSFN areas. This info is the *eMBMS Service*

Interest mentioned in Chapter 3. The source eNB should already get this info and insert it as a new information element (IE) in *UE Context Information* [55] field of the Handover Request message. If this IE is missing, it means that the UE is not interested in eMBMS.

In response, if the target cell accepts the HO request, besides the parameters required for creating normal unicast connection, we suggest the target eNB add its SIB13 and MCCH into the Handover Command message so that the UE does not need to collect them after connecting to target cell. By this way, the eMBMS acquisition time of the UE can be reduced considerably. But will putting these extra data in HO request and acknowledge message lengthen the handover duration ? The answer is : it hardly affects the procedure because the size of these extra messages are quite small in comparison to the Handover Request or Handover Request Acknowledge (e.g. in the implementation under our real-time platform, an encoded MCCH message is less than 12 bytes while the normal Handover Command following 3GPP specification Rel-9 is about 80 bytes). However, before sending the HO request, the source eNB should verify whether it and the target eNB are in the same MBSFN area providing the services UE is interested in or not. If they are in the same MBSFN area, the UE does not realize the mobility in term of eMBMS service and therefore, source eNB will not add the new IE into the HO request to prevent target eNB includes MCCH and SIB13 in HO command message.

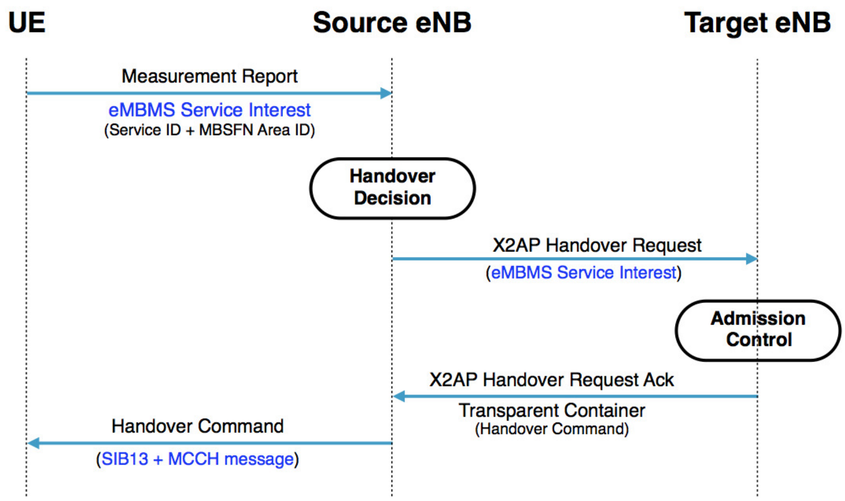


Figure 4.8 – Modification in X2 Handover procedure.

By ejecting the ID of MBSFN area and service user required in the request, the target cell knows which MCCH message (one cell can belong to more than one MBSFN area, i.e. target cell could have more than one MCCH message) it should enclose in the response. With this design, only the appropriated MCCH message is transferred to the needed UE and thus, it is optimized in terms of energy saving. The X2-based HO procedure with the support for eMBMS service is described in Fig. 4.8

The reason we do not send the MSI in HO command is that it could change quite frequently (80 ms) in comparison with the MCCH message (5.12 seconds) and is approximate the HO duration, thus, when the HO procedure is done, the MSI might have changed already. Moreover, the MSI control element is created at MAC while other messages are at RRC level, hence sending MSI from MAC to RRC and putting it in the Handover Command is not convenient in terms of practical implementation.

The similar strategy might be applied when there is no X2 connection between source and target eNB. In S1-based handover procedure [56], the source eNB firstly sends the HO Required message to the MME which will transfer the HO request to the target eNB with the information of UE context. Then like in X2 handover, the target eNB does admission control and replies the request by an acknowledgment with the HO Command message. This message reaches the UE after passing through the source eNB.

To support the eMBMS service, the same concept is used, which means the new IE with eMBMS service ID and corresponding MBSFN area ID will be transferred from the UE to the source and then to the target cell via the MME. In other direction, the SIB13 and MCCH message would go from target eNB (or MCE) to MME, the source eNB and finally the UE as described in Fig. 4.9.

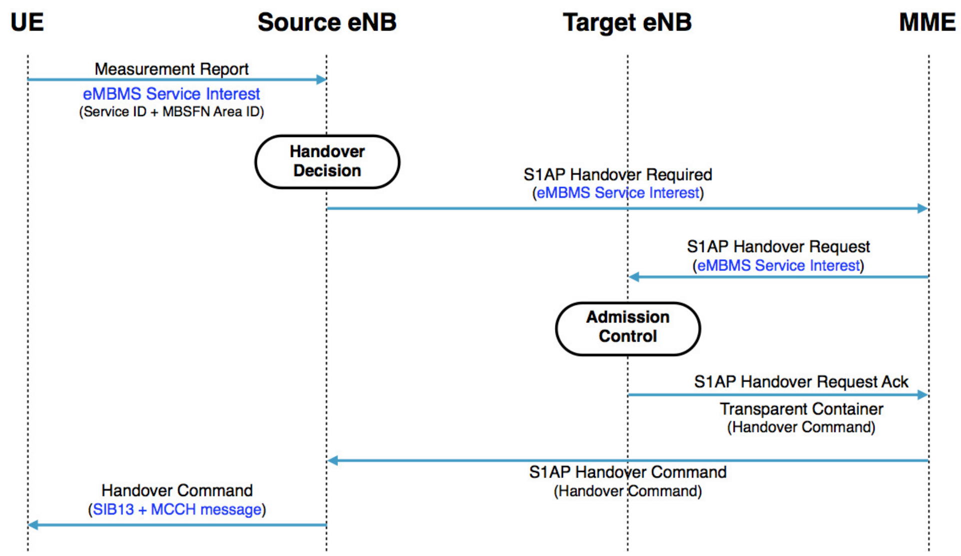


FIGURE 4.9 – Modification S1 handover procedure.

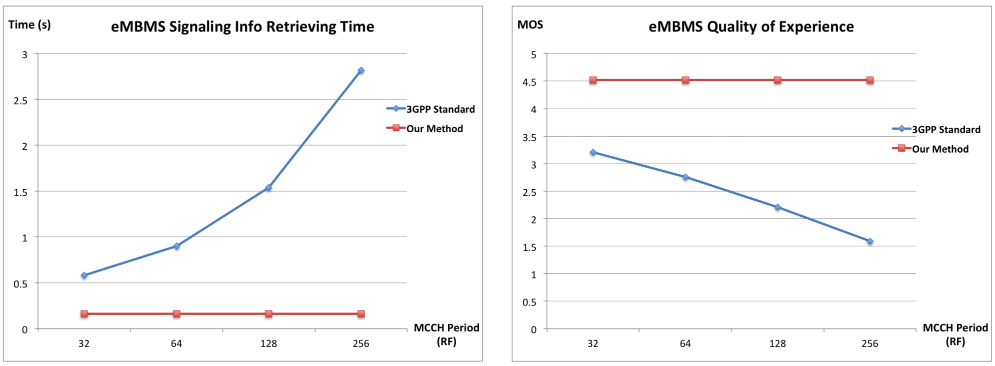
Unlike in RRC connected mode, the Idle user in LTE network does not have a dedicated connection with the base station, it can only listen to the common broadcast channel. For this reason, in order to provide the eMBMS-related information to the UE before it camps to another cell, the current cell has to broadcast the information of its neighbors. However, the current eNB does not know if there is an eMBMS user or not, nor when a user is preparing for the cell re-selection procedure, hence, it has to broadcast the eMBMS information of its neighbors periodically with full power to assure any UE in its coverage can get these infos whenever they need. Moreover, the current eNB does not know which service the UE is receiving or interested in receiving, so it has to broadcast SIB13s and all MCCH message supported in all of its neighboring cells. This results to a large amount of information need to be transferred frequently by one base station, which is obviously not an efficient method to trade off the delay for few eMBMS users. That is the reason why we do not modify the standard and let the idle users collect eMBMS information in target cell after camping to it.

4.5 Conclusion

This chapter discusses the continuity of the media stream during the transition period when a user moving from one base station to another one. Depending on the ability in supporting eMBMS services of the target and serving cell, the media stream could be received continuously in user terminal or there is small disruption during the changing moment. There are many factors that could affect the eMBMS service interruption time when an UE leaving one cell and entering a new one. They include : the handover/cell re-selection procedure, the synchronization procedure (in case the UE changes to a new frequency or component carrier) and the process of collecting the eMBMS-related information.

Our interest is the LTE broadcast service, consequently we focus on the time that a user terminal needs to acquire the necessary information to receive an eMBMS service. A general analysis is given at the beginning of this chapter showing that the eMBMS control information acquisition time has a strong impact on the service interruption time. The quantitative analysis on the disruption of the media stream is also done after a thorough study on the way eMBMS system organizes the service diffusion. Because the manner of allocating resources for eMBMS services is quite complicated, the detail on resource allocation and service reception helps us to understand better how the eMBMS works and through that, to find the solution for the stream disruption issue.

Finally, a novel method is presented to improve the quality of the service by reducing the service interruption time when the users are changing from one eNB to a new one. Our method takes advantage of the connection between the serving eNB and the target eNB or the MME/S-GW network entity to transfer necessary eMBMS information to the mobile users. With this mechanism, the interruption time of eMBMS service is chopped down significantly, giving a better Quality of Experience for the users.



(a) (b)

FIGURE 4.10 – Impact of eMBMS Control Information Collecting Time on QoE.

As an example, in case the repetition period of SIB13 and MSI are chosen equal to 80 ms and 160 ms, respectively, when our method is applied, the total time to collect all necessary eMBMS control information is equal to the time to collect the MSI only. Therefore, it will be a horizontal line as seen Fig. 4.10(a) with the value is the MSI period. Actually, the time to receive the MSI control element is corresponding to the zapping time as we mentioned in Chapter 2 because the MSI allows the mobile terminal to identify the resources reserved for each individual MBMS service. And changing from one MBMS service to another is equivalent to the channel switching. For that reason, we think it is appropriated to estimate the impact of eMBMS signaling retrieving time on the perceive quality of the service using this formula [38] :

$$MOS = max\{min\{2.65 - 1.02 * ln(Zapping\ Time), 5\}, 1\} \tag{4.2}$$

Fig. 4.10(b) shows the QoE evaluation based on the theoretical time for collecting the control information in current LTE standard and our proposed method. These MOS values clearly says that the quality of eMBMS service during the handover is improved considerably thank to our mechanism. In order to have the result with a high degree of confidence, an evaluation through real implementation will be conducted and presented in the next part.

Deuxième partie

LTE Broadcast - Practice

Overview of Part II

In this part, we will mention the practical aspect of the LTE-Broadcast service : from the implementation in a real-time system to the performance evaluation and Quality of Experience assessment for the service during the period of transition between cells.

The implementation of eMBMS system following the LTE standard (release 10) in an open source platform is presented in Chapter 5. This implementation covers the whole protocol stack from RRC level to layer 2 including PDCP/RLC/MAC sublayer and down to the Physical layer. This is considered as a value contribution of the thesis due to the fact that, in our knowledge, it is the only open-source implementation of eMBMS in a real system at the moment. With this implementation in OAI platform, we can have a useful simulation/emulation tool for further research on many aspects of eMBMS service.

In Chapter 6, a series of test has been conducted in OAI platform to validate our implementation and evaluate the performance of eMBMS transmission. The scenario of these emulations together with the configuration of eMBMS system will be described in detail in the same chapter. An experiment in real environment with devices over a real telecommunication network has also been done. The objective of this field-test experiment is to evaluate the efficiency of our method in providing a better quality for eMBMS service during the handover. This evaluation for the continuity of a media stream is given in QoE value thank to the powerful measuring tool - TEMS Investigation. Through the result from the experiment, we can confirm about the effectiveness of our proposal.

Chapter 5

Implementation of eMBMS in a Real-Time System

5.1 Introduction

Starting from the lack of a real eMBMS implementation and the need of a simulation/emulation tool for evaluating the proposed solution, we have implemented the eMBMS system in an open-source platform which is developed in our laboratory - the OpenAirInterface [21]. The first section of this chapter will give a quick look at OpenAirInterface platform and its features. In the next section, detail of the implementation is described.

To support the eMBMS service in OAI platform, these following modifications and extensions have been made in the standard LTE system implementation :

— New information element which indicates the subframes for eMBMS transmission is added to SIB2.

— The dedicated eMBMS control informations - SIB 13 and MCCH message - have been created at RRC level.

— At PDCP and RLC sublayer, the interface with RRC and MAC have been adjusted to support the eMBMS bearer.

— In MAC layer, the scheduler has been modified taking into account the resources allocated for eMBMS service. In addition, a new Control Element containing the MTCH scheduling information is generated together with the function for parsing the MAC header of MCH transport channel.

— At the Physical layer, the special requirements for eMBMS are added or modified including the new Reference Symbol set, new scrambling sequence generator and the interface between MAC and PHY.

5.2 Overview of 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 [57–59]. The platform consists of both hardware and software components providing all-IP wireless networking and it can be used for link-level simulation, in-lab system emulation and indoor/outdoor real-time 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 and NAS driver) for both eNB and UE side as well as a subset of the 3GPP-LTE evolved packet core (EPC or core network) protocols.

The objective of this platform is to provide methods for protocol and algorithm analysis, performance evaluation and pre-deployment system testing. The key features of OAI include :

— Full protocol stack for both eNB and UE implementations.
— Provides Linux networking interface to run any application on top.
— Carrier aggregation possibility.
— Implements some important transmission modes (TM) of LTE
  — LTE TM 1 (SISO)
  — LTE TM 2 (STBC - Alamouti Codes)
  — LTE TM 5 (MU MIMO)
  — LTE TM 6 (Transmit Precoding)

The methodology in OAI platform is to use the real stack to perform more realistic and reliable simulations/emulations. This also reduces the development time since the code can be ported to the final real-time implementation with very little redesign. 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 [60], 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.

5.3 Implementation of eMBMS in OpenAirInterface

After studying thoroughly the standard, we start to implement eMBMS service into OpenAirInterface platform following the 3GPP specifications. As we mentioned in Chapter

2, there are two alternatives for deploying Multicell Coordination Entity : centralized and distributed MCE. The latter one is chosen for implementing in OAI platform, i.e. MCE is considered as one part of eNB. The main reason for choosing distributed MCE model is that we want to reduce the complexity of the implementation and this deployment is more convenient for us to implement in OAI platform with the purpose of studying and evaluating the performance of eMBMS system. The actual design choice in a real LTE network depends on the operators' requirements and type of network deployment.

5.3.1 Radio Resource Control (RRC) Level

Based on the eMBMS structure, new components and functions for eMBMS service are added to OAI platform. In the control plane, the specified system information block SIB13 and MCCH message are generated at Radio Resource Control unit in eNB side. Besides, an information element (IE) related to the subframes reserved for eMBMS is also added into the normal SIB2.

5.3.1.1 System Information Block

In the SIB13, apart from the information of MCCH change notification, a sequence of components containing the MBSFN Area configuration is constructed. Each component corresponds to one MBSFN area with the values of parameters specified in [41]. The 6-bit string indicating the position of the subframe that conveys the MCCH message for one MBSFN Area is represented by a hexadecimal value in the platform. Depending on duplex type of the system (TDD or FDD), the appropriated configuration for this bit string is generated.

A new IE namely mbsfn-SubframeConfigList is added to the SIB2. This extension in SIB2 is introduced to inform mobile terminals about the set of downlink subframes reserved for MBMS transmission. This helps the receiver not to be confused by the eMBMS data transmissions when trying to decode specific cell Reference Signals and PDCCH. For the simplicity, we use one-frame pattern to allocate the MBMS subframe in OAI platform, however, this configuration can be modified easily to the four-frame pattern. In our platform, the SIB2 and SIB13 are put in the same SI window (together with the SIB3 as well), i.e. these two system information blocks are created at same time when configuring one eNB instance.

It is worth noting that the MCCH message are also transmitted on the MBMS subframes, thus, an accordance needs to be made between the position of MCCH in SIB13 and the MBMS subframe pattern in SIB2. Fig. 5.1 shows the SIB13 and the MBMS part of the SIB2 which are created in our platform. In this example for FDD mode, the eMBMS data are transferred every four frames, in four subframes (corresponding to four bits are set to 1 in the bit string). Looking at the bit string in SIB2 (111100) we know that subframe #1, 2, 3 and 6 are reserved for eMBMS while the bit string in SIB13 (100000) tells us that the MCCH will appear at the subframe #1. Also in SIB13, we realize that the period of MCCH message is set to 32 radio frames and the MCS value used for it is 13.

```
result_fdd_s15_mcs17_4sf_2.txt
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            <additionalSpectrumEmission>1</additionalSpectrumEmission>
        </freqInfo>
        <mbsfn-SubframeConfigList>
            <MBSFN-SubframeConfig>
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                <radioframeAllocationOffset>1</radioframeAllocationOffset>
                <subframeAllocation>
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                    </oneFrame>
                </subframeAllocation>
            </MBSFN-SubframeConfig>
        </mbsfn-SubframeConfigList>
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    </sib2>

    <sib3>
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        </cellReselectionInfoCommon>
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            </neighCellConfig>
            <t-ReselectionEUTRA>1</t-ReselectionEUTRA>
        </intraFreqCellReselectionInfo>
    </sib3>

    <sib13-v920>
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            <MBSFN-AreaInfo-r9>
                <mbsfn-AreaId-r9>1</mbsfn-AreaId-r9>
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                    <mcch-Offset-r9>1</mcch-Offset-r9>
                    <mcch-ModificationPeriod-r9><rf512/></mcch-ModificationPeriod-r9>
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                    </sf-AllocInfo-r9>
                    <signallingMCS-r9><n13/></signallingMCS-r9>
                </mcch-Config-r9>
            </MBSFN-AreaInfo-r9>
        </mbsfn-AreaInfoList-r9>
        <notificationConfig-r9>
            <notificationRepetitionCoeff-r9><n2/></notificationRepetitionCoeff-r9>
            <notificationOffset-r9>0</notificationOffset-r9>
            <notificationSF-Index-r9>1</notificationSF-Index-r9>
        </notificationConfig-r9>
    </sib13-v920>
                </sib-TypeAndInfo>
            </systemInformation-r8>
        </criticalExtensions>
    </systemInformation>
  </c1>
 </message>
</BCCH-DL-SCH-Message>
[RRC][D][eNB] SystemInformation Encoded 319 bits (40 bytes)
[RRC][D][eNB 0] mbsfn Subframe pattern is  = 240
```
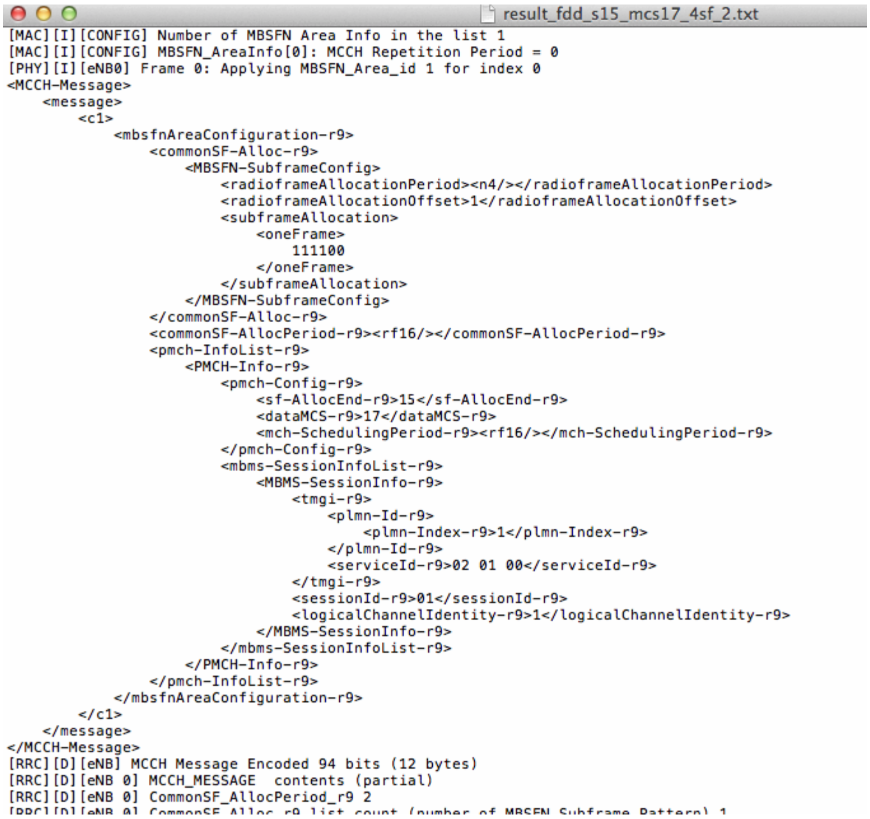

FIGURE 5.1 – SIB13 Message in OAI.

5.3.1.2 Multicast Control Channel (MCCH) Message

One or more MCCH messages, the principal signaling information of eMBMS service are generated following the 3GPP standard with some remarks below :

- The MCCH is updated whenever a new service/session comes or an existing one terminates.
- The resources indicated in SIB2 are for all MBSFN Areas supported in the corresponding eNB, hence the MBMS subframe pattern in every MCCH message should be a part of the one in SIB2. In case the eNB belongs to only one MBSFN Area, one MCCH message is created and the subframe pattern in this message and that in SIB2 should be identical.
- Eligible subframes for MBMS in TDD and FDD are different, therefore the value of the bit string generally represents different subframe in TDD and FDD (e.g. the



result_fdd_s15_mcs17_4sf_2.txt

```
[MAC][I][CONFIG] Number of MBSFN Area Info in the list 1
[MAC][I][CONFIG] MBSFN_AreaInfo[0]: MCCH Repetition Period = 0
[PHY][I][eNB0] Frame 0: Applying MBSFN_Area_id 1 for index 0
<MCCH-Message>
    <message>
        <c1>
            <mbsfnAreaConfiguration-r9>
                <commonSF-Alloc-r9>
                    <MBSFN-SubframeConfig>
                        <radioframeAllocationPeriod><n4/></radioframeAllocationPeriod>
                        <radioframeAllocationOffset>1</radioframeAllocationOffset>
                        <subframeAllocation>
                            <oneFrame>
                                111100
                            </oneFrame>
                        </subframeAllocation>
                    </MBSFN-SubframeConfig>
                </commonSF-Alloc-r9>
                <commonSF-AllocPeriod-r9><rf16/></commonSF-AllocPeriod-r9>
                <pmch-InfoList-r9>
                    <PMCH-Info-r9>
                        <pmch-Config-r9>
                            <sf-AllocEnd-r9>15</sf-AllocEnd-r9>
                            <dataMCS-r9>17</dataMCS-r9>
                            <mch-SchedulingPeriod-r9><rf16/></mch-SchedulingPeriod-r9>
                        </pmch-Config-r9>
                        <mbms-SessionInfoList-r9>
                            <MBMS-SessionInfo-r9>
                                <tmgi-r9>
                                    <plmn-Id-r9>
                                        <plmn-Index-r9>1</plmn-Index-r9>
                                    </plmn-Id-r9>
                                    <serviceId-r9>02 01 00</serviceId-r9>
                                </tmgi-r9>
                                <sessionId-r9>01</sessionId-r9>
                                <logicalChannelIdentity-r9>1</logicalChannelIdentity-r9>
                            </MBMS-SessionInfo-r9>
                        </mbms-SessionInfoList-r9>
                    </PMCH-Info-r9>
                </pmch-InfoList-r9>
            </mbsfnAreaConfiguration-r9>
        </c1>
    </message>
</MCCH-Message>
[RRC][D][eNB] MCCH Message Encoded 94 bits (12 bytes)
[RRC][D][eNB 0] MCCH_MESSAGE  contents (partial)
[RRC][D][eNB 0] CommonSF_AllocPeriod_r9 2
[RRC][D][eNB 0] CommonSF_Alloc_r9 list count (number of MBSFN Subframe Pattern) 1
```

FIGURE 5.2 – MCCH Message in OAI.

string 010000 in TDD means that suframe # 4 is an MBMS subframe while in FDD, subframe #2 is reserved for eMBMS).

One MCCH message generated in OAI platform is illustrated in Fig. 5.2. There is one PMCH in this example with the CSA period equals to 16 radio frames and the MCS value for eMBMS data is 17. We can see that the period of the MSI for this MCH is set to 16 radio frames as well and the total size of this message is 94 bits.

Similar to other system information of unicast transmission, eMBMS control informations are transferred directly from RRC to MAC sublayer via BCCH and MCCH logical channel as described in Fig. 5.3. Another task of RRC unit is configuring the data bearers for eMBMS services at PDCP and RLC sublayer using the parameters given in SIB13 and MCCH message.

5.3.2 Packet Data Convergence Protocol (PDCP) and Radio Link Control (RLC) level

For transporting the eMBMS user data, we implemented the full protocol stack in the data plane according to the standard at layer 2 including PDCP, RLC and MAC sublayer. As stated in [41], the Packet Data Convergence Protocol (PDCP) is not used when eMBMS service is broadcasted in the E-UTRAN. The PDCP is used for header com-

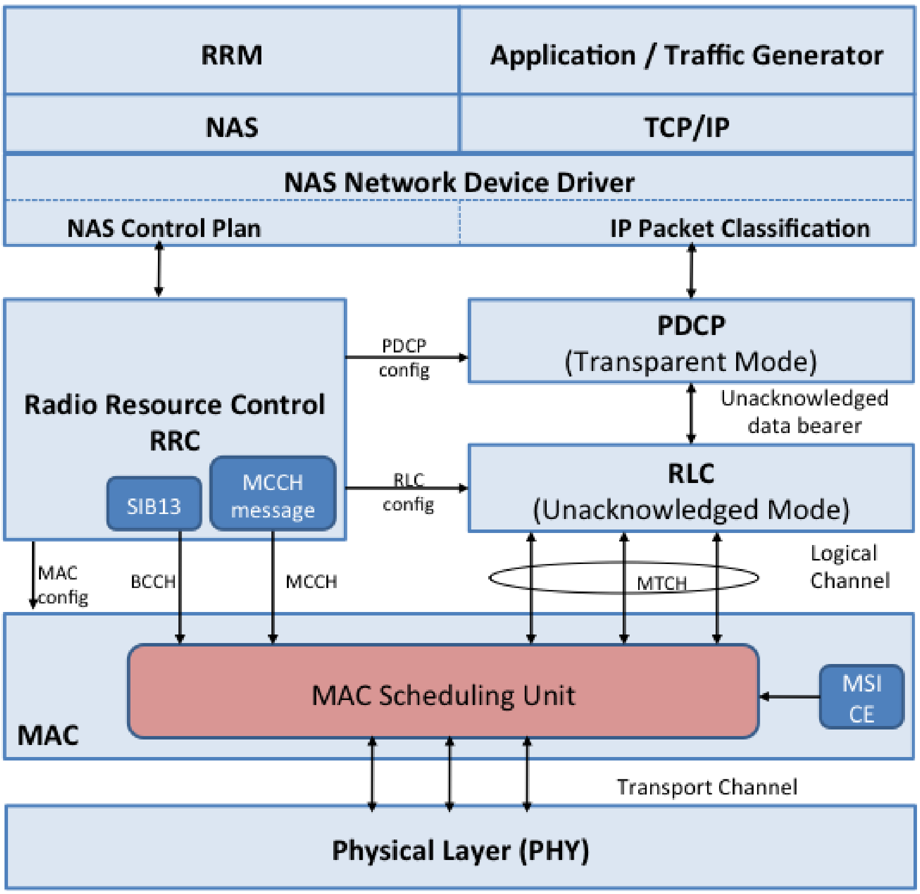


FIGURE 5.3 – eMBMS protocol stack in OAI.

pression/decompression (ROHC-Robust Header Compression) and ciphering/deciphering for unicast data, however, for eMBMS traffic, PDCP is just an empty box that gets the data packets from the upper layer (IP) and forwards them to the lower sublayer. In OAI platform, the PDCP operates in transparent mode (TM mode), which means the Protocol Data Unit (PDU) is handed directly to the Radio Link Control (RLC) sublayer in eNB side (or to upper layer at the receiver side) without header and trailer appended.

At Radio Link Control level, eMBMS uses the Unacknowledged Mode (UM) and one RLC-UM entity is created for one data bearer (one session). RLC entity puts the packets received from PDCP into the RLC buffer. An RLC instance is responsible for segmenting the received SDU into smaller packets depending on the request of the MAC scheduler. The packet size is determined by the MCS value used for that transport channel. Few bits for RLC header is also added into the original payload before the RLC-UM instance sends them to MAC sublayer via MTCH logical channels in the transmitter side. An inverse procedure is applied in the receiver side to reassemble these segments.

Fig. 5.4 illustrates the RLC-UM entities at the transmitter and receiver that are used for MTCH with the duplicate avoidance and reordering. To differentiate with unicast transmission, an array of eMBMS RLC entities is dedicatedly created in OAI and it is indexed by the service and session identity. Also, the sequence number field length for eMBMS RLC entity is specified equal to five bits.

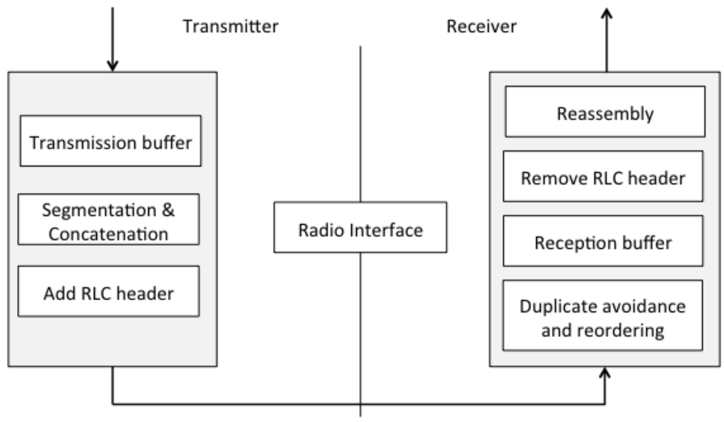


FIGURE 5.4 – RLC-UM entity for eMBMS.

5.3.3 Medium Access Control (MAC) Layer

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

A new scheduling unit for multiplexing the MCCH and MTCHs is implemented in this level. One point to be noticed here is that a single MAC Protocol Data Unit should carry data of only one MCH. It means the data of several services (MTCHs) that have the same quality requirement and maybe the MCCH message could be transferred in one MAC PDU. Another point is, in EUTRAN, only mixed-cells (transmit both unicast and broadcast/multicast) are supported for eMBMS ; hence, the MAC scheduler should be modified so that the scheduling for eMBMS will not affect the unicast traffic. In order to do this, the eMBMS scheduling function uses the parameters provided by RRC and checks whether a subframe is reserved for eMBMS or not. If that subframe is allocated 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.

At the eMBMS subframe, MAC will create the control element MSI, get the MCCH control message from RRC or request MTCH user data from RLC. The Transport Block Size (TBS) and the Modulation Coding Scheme (MCS) are also calculated during the scheduling procedure. The following tasks are done by the eMBMS scheduler at MAC layer in the transmitter (i.e. the eNB side) :

— To generate the MSI : based on the number of MBMS Service Data Units (SDUs) that are transfered in this subframe, the MSI is created following the format described in Fig. 5.5. One MSI consists of one or more basic elements, each of them represents one MTCH or MCCH channel. In one basic element, there are two fields : one for the Logical Channel Identification (LCID) of the MTCH or MCCH, and the other one denotes the last subframe containing data of that channel.

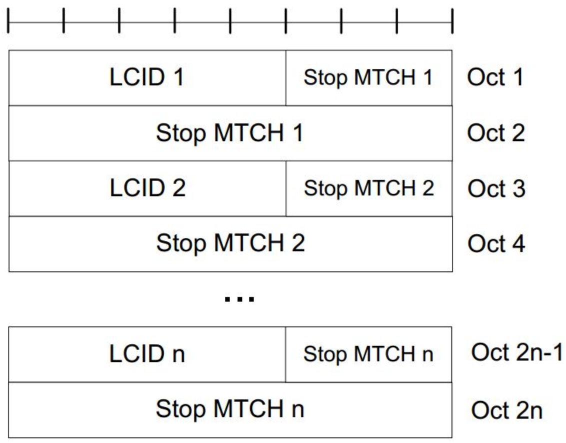


FIGURE 5.5 – MSI control Element [4].

From the structure, we can see clearly that the MSI carries the mapping between MTCHs and their subframes within an MSP. The possible LCID value for a channel is specified in Fig. 5.6 while value of 'Stop MTCH' field expresses the index position counting only MBMS subframes allocated for this MCH.

Index	LCID values
00000	MCCH (see note)
00001-11100	MTCH
11101	Reserved
11110	MCH Scheduling Information
11111	Padding
NOTE: If there is no MCCH on MCH, an MTCH could use this value.	

FIGURE 5.6 – LCID Value for MCH [4].

— To calculate the Transport Block Size (TBS) : the TBS calculation is based on the Modulation Coding Scheme (MCS) value as specified in [61]. If one MCH conveys both user traffic (MTCH) and signaling traffic (MCCH or MSI), the MCS of signaling traffic will be assigned. The TBS is used to demand the amount of eMBMS data from RLC buffer.
— To get the eMBMS SDU from RRC level if MCCH is transmitted and the RLC SDU containing eMBMS payload if there are MTCHs in this subframe. The scheduler will put these SDUs into the PDU buffer in the order as listed in MSI.

— To generate the header for MAC PDU : before sending PDU to the PHY layer on MCH transport channel, MAC creates the header depending on the number of SDUs received and control elements in this subframe. For the MCH channel, the MAC PDU uses the same format as in the DL-SCH channel.

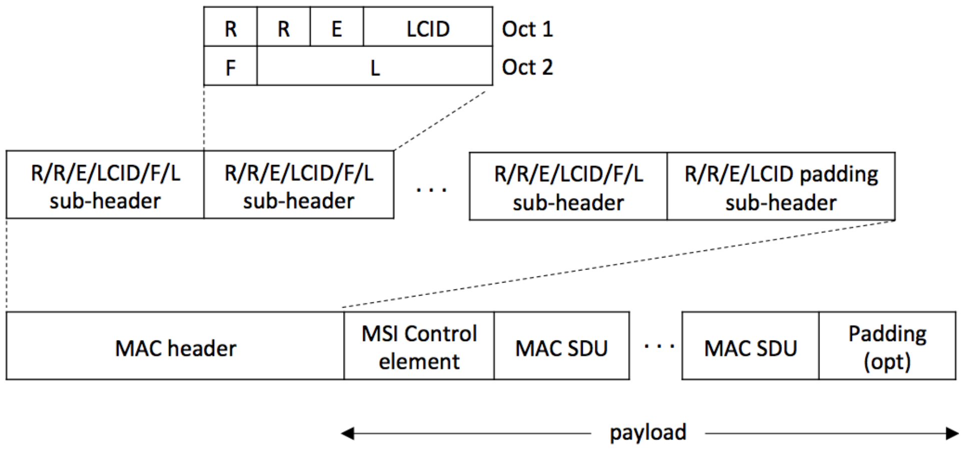


FIGURE 5.7 – MAC PDU Structure for MCH Channel

A MCH MAC header may consist of many sub-headers ; each sub-header corresponds to a MSI control element, an MTCH SDU or an MCCH SDU. The order of sub-headers in the MAC header follows the order of SDUs they represent, i.e. the sub-header for MSI control element is always at the first position in MCH MAC header because MSI stands before any MTCH or MCCH SDU in the MAC payload. Different from the usual control element with fixed size, the MSI has a variable size due to the number of MCCH and MTCH in the subframe, thus the sub-header for MSI has six fields as we can see in Fig. 5.7. After creating the header, MAC puts it at the beginning of the buffer containing SDUs and the MAC PDU is ready to be sent to the lower layer.
We remind that the Hybrid Automatic Repeat Request (HARQ) is not used in eMBMS. One more thing to be noticed, the MAC sublayer in receiver UE does not have the scheduling task but it does need to know the position of the MBMS subframes to order PHY layer to decode the PMCH.

5.3.4 Physical Layer

At the physical layer, most of PHY procedures for eMBMS are the same with those in unicast downlink transmission. The Cyclic Redundancy Check (CRC) calculation, the channel coding scheme (turbo encoder with coding rate equal 1/3) and the rate matching for MCH and DL-SCH transport channel are identical [62]. In the scrambling procedure, there is a small difference in calculating the initial value of scrambling sequence for eMBMS because the scrambling for eNB participating MBSFN transmission is depended on the MBSFN Area ID instead of the cell ID as usual.

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 (0 to 28) 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 [5] and its sequence generating is also defined in the same document.

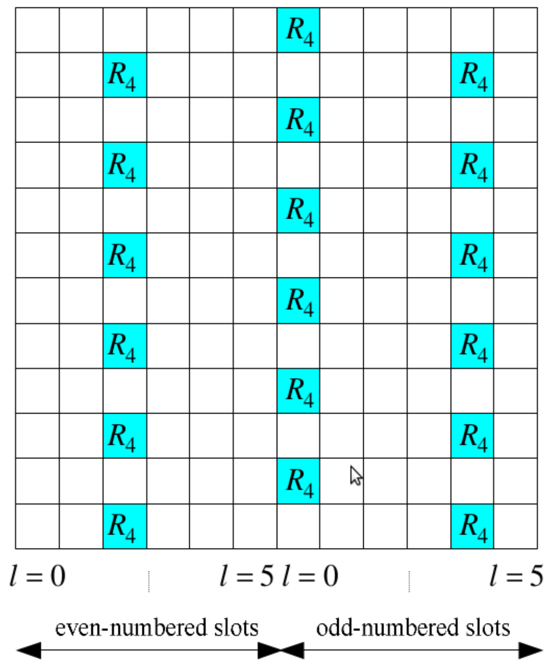


FIGURE 5.8 – Reference Signals Antenna Port 4 for MBMS [5].

At MBMS subframe, the cell-specific reference signal can be generated at non-MBSFN region (in OAI, we implement 2 first symbols of the subframe for this region). The PMCH can be transmitted in the rest part of the subframe. The extended cyclic prefix is always used for PMCH while two control symbols can use normal cyclic prefix. In this case, there will be a hole in downlink transmission between unicast and MBSFN symbols. In addition to the 15 kHz subcarrier spacing, a reduced subcarrier spacing $\Delta = 7.5$ kHz is also can be used for MBSFN transmission. However, in OAI, we only using the 15kHz subcarrier for MBMS.

5.4 Conclusion

This chapter has provided a brief introduction to the OAI platform and mentioned in detail all necessary modifications and extensions to allow the eMBMS transmission. As a summary for the chapter, we describe below the eMBMS traffic flow in OAI platform.

In the transmitter side, at the RRC level, an information element concerned with the radio resources allocated for the eMBMS service will be added to the SIB2. The SIB13 and the signaling MCCH message are also generated at this level. After creating the control information, the RRC unit in the eNB is responsible for configuring the MBMS bearer at PDCP and RLC sublayer (although PDCP does not have any role in eMBMS data transmission, the bearer still need to be configured). In parallel, the information related to eMBMS service and transmission is store at the MAC instance of the eNB for the scheduling purpose.

If there are eMBMS data coming from the network layer and the corresponding eMBMS bearer has been already created, the PDCP will forward these packets to eMBMS RLC-UM instance. It will store these data in the buffer and wait for the command from MAC layer. As its turn, MAC layer in eNB's side uses the information from SIBs and MCCH message to schedule the transmission. At each subframe, the MAC scheduling function will verify the subframe is reserved for an unicast or eMBMS transmission. If it is an eMBMS subframe, MAC will request the RLC entity to transfer eMBMS data with the packet size corresponding to the MCS value. Receiving the order, the RLC-UM does the segmentation for eMBMS packets, adds the RLC header and transfers the required amount to MAC. In case this subframe also conveys MCCH or MSI, MAC scheduler will get the MCCH message SDU from BCCH channel or create the control element, respectively, and put them together with the RLC SDU. If neither MCCH nor MSI is scheduled for the subframe and there is no data in the RLC-UM buffer, MAC instance will not generate the MBMS PDU.

The header is generated to complete the eMBMS MAC PDU and it is transported to PHY layer over the MCH transport channel. At PHY layer, if the abstraction mode is used in OAI, then the MBMS data will be transfered directly to PHY layer of the receiver in case eNB and UE are hosted in the same physical machine via memory copying technique. If eNB and UE are built in different machine, the data will be transfered over the Ethernet link and stored in the UE's PHY layer. Otherwise, if a full PHY protocol is used, the MBMS data will go through the PHY procedures (channel coding, rate-matching, interleaving, modulation,etc.) before reaching the physical layer of the UE.

In the other side, at every subframe, PHY layer of the receiver queries MAC whether it should decode the received data or not. Thanks to the information getting from SIB2 and SIB13, MAC will indicate the subframe PHY should decode together with the MCS value. After doing the reversed procedures (demodulation, de-interleaving, etc.), PHY sends the MBMS SDU to MAC where the MAC header is parsed and the payloads are read. If it is the encoded MCCH message, it will be decoded and the information extracted from the MCCH message is used to configure the bearer at RLC and PDCP level of the UE.

If the MAC SDU is the MSI control element, MAC will store the information and use it to order PHY to decode the data of a particular eMBMS service at the right time. At the subframe containing its specific MBMS service (MTCH), MAC extracts the SDU and sends it up to RLC level where the RLC header will be removed. When the whole packet is reassembled, RLC instant will send it to PDCP and from there the packet goes to upper layer.

Chapter 6

Experiments & QoE Evaluation

6.1 Introduction

In order to validate our implementation as well as to evaluate the performance of eMBMS transmission in OpenAirInterface, we have run the emulations of LTE Broadcast service with different configurations in different scenarios. In addition, we want to see how the acquisition time of control information affect to the eMBMS stream disruption during the handover as mentioned in Chapter 4. With this purpose, a series of emulation is carried out to calculate the time for retrieving every signaling message related to eMBMS service. This chapter aims to describe the methodology and scenarios of these emulations. From emulation results, we can observe that with our proposed mechanism, the service quality will be improved considerably during the handover period.

It has been proven that the technical parameters sometimes do not reflex the quality of service perceived by the human users, especially when assessing video services. Therefore, we would like to estimate the efficiency of our solution for eMBMS service using the Quality of Experience metric. Unfortunately, although the eMBMS system has been integrated, the OAI platform however has not supported yet a proper X2 handover procedure. Hence, we have to find an alternative way to get the QoE assessment for stream interruption during the handover period. Our strategy is to combine the results from an unicast handover scenario in a real 4G/LTE network and those from multicast emulation in a real-time system. Details on the handover field-test and emulator's setting will be mentioned in this chapter.

6.2 Methodology

6.2.1 Link Level Emulation

To evaluate the performance of the implemented eMBMS system at link level, 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 and one static UE to measure the best case performance. This emulation uses the full physical layer (PHY) over the specific propagation channel in a multi-path fading environment as indicated in [63].

6.2.2 System Level Emulation

For the emulation in system level, we have deployed OAI in two physical machines equipped with processor Intel(R) Core(TM) i3 3.1Ghz running Ubuntu version 12.04 LTS : one machine is used for one OAI eNB instance while the other machine hosts several OAI UE instances. These two machines are connected via Ethernet link.

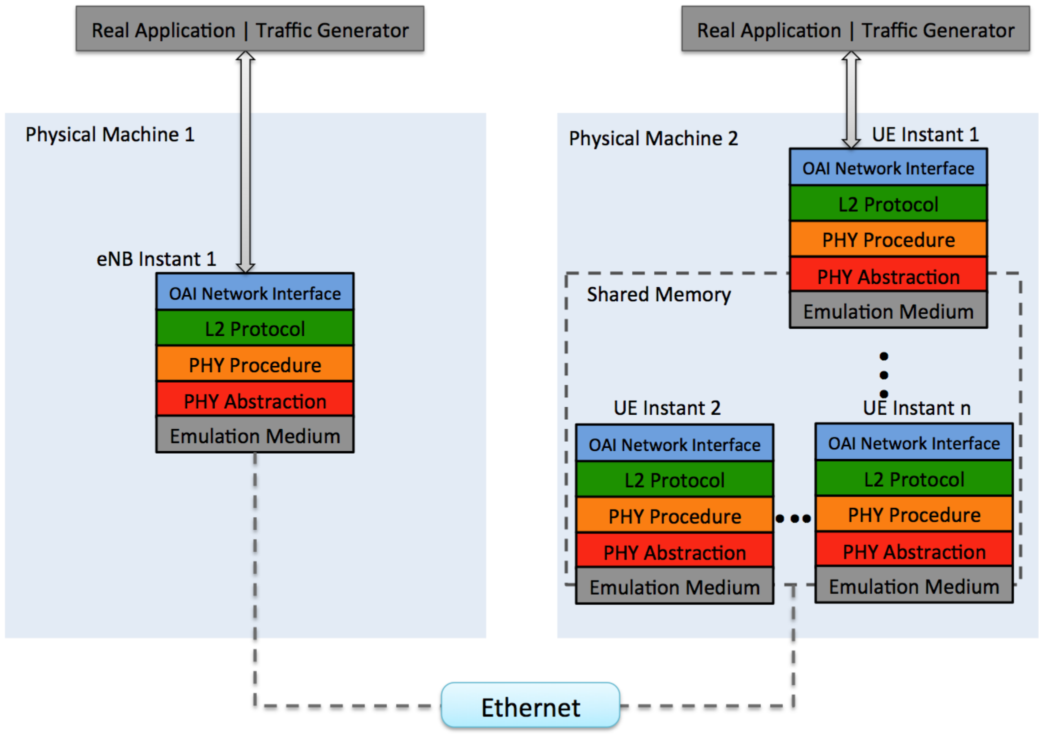


FIGURE 6.1 – Illustration for System Level Emulation.

There are two ways to generate the eMBMS traffic in this emulation. In the first method, we use a tool called OpenAirInterface Traffic Generator (OTG) [64]. This tool is a realistic packet-level traffic generation tool for emerging application scenarios. Developed in C under Linux environment, OTG allows generating 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.

The other way to generate the user data is using the real application. More precisely, we use the VideoLAN (VLC) streaming application to transfer a video from one machine (referred to as the transmitter) to the other one (receiver) through the OAI protocol stack.

In the transmitter machine, the video is trans-coded to H.264 format and sent over Real-time Transport Protocol (RTP)/User Datagram Protocol (UDP) to a multicast address over eMBMS bearer. Thanks to the network driver, the media flow will be routed through the OAI eNB instance in the transmitter side before being transferred on emulation medium (which is IP multicast) to the OAI UE instance. At the receiver machine, the media data will pass to the OAI protocol stack, be reassembled and sent to the VLC application to display in the VLC player.

In the effort of running DASH video over an eMBMS bearer, we try to set up an emulation in OAI with the video source is a DASH dataset. Because the protocol FLUTE has not been implemented in our OpenAirInterface platform yet, a proper DASH in eMBMS using download delivery method can not be applied as defined in the standard. As an alternative solution, we run DASH with the HTTP protocol but the data stream will be driven through the eMBMS bearer in OAI.

For the video source, we use a DASH dataset of the famous Big Buck Bunny video provided by the Institute of Information Technology (ITEC) at Alpen-Adria University Klagenfurt, Austria. Multiple DASH datasets of other videos with different representations can be found at [65]. The video segments in dataset are generated by their tool called DASHEncoder [66] which encodes the original video, generates a set of representations with variable size, bitrate and resolution. The Media Presentation Description (MPD) which is compliant with DASH VLC plugin is also generated for the corresponding set of segments. The DASH plugin (also developed by ITEC) is officially supported by VLC player, hence, with the obtained DASH dataset, we are able to make the emulatioin with DASH video over the eMBMS bearer using VLC player.

In order to conduct this emulation, we have installed the Apache server and locally store the DASH dataset in the machine where the OAI eNB instance resides. At the receiver machine, the VLC player will request the MPD file from the server through network stream feature with the address of the OAI eNB instance's interface. From the content of MDP file, the segments of the video will be streamed to the receiver side via the OAI protocol stack and visual in the player.

6.2.3 Handover Field-Test Experiment

In Chapter 4, we have presented a method to reduce the interruption time of an eMBMS service during the handover period. Since the implementation of eMBMS system in our real-time platform is validated, our desire is to apply the eMBMS transmission into a mobility context (in a handover situation between MBSFN Areas for more precisely) and measure the improvement in terms of Quality of Experience (i.e. the MOS score). That was one of the motivation for us to do the work described in Chapter 5. However, due to the limitation in time and the supportability of the OpenAirInterface for X2-based Handover procedure, we can not realize the emulation in OAI to assess the efficiency of our mobility support method for the LTE Broadcast service. Additionally, there is still no accessible eMBMS framework that allows us to integrate and through that, to evaluate our solution in QoE.

For these above reasons, we have to find an indirect way to evaluation the enhancement of eMBMS service during the MBMS Area transition period when applying our method. The experiment is described in two following steps :

Step 1 In the first step, we try to figure out the interruption time of an eMBMS service when a mobile terminal performs the HO procedure. The stream disruption in this case is mainly driven by the handover procedure and the time to retrieve the eMBMS control information. Since the objective is to evaluate our mobility support solution, we focus on measuring the disruption part which is caused by the time for retrieving eMBMS signaling messages. In our proposed method, these control messages of the target cell are provided to the UE during the handover, thus, the interruption time will be reduced an amount corresponding. We will estimate this amount of time through the emulation in OAI platform.

Step 2 To see how the satisfaction of a user is affected by the media stream interruption during the handover, we carry out a field-test in a real cellular network. In this experiment, we use a 4G/LTE Huawei USB modem connect to a laptop as the mobile user. While being placed inn a car moving with the speed of 50-60 km/h, this mobile terminal uses the VLC player to stream a video over the Internet. The car will go to the overlap area between two base stations and the handover will be triggered. During this time, the mobile terminal is still receiving the video stream and the impact of handover procedure on the QoE of the streaming service is measured by the Video Streaming Quality Index (VSQI) method [35].

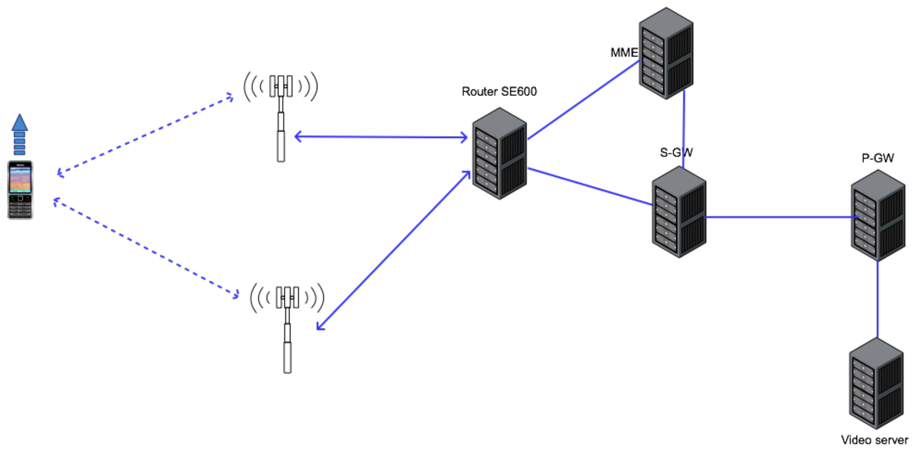


FIGURE 6.2 – Handover field-test Scenario.

The experiment is conducted in Sophia-Antipolis, the south area of France, in co-operation with Com4Innov telecoms company [67]. The video streaming service is done thanks to the Com4Innov's equipments integrated in the network operator's infrastructure while the QoE measurement is given by the TEMS Investigation tool [36] in VSQI metric. Fig. 6.2 describes the scenario of the experiment.

Normally, in the LTE handover procedure, the data forwarding is applied to transfer packets from the source eNB to the target eNB and then to the mobile terminal. The purpose of data forwarding is to avoid the packet loss and moderate the service interruption. With the aim to imitate the broadcast streaming service, the forwarding feature will not be used in our experiment. In addition, the LTE handover duration is quite short, and thus, we cannot see clearly the service disruption time as well as its impact on the quality perceived by the human users. To manipulate the influence of eMBMS-related procedures on the streaming service, a delay in Control-plane might be added to the X2 interface between two base stations in our experiment. This extra delay leads to an interruption in the User-plane which can be seen as the stream disruption produced by the control information of eMBMS service. The QoE is then calculated based on this interruption of the video stream.

6.3 Validation and Evaluation of eMBMS in OAI platform

For the validation of the implemented eMBMS service in OpenAirInterface platform, the first metric we want to measure is the Block Error Rate (BLER) which allows us to infer about the physical layer properties. According to [63], 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. With this emulation, the scenario with only one service group (one MCH) and one eMBMS service (MTCH) is applied. More detail about simulation parameters can be found in Table 6.1.

Table 6.1 – Simulation Parameters for eMBMS

Parameters	Setting
Transmission Bandwidth	5MHz
Number of pairs of RBs available for eMBMS	25
Transmission Time Interval	1ms
Radio Frame Duration	10ms
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)

We have done the simulation with the same condition as used in the standard requirement (R.39-1 channel) for three different Modulation and Coding Schemes (MCS = 17, 20, 22). As we can observe in Fig. 6.3, the eMBMS transmission in the emulation obtains a gain about of 3dB at BLER=1% against the standard requirement (the x point in the graph).

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 Fig. 6.4 shows the throughput of eMBMS transmission in FDD with different MCS values and different number of eMBMS subframes in one radio frame. To remind, maximum six out of ten subframes can be allocated to eMBMS in one radio frame.

At the moment, in mode TDD, our OAI platform only supports the TDD configuration mode 3 which allows transmitting the eMBMS data maximum in three subframes (#7, #8 and #9). Thereby, when we run the emulation in TDD mode, only three subframes are

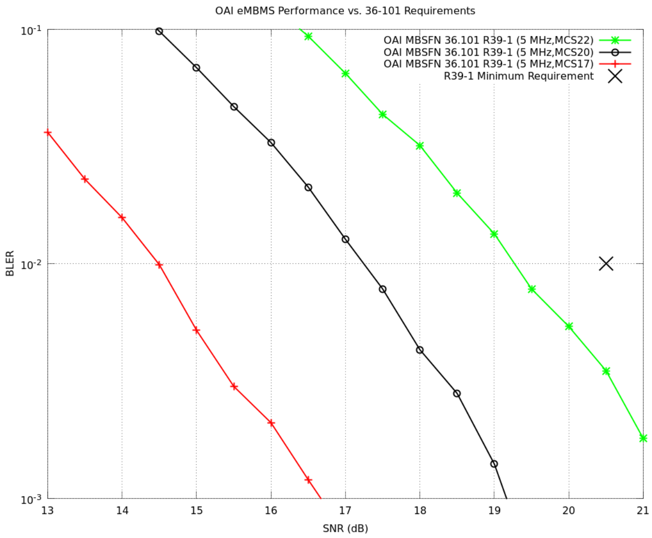


FIGURE 6.3 – BLER for eMBMS Transmission in OAI.

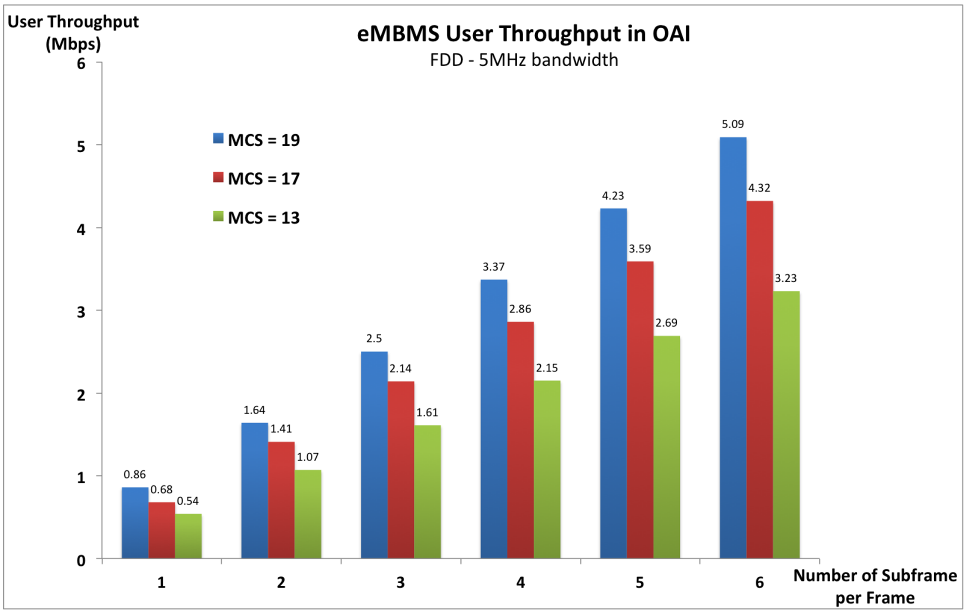
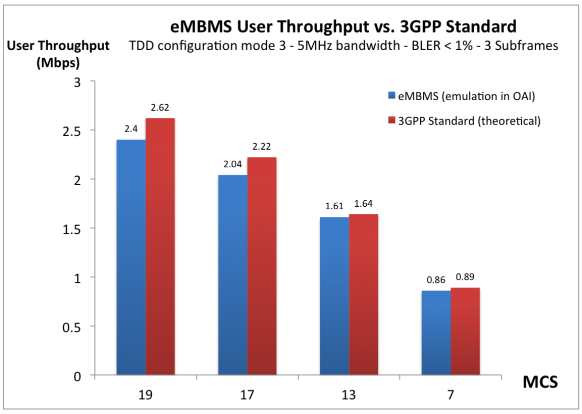


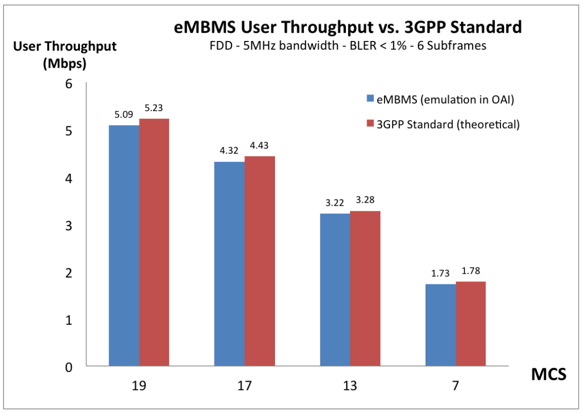
FIGURE 6.4 – User Throughput of eMBMS Transmission with different MCS values.

allocated for eMBMS while with FDD, all six eligible subframes can be used. The emulation results for the eMBMS throughput in TDD mode with difference MCS values are shown in Fig. 6.5.

In the figure, the red bars represent the user throughput of eMBMS system calculated by OTG at the receiver side while the blue bars represent the maximum transmission throughput for eMBMS calculated from 3GPP specifications [61]. There is a slightly difference between these two values in each MCS configuration which can be explained as



(a) TDD



(b) FDD

FIGURE 6.5 – eMBMS User Throughput in OAI.

follows : 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 affects the user throughput. The BLER result satisfies the minimum requirement of 3GPP standard and the obtained user throughputs in different MCS values are very closed to the theoretical value have proved that our eMBMS implementation in OAI is correct and reflexes the standard.

To measure the time for retrieving eMBMS control informations in OAI platform, we use the emulation with two physical machines : the first one hosts one eNB instance, ten UE instances are generated in the second machine. In this experiment, we collect the time to retrieve the SIB13, MCCH message and the MSI of all UE instances and compute the average time to receive each type of eMBMS signaling information. The retrieving time is calculated from the moment when an UE activates (turns on) until the moment when it decodes successfully the respective control information. With one MCCH repetition period value, we do the emulation for 1000 times and in each time, the UEs are programmed to switch on at a random moment following the uniform distribution. In the emulation, the

SIB13 is repeated every 8 radio frames and the MSP is set to 16 radio frames while the MCCH period varies from 32 to 256 radio frames. The results are given in the Table 6.2 and Fig. 6.6.

Table 6.2 – Retrieving Time for eMBMS Control Information.

MCCH period	SIB13		MCCH		MSI	
	Average	Deviation	Average	Deviation	Average	Deviation
32 (RFs)	4.03	2.24	16.34	9.17	32.31	18.25
64 (RFs)	4.03	2.23	32.20	18.42	48.21	27.31
128 (RFs)	4.01	2.24	64.24	36.79	80.47	46.24
256 (RFs)	4.02	2.27	128.27	73.78	144.42	82.85

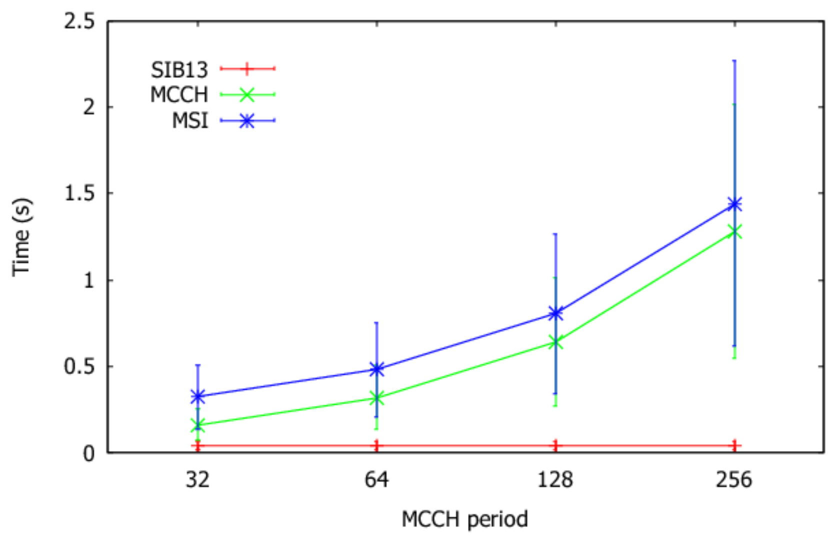


FIGURE 6.6 – Retrieving Time for eMBMS Control Information.

Look at the emulation results, we can realize that the time for retrieving SIB13 and MCCH is approximately a half of their repetition periods while the MSI is obtained about one MSP after receiving the MCCH message. It is because the UE switches on randomly during the period of SIB13/MCCH and at the end of the period, it can decode the message. Whereas, we schedule the MCCH and MSI at the same subframe, therefore, the UE has to wait to the next MSP to get the MSI.

From these results, we can infer that if the SIB13 and MCCH message are transferred to the RRC-Connected UE during the Handover procedure, in average, the UE can save a time equal to half of the MCCH period (with the assumption that the added information does not affect the decoding time). In other words, the service interruption time can be reduce an amount equivalent to half of MCCH period. For example, in case the system uses the repetition period of 256 radio frames for MCCH, with our solution, the disruption time might be reduced an amount of 2560/2=1280 ms or 1,28 s. This amount is quite large in a streaming service and from the result in our field test with a real 4G/LTE network, we will see how it could impact the quality of a broadcast stream in terms of QoE.

6.4 Quality of Experience Evaluation

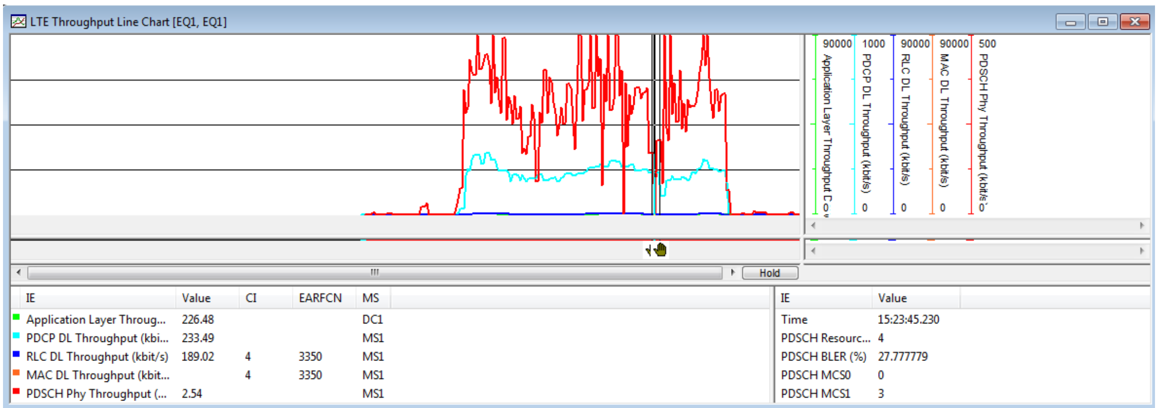
We have conducted the handover field-test multiple times with two main types of scenario : in the first one, the mobile device requests a streaming service from a server over the Internet. While receiving the video, the device gets out of the current cell's coverage and the handover happens as the way it should be ; In the second scenario, all conditions remain the same as they were in the previous test except that we put a delay into the control-plane in the handover procedure so that a disruption will be created in user-plane with an amount corresponding to the one we get from the emulation. For example, with the round trip delay of 600 ms to the Control-plane, the interruption time is about 1 second (approximately equal to the disruption given by OAI emulator in case our solution is not applied and the MCCH repetition period is 256 radio frames)

With both experiment scenarios, we identify the media stream disrupted time by measuring the user throughput at the mobile device. TEMS Investigation [36], the industry-leading tool for troubleshooting, verification, optimization, and maintenance of wireless networks, is used for the measurement. Integrated with VSQI method, this tool is also able to estimate the service quality and generate the QoE value for streaming service in real time. This value is comfort with MOS (i.e. it takes the value from 1 to 5). Some experiment results are given in the following figures.

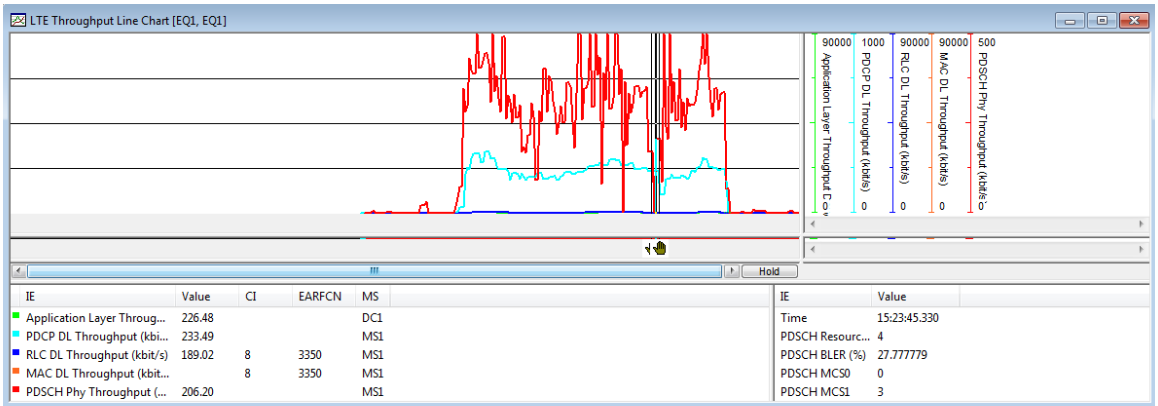
Fig. 6.7 indicates the throughput at the mobile device in the first experiment. We can observer that, during the Handover, there is a moment where the throughput at physical layer of the receiver is dropped to zero, which means that the user does not receive any data from the source at that time. The interval where the throughput stays at zero corresponds to the stream interruption in user-plane. Following the record in TEMS, this disruption of the video stream in the first test is about 90-100 ms and it is hardly recognized in the video player. This amount of interruption is corresponding to the case when our method is applied with the repetition period of MSI equals to 16 radio frames.

The QoE value of the service during the handover procedure in this experiment is displayed in Fig. 6.8. As we can see, the QoE, or to be more exact, the VSQI value of the service during the handover declined a little but still at the acceptable level (from 4 to 3.4) and it goes back to the level as it was before the handover in 12 seconds.

In the second scenario, when we add a delay to the control-plane, the interruption time in the user-plane increases to one second as shown in Fig. 6.9. And as expected, with this disruption, the VSQI value dropped dramatical from 4 to 1, which is a very bad quality. We have done the experiment for this scenario several times and receive the similar results in stream disruption time and QoE value as given in Fig. 6.10 and Fig. 6.11

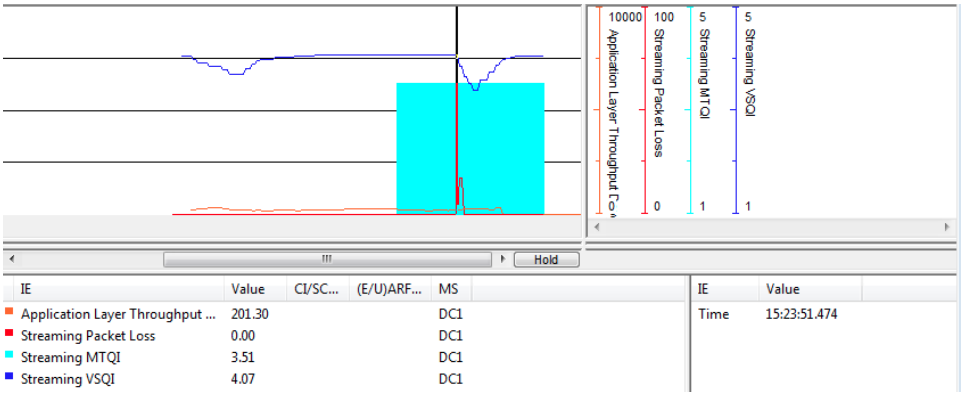


(a) Diruption Starts

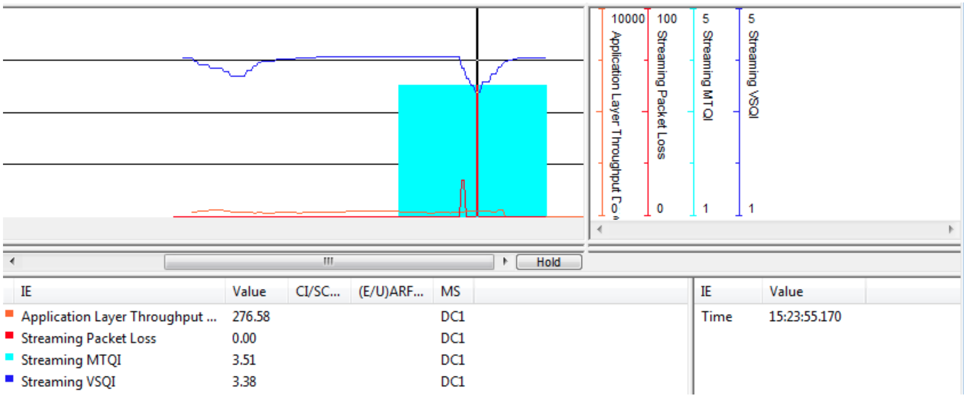


(b) Diruption Ends

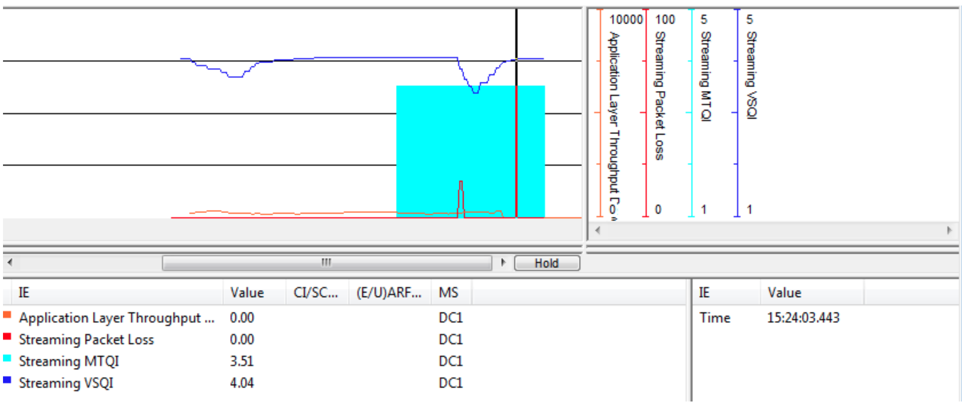
Figure 6.7 – U-plane Interruption Time in normal HO Procedure.



(a)

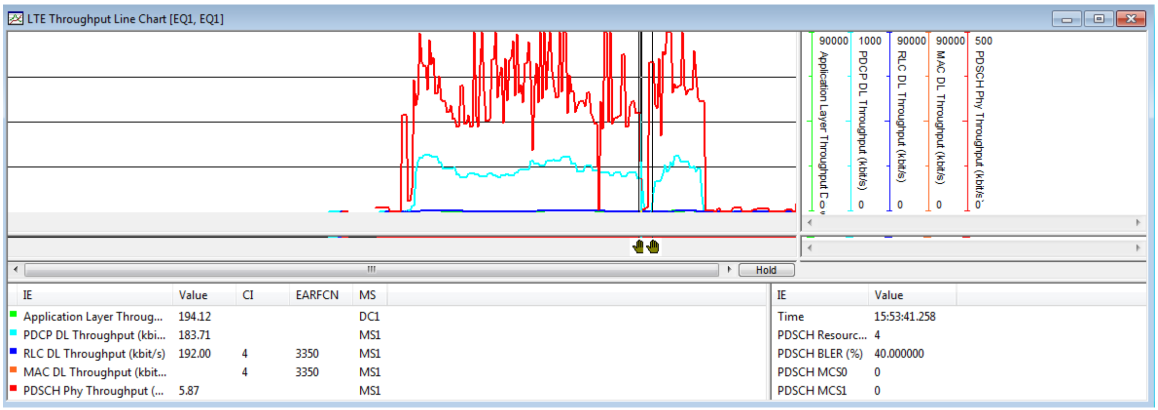


(b)

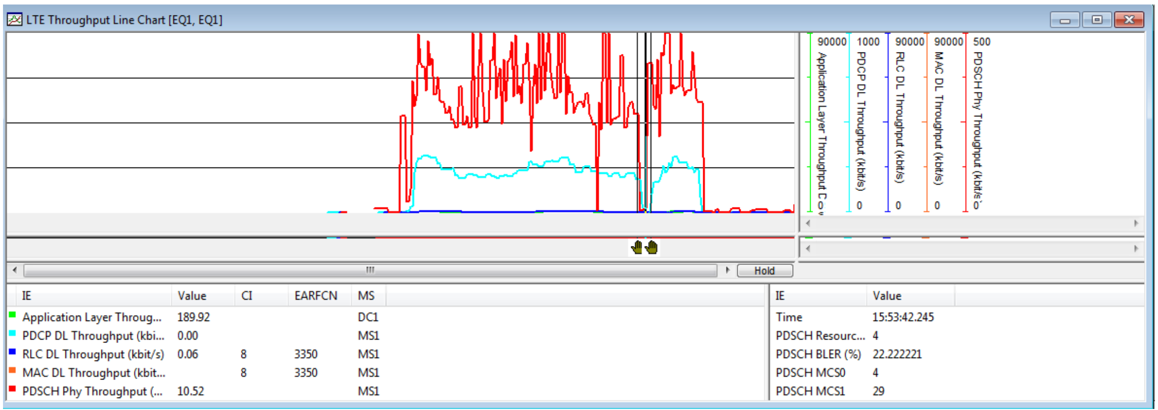


(c)

FIGURE 6.8 – QoE of the Service during normal HO Procedure.

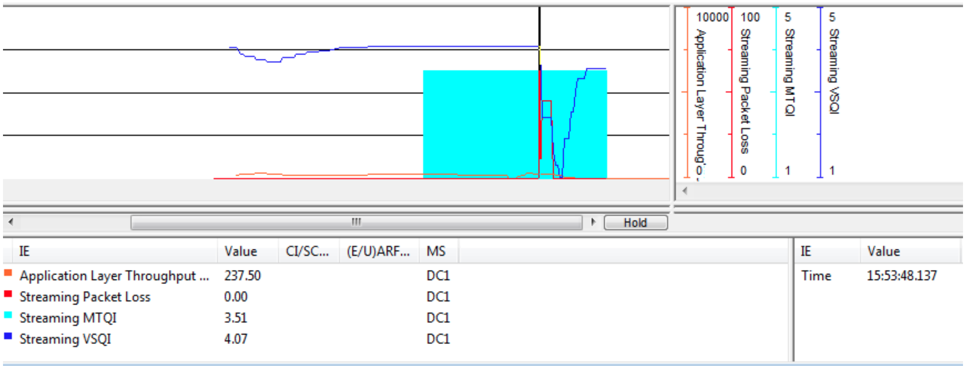


(a) Time Diruption Start

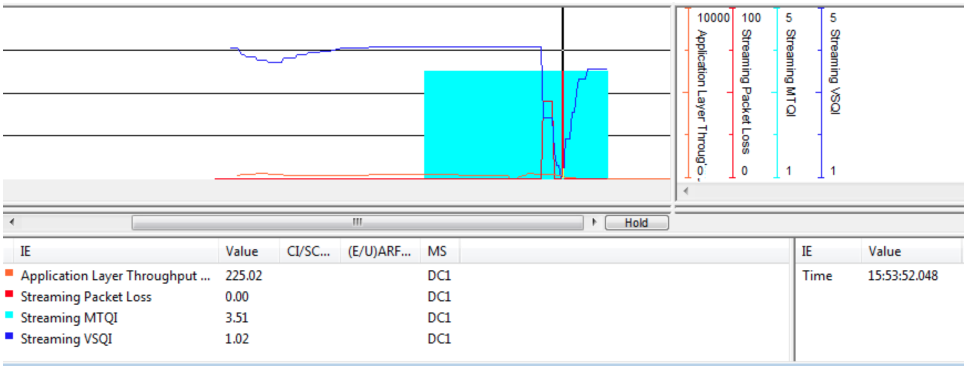


(b) Time Diruption End

FIGURE 6.9 – U-plane Interruption Time with the delay in C-plane.



(a)



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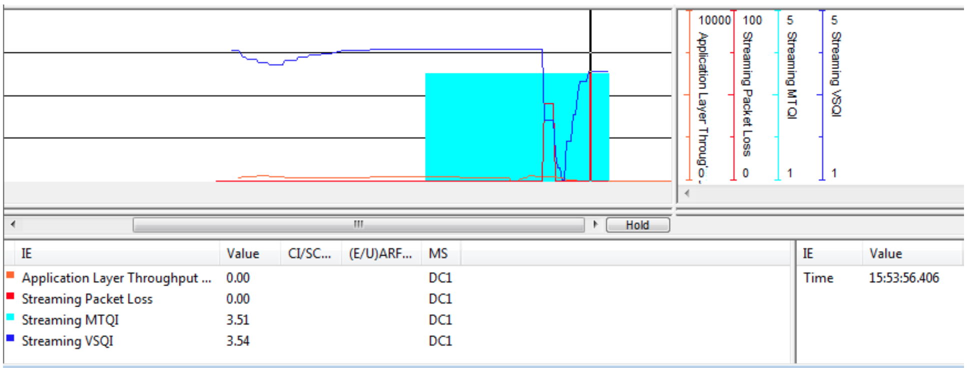
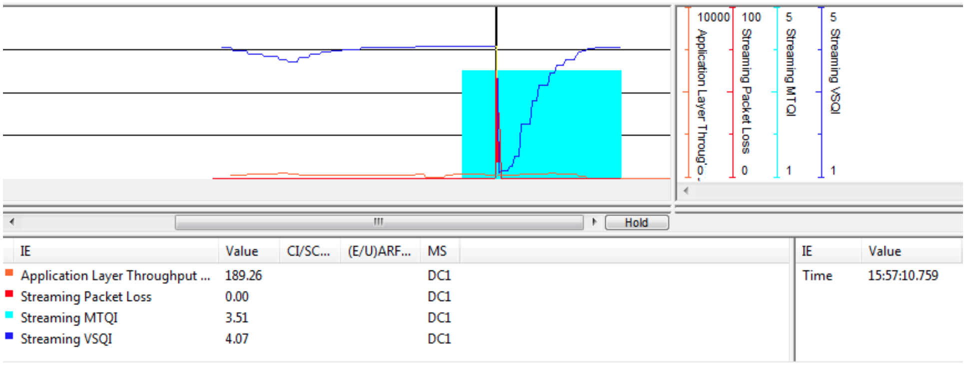
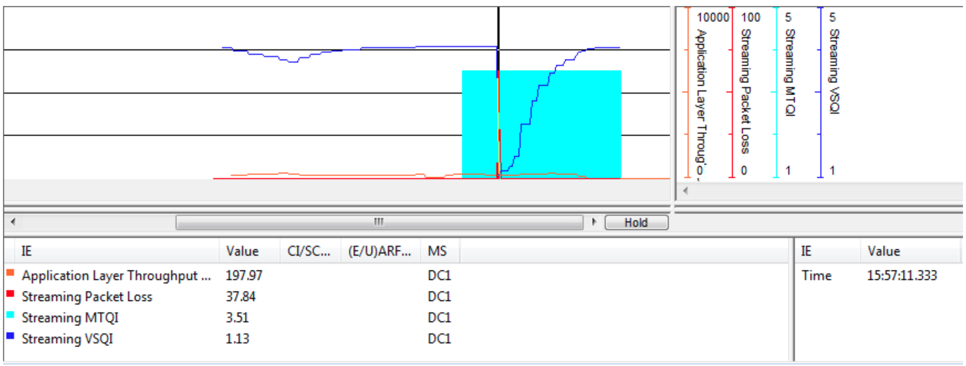


(c)

FIGURE 6.10 – QoE of the Service in case delay is added to the C-plane (first trial).



(a)



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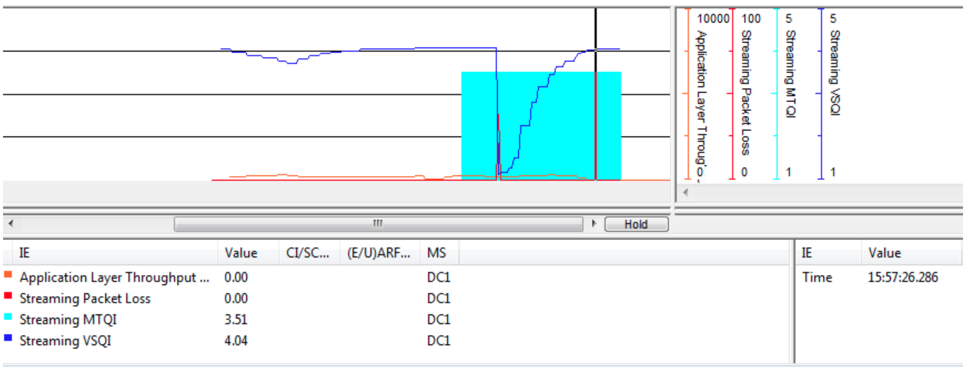


(c)

FIGURE 6.11 – QoE of the Service in case delay is added to the C-plane (second trial).

6.5 Conclusion

In this chapter, we have done the emulation with different scenarios to validate the implementation of eMBMS in OpenAirInterface platform. The in-lab emulations in both link level and system level have been carried out to evaluate the BLER and user throughput of the eMBMS system. Moreover, we have tested the eMBMS transmission in both TDD and FDD system using the traffic generator tool OTG as well as the real VLC video streaming application for creating the source data. The emulation results have validated our eMBMS implementation in a real time system and it is ready to be embedded into hardware for a real environment test. The emulation also allows identifying the time for retrieving every eMBMS signaling information. From the analysis, we know that the total time to collect all control information is one of the main factors contributing to the service interruption time during the handover procedure. Therefore, our method that helps to transfer a large part of these signaling messages to the user during handover period can reduce considerably the interruption time and thus improve the service quality.

In another effort, we have conducted a field-test in real environment to identify the impact of service disruption on the QoE. The outcome of real experiments has confirmed the influence of disruption time on the quality perceived by the users (i.e. the VSQI metric). Particularly, in case the user-plane interruption when not using our method is about one second (which is roughly equal to the disruption in eMBMS service during the handover with the MCCH period of 32 radio frames), the service quality will change from good to very bad level. While if our mechanism is applied, the quality is only dropped a bit, to accepted level. This result has allowed us to conclude that our proposed solution can enhance the quality of eMBMS service perceived by the human users in handover situation.

Chapter 7

Conclusions & Perspectives

7.1 Conclusions

Nowadays, in the era of wireless communication, the services with rich multimedia content have dominated the overall mobile traffic. In respond to the tremendous demand for these services from the customers, the 3GPP standardization body has defined eMBMS as an efficient solution for delivering multimedia data to massive number of users via the cellular network. It is expected to replace other traditional broadcast systems such as DVB, DMB or satellite broadcasting. Realizing the promising future of eMBMS, this thesis aims to give an introduction to the cellular broadcast technology and put emphasis on the performance of eMBMS in the context of mobility. Both theoretical and practical aspects of the broadcast service in LTE network are mentioned in our work. The theoretical part describes the whole picture of the eMBMS service and points out the problems that a user might face to when using eMBMS in a high mobility environment ; whereas the practice part expresses the performance of the eMBMS system in a real-time platform. The major achievements of the thesis are the following :

- **Identify and analyze the mobility-related issues of the eMBMS service** : In this thesis, we have studied in depth the eMBMS standard and classified the situations that affect the reception of LTE-Broadcast service due to the movement of mobile terminals. The detail analysis has clarified the limitation of mobility support procedures for eMBMS in 3GPP standard and in the literature at the moment. It also allows us to recognize the missing information that causes the service disruption and suggests the idea to solve this problem.
- **Propose a complete solution for eMBMS service continuity in LTE/LTE-Advanced network** : Based on the drawbacks of the existing mobility support mechanisms, we provide a method that helps the users to continue receiving their interested eMBMS service in all possible mobility scenarios. According to the proposal, if all the neighboring cells do not belong to the same MBSFN Area with the current cell, the UE will try to look for a candidate that belongs to other MBSFN

Areas in the same frequency layer but still supports the required service. If no suitable candidate was found, the UE continues searching cells in other frequencies to find out the appropriate one. At the last attempt when all neighboring cells in other frequencies do not transmit the needed service, the network will inform the device about the eMBMS service supported by other broadcast technologies. With our solution, the service continuity is guaranteed through different MBSFN Areas and on all frequencies while the current LTE standard only supports for the movement within one MBSFN Area. Moreover, even though the convergence among broadcast technologies is under research, a signaling method is available in our proposal so that the mobile device can change to another radio access technology and receive its ongoing service.

— **Present a mechanism to reduce the media stream interruption time during handover period** : An important objective of mobile network operators is to provide a seamless service (particularly video-related services) to mobile customers in a high mobility environment. The eMBMS service, with its streaming feature, is thus expected to be as smooth as possible in the transition period. However, different from the unicast transmission, there is no data forwarding for an individual user in eMBMS to moderate the impact of the disruption time on the quality of media stream. Additionally, when changing from one MBSFN Area to another one, the UE cannot get the data right after connecting to the target cell, it needs time to gather control informations and identify the position of its required service in the new cell. For these reasons, the eMBMS users will face to a stream interruption when the handover occurs. In order to minimize the influence of the eMBMS signaling retrieving time, we suggest using the Handover Command message to convey the necessary information to the UE. Our mechanism comprises a method of exchanging the eMBMS information between the serving and target eNB in both X2-based and S1-based HO procedure. With this suggestion, the terminal is able to quickly access to the real media data without spending time for listening to eMBMS control messages and hence, the stream disruption time is reduced significantly.

— **Provide a real implementation of eMBMS system in an open-source platform - the OpenAirInterface** : Started from the need to evaluate our proposed solution concerned the service continuity, we have implemented the eMBMS service into real-time OAI platform. Our work also responses to the shortage of a simulation/emulation tool for LTE-Broadcast in the research community. The implementation of eMBMS in OAI platform covers the access stratum in LTE including RRC level, PDCP/RCL/MAC sublayers and full PHY layer. It not only helps us to evaluate our mobility support solution through experiments with high degree of confidence but also is available as a simulator/emulator for other researchers doing further research in eMBMS.

— **Highlight the importance of eMBMS handover on the quality perceived by human users (QoE) in LTE-Broadcast service** : Despite the limitation of OAI platform in supporting X2-based HO procedure, we managed to evaluate the QoE of eMBMS service in mobile scenario by combining the results from eMBMS emulation and the experiment in real cellular network. The OAI emulator was used to determine the stream interruption time while in the field-test, we use TEMS Investigation tool and its VSQI algorithm to derive the QoE estimation for the video stream during handover. The deterioration of VSQI value related to the disruption time in the experiment indirectly reveals the improvement in QoE that we can attain if our method is applied.

In conclusion, this thesis has provided the fundamental knowledge of the multimedia broadcast/multicast service in LTE/4G networks as well as the state of the art for eMBMS mobility support. A solution to ensure the service continuity and improve the service quality is also presented together with the performance evaluation through real experiment.

7.2 Perspectives

Due to the difficulty of implementation in real-time system as well as the time constraint, this thesis is not able to provide a realistic mobility scenario for studying the behavior of eMBMS in full protocol stack (DASH with FLUTE and Raptor Code for FEC) and X2 interface between two base stations. This could be a good direction for extending our work. Furthermore, the Carrier Aggregation feature is under development in our platform and when it is done, we can investigate the impact of frequency switching procedure on the service quality received by the eMBMS users. The ultimate goal of these studies is to build an optimized criteria system based on QoE metric for the network selection procedure taking into account the eMBMS reception.

Although, LTE-Broadcast is about to be commercialized shortly, many aspects are potential for future research to improve the performance of eMBMS system : in physical layer, a longer cyclic prefix (33,3 μs instead of the current 16.7 μs) or MIMO technique for eMBMS transmission should be studied ; An uplink to report the quality and optimize the MBSFN transmission or a dedicated component carrier for eMBMS are also the potential research objectives.

Another direction is the convergence of broadcast technologies. Some studies have been done with the aim to merge two terrestrial broadcast systems : eMBMS and DVB-T2. Such a common broadcast system allows increasing the coverage and service availability as well as ensuring the good service quality for the customers. The hybrid satellite/LTE network also becomes a prominent topic in offering a seamless video delivery system. The cooperation of satellite transmission in LTE eMBMS might be seen as the broadcast service in cellular network with an extra component carrier. A significant adjustment in PHY is envisioned for the switching between these two access technologies.

In a different point of view, we can exploit the usage of LTE-Broadcast in other applications rather than just for conventional download or streaming services. eMBMS can be used as an efficient way to transfer messages for the public safety purpose. The network may need just a small portion of radio resources to send the warning via eMBMS bearer to concerned habitants in a specific area about the natural disasters such as tsunami, earthquake or volcano eruption, etc. The eMBMS's application may appear in the Intelligent Transport System (ITS) as well : new generation vehicles whose operating system connects to the smartphone can get the traffic information from cellular network through eMBMS and then inform to the owners.

Appendices

Annexe A

Résumé de la Thèse en Français

A.1 Introduction

L'évolution des technologies sans fil et la tendance de la mobilité des clients ont fait que le marché des appareils mobiles continue d'évoluer et de croître rapidement. Cette croissance phénoménale d'appareils mobiles conduit à l'explosion du trafic des données mobiles au cours des dernières années. Dans ce volume massif de données, le trafic de la vidéo mobile domine sur les autres types de données. Les services vidéo sur mobile peuvent fournir la vidéo en direct ou sur demande en streaming et leur contenu multimédia peut être offert par les opérateurs de réseau ou par un fournisseur tiers tels que : Skype, WhatsApp, Youtube ou Viber.

Traditionnellement, le service vidéo sur les réseaux cellulaires est prévu dans le modèle de monodiffusion. Cela signifie que même si le même contenu est demandé simultanément par différents utilisateurs mobiles dans la même zone, une ressource dédiée est utilisée pour chaque utilisateur. Cela peut conduire à une surcharge du réseau. Pour résoudre ce problème et apporter une solution à la demande massive pour les services multimédia mobiles, le Third Generation Partnership Project (3GPP) a défini la norme « Multimedia Broadcast Multicast Service » (MBMS) [1] comme une solution pour livrer des contenus multimédia à de nombreux utilisateurs en même temps. MBMS permet de diffuser le même contenu à un groupe d'utilisateur du réseau plutôt que d'envoyer des flux vidéo individuellement à chacun d'eux.

Construit sur le réseau cellulaire 3GPP, MBMS ne nécessite pas un spectre dédié ou un récepteur spécial, ce qui a fait l'échec de MediaFLO [8] - la technologie de Qualcomm. MBMS permet aux opérateurs de déployer le système avec une petite modification dans la structure (principalement pour mettre à jour les logiciels de leurs entités réseau) et permet aux utilisateurs d'accéder au service au moindre coût. Dans les réseaux LTE (Long Term Evolution), MBMS est amélioré en MBMS évolué (eMBMS) et devient une technologie de diffusion ayant un grand prospectif. Grâce à la performance avancée des technologies d'Orthogonal Frequency-Division Multiplexing (OFDM) et Single Frequency Network (SFN), l'eMBMS (aussi connu comme LTE-Broadcast) est maintenant considéré comme le principal concurrent de la technologie déjà bien-connue Digital Video Broadcasting (DVB). Beaucoup de sociétés de télécommunication, y compris Qualcomm, Samsung, Ericsson, Huawei, Alcatel et d'autres, ont décidé d'adopter eMBMS comme une solution efficace et à faible coût pour fournir du contenu multimédia. La coopération versatile entre les fabricants des circuits intégrés, les fabricants d'appareils mobiles et les opérateurs de réseaux mobiles du monde entier ainsi que l'intérêt des fournisseurs de services de médias a souligné l'énorme potentiel de l'eMBMS sur le réseau LTE dans les années à venir. Comme autres services de streaming vidéo dans les réseaux sans fil, eMBMS fait face à deux défis principale :

— Assurer la continuité de service dans un environnement à haute mobilité.
— Garantir la meilleure qualité pour les utilisateurs pendant le mouvement.

Au début de la thèse, l ;eMBMS était encore dans la phase de normalisation et la continuité de service n'a pas été prise en charge. En raison de la caractéristique des eMBMS, un service particulier n'est disponible que dans certaines régions qui contiennent un nombre limité de stations de base. Ces stations de base sont synchronisées pour effectuer la transmission à l'unité de réseau de fréquence. Le fait que toutes les stations de base ne transfèrent pas de service eMBMS peut provoquer l'interruption du service. Ainsi, lorsqu'un terminal mobile se déplace dans le réseau, il peut entrer dans une station de base qui ne prend pas en charge l'eMBMS et il ne peut plus continuer à recevoir le service. Cette limitation de la norme 3GPP d'une part et le rôle important de la technologie de diffusion LTE sur le marché de streaming vidéo d'autre part nous ont motivés dans la recherche pour soutenir la continuité de service avec l'eMBMS.

Le but ultime des opérateurs et des fournisseurs de services est de donner le meilleur service eMBMS aux utilisateurs. Dans la dernière décennie, le terme Qualité de l'expérience (QoE) a été défini et est devenu le critère le plus important pour évaluer la qualité du service des médias, en particulier pour les services vidéo. Suivant la tendance, dans cette thèse, nous allons examiner la qualité du service eMBMS perçue par les utilisateurs finaux.

Les principaux objectifs de cette thèse sont ceux de proposer une solution pour soutenir la continuité de service et de gérer la qualité du service évolué de diffusion multimédia dans les réseaux LTE et LTE-Advanced. Plus précisément, nous cherchons à résoudre ces problèmes suivants :

— *L'absence d'un simulateur en temps réel / émulateur pour eMBMS.* Par rapport à notre connaissance, il y a peu de véritables implémentations d'eMBMS à l'heure actuelle dans la communauté de recherche. Par conséquent, nous avons intégré le système eMBMS dans une plateforme de radio temps réel en open-source - l'OpenAirInterface [21]. Notre mise en œuvre des eMBMS fournit un outil de simulation / émulation pour évaluer la performance du service avec un haut degré de confiance par rapport à des outils de simulation habituelles. Il permet à d'autres chercheurs de comparer leurs études liées au service eMBMS tel que le nouvel algorithme d'allocation de ressources ou la transmission MIMO.
— *La discontinuité du service eMBMS lorsque les utilisateurs se déplacent dans le réseau.* La continuité du service est toujours un problème crucial dans la communication sans fil. Pour résoudre ce problème des eMBMS, une nouvelle méthode est proposée pour maintenir le service dans un contexte de mobilité. Cette méthode couvre tous les scénarios de mobilité et assure la réception d'eMBMS pour les uti-

lisateurs à travers les différentes cellules, à travers des zones MBSFN différentes et sur des différentes fréquences. De plus, en utilisant cette technique, les terminaux mobiles ont également la possibilité de se connecter à d'autres systèmes de diffusion pour recevoir les services eMBMS intéressés.

— *L'interruption du service pendant de la procédure de handover intercellulaire.* Un flux de média discontinu peut causer la gêne aux utilisateurs, en particulier dans les services de streaming en direct. Dans un contexte que eMBMS va être commercialisé très prochainement, nous avons conçu un mécanisme pour améliorer encore les performances du service de diffusion LTE dans un environnement à haute mobilité. L'objectif de ce mécanisme est de minimiser le temps d'interruption de service quand un utilisateur se déplace d'une cellule à une autre. Profitant de l'échange d'informations entre la cellule de desserte et ses voisins ou entre des entités du réseau, certains eMBMS contrôlent les messages qui seront envoyés à l'équipement mobile pendant la période de handover. De cette manière, il n'est pas nécessaire de les recueillir après la connexion à la nouvelle cellule. C'est un moyen efficace de réduire le temps d'acquisition des informations de signalisation nécessaires, ce qui permet aux utilisateurs d'accéder aux médias en temps réel plus rapidement.

A.2 eMBMS - Le Service de Broadcast en rèseau LTE

Avoir été mis en place depuis les spécifications 3GPP Rel. 6, le service de diffusion multimédia multicast est encore en développement (Rel. 12). Ce chapitre donnera aux lecteurs une vision globale du service de diffusion (ou broadcast) dans les réseaux cellulaires LTE. Nous allons commencer avec de nouveaux définitions en service MBMS, et puis l'architecture du système ainsi que le transport des flux medias en LTE Broadcast sont introduits.

A.2.1 Les nouveaux termes d'eMBMS

La zone de service Broadcast/Multicast : La zone dans laquelle une émission ou un service de multidiffusion est disponible. La zone de service multidiffusion peut représenter la zone de couverture de l'ensemble du PLMN, ou partie (s) de la zone de couverture de la PLMN. C'est la somme de toutes les zones locales de diffusion / multidiffusion offrant le même service.

La zone de service MBMS : La zone géographique dans lequel les données d'une session MBMS spécifique (ou service) sont envoyées. Chaque session MBMS individuelle d'un service MBMS peut être transférée à un autre zone de service MBMS (c'est-à-dire que les zones de service MBMS sont indépendantes les unes des autres et peuvent se chevaucher). Cette zone de service MBMS est le même ou est un sous-ensemble de zone de servicede diffusion ou de multidiffusion.

Le service Broadcast/Multicast ou service MBMS : un service point-à-multipoint unidirectionnel dans lequel les données sont transmises de manière efficace à partir d'une source unique pour plusieurs utilisateurs dans la zone de service de diffusion/ multidiffusion associée.

La session de Broadcast/Multicast ou MBMS : Une réception continue et le temps de réception réduit d'un service de diffusion / multidiffusion ou MBMS. Un service

MBMS ne peut avoir qu'une session à tout moment et il pourrait se composer de plusieurs sessions successives. Pour ne pas manquer entre le service et la session, on peut considérer qu'un service MBMS est une chaîne de télévision alors que la session MBMS est un programme dans ce canal.

L'MBMS sur un réseau isofréquence (MBSFN) : Une technique qui permet à plusieurs cellules de transmettre le même contenu simultanément en utilisant une forme d'onde identique. Les cellules participant à la transmission MBSFN doivent être synchronisées étroitement dans le temps. Une transmission MBSFN depuis plusieurs cellules dans une zone MBSFN est considérée comme une seule transmission par des utilisateurs mobiles.

La zone synchronisation de MBSFN : Une zone où tous les eNodeB (ENBS) peuvent être synchronisés et exécuter des transmissions MBSFN. Les zones de synchronisation MBSFN sont indépendantes de la définition de la zone de service MBMS.

La zone MBSFN : Une zone de MBSFN se compose d'un groupe de cellules au sein d'une zone synchronisation de MBSFN dans un réseau. Ces celluales sont coordonnés pour réaliser une transmission MBSFN. Sauf pour les cellules réservées de la zone MBSFN, toutes les cellules dans une zone MBSFN contribuent à la transmission MBSFN et annoncent sa disponibilité. Il pourrait y avoir jusqu'à 256 zones de MBSFN différentes distinguées par leur identité et ils sont statiquement configurés par le réseau. Les domaines de MBSFN peut chevaucher les uns les autres, dans ce cas, une station de base appartient à multiples zones MBSFN. Le nombre maximum de zones de MBSFN qu'une station de base pourrait soutenir dans le réseau LTE est huit.

Le cellule réservée de la zone MBSFN : Une cellule dans une zone MBSFN mais elle ne contribue pas à la transmission MBSFN. Pour éviter les interférences, les cellules de ce type sont autorisées à utiliser la ressource réservée pour la transmission MBSFN pour d'autres services, mais seulement avec le pouvoir restreint.

A.2.2 L'architecture de l'eMBMS

L'architecture de réseau mobile est évoluée avec de nouvelles entités, comme le montre dans Fig. A.1, pour soutenir l'opération MBSFN et le service eMBMS.

Le Centre de services de diffusion/multidiffusion (BM-SC) est l'entité qui relie le réseau mobile et les fournisseurs de services. BM-SC sert de point d'entrée pour le trafic de données MBMS IP depuis les fournisseurs de contenu multimédia et il prendra soin de la distribution de données MBMS intérieur de réseau mobile.

La passerelle MBMS (MBMS Gateway) est une nouvelle entité logique créé en EPS pour le service MBMS. MBMS-GW pourraient être soit une entité du réseau autonome reliant le BM-SC et RAN ou être une partie de l'autre entité de réseau. Il est impliqué à la fois dans la signalisation et les données délivrant partie de eMBMS. Dans le plan d'utilisateur, le service MBMS-GW envoie le paquet de données MBMS directement à l'E-UTRAN à l'aide de la multidiffusion IP.

Le multi-cellulaire/multidiffusion coordination entité (MCE) est défini dans E-UTRAN assidûment pour le plan de contrôle. Le réseau peut déployer MCE dans un seul nœud physique ou l'intégrer comme une partie d'un eNB. Il est considéré comme l'élément clé de eMBMS dont la tâche est d'organiser la répartition des ressources de tous les ENBS dans une même zone MBSFN. Il assure la configuration appropriée dans la couche MAC de ces ENBS sorte que les mêmes blocs de ressources radio sont allouées aux services

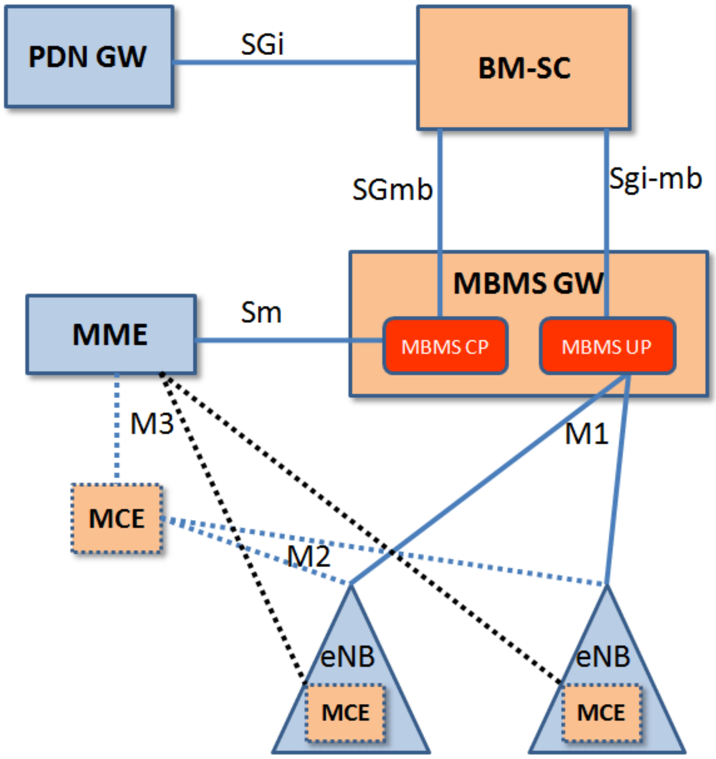


FIGURE A.1 – eMBMS Network Architecture with 2 MCE deployments.

MBMS spécifiques à réaliser l'opération MBSFN. Un autre travail de MCE fait le contrôle d'admission pour les sessions MBMS, soit il décide d'établir le support radio pour une nouvelle session MBMS ou non créer le support pour une session qui nécessite plus de ressources que celles de radio sont disponibles. En outre, il contrôle la programmation de canaux de transport MBMS dans une zone MBSFN.

A.2.3 Le transport des données dans eMBMS

En réseau LTE, le service eMBMS est multiplexé dans le temps avec un service unicast, ce qui signifie que une ressource radio peut soit transmet le trafic eMBMS (signalisation ou l'utilisateur des données) ou le trafic unicast. Dans un trame de LTE, au maximum six des dix sous-trames pourrait être utilisé pour fournir des données de eMBMS. Dans chaque sous-trame eMBMS, une ou deux premier symbole OFDM est réservé pour le trafic de monodiffusion. La raison est parce que les utilisateurs mobiles exigent encore l'information sur la planification et le contrôle commande de puissance pour les sens montant dans la transmission unicast.

Concerne les protocoles pour l'eMBMS, SYNC et DASH sont deux des plus importants. Pour réaliser l'opération MBSFN avec efficacité spectrale supérieure, tous les eNBs dans une zone MBSFN doivent être étroitement synchronisés en temps pour transférer le contenu eMBMS. Afin de s'assurer que tous les eNBs diffusés exactement le même contenu, le protocole de synchronisation (SYNC) est appliqué dans le plan de l'utilisateur (U-Plane) sur l'interface M1. Le MBMS-GW envoie à toutes les stations de base qui participant à la transmission de eMBMS le paquet de données avec les eMBMS informations de protocole de synchronisation. Ces informations de SYNC permet les eNBs de déterminer le moment de transmission des trames radio ainsi que détecter la perte de paquets.

Une évolution a été prise placé dans l'industrie de streaming vidéo : l'Hypertext Transfer Protocol (HTTP) protocoles de streaming basé comme Apple HTTP Live Streaming (HLS), HTTP Dynamic Streaming Adobe (HDS) ou Microsoft SmoothStreaming ont dominé le Temps réel traditionnelle Transport Protocol (RTP) de protocole de streaming en fonction. La standardisation 3GPP et Moving Picture Experts Group (MPEG) a également présenté le Dynamic Adaptive streaming via HTTP (DASH ou MPEG-DASH) protocole pour la prestation de services de streaming DASH clients à partir de serveurs HTTP.

Il ya deux concepts doivent être compris dans DASH : la présentation des médias Description (MPD) et segment. Un segment est un petit morceau de contenu des médias et le MPD est un fichier manifeste sous forme de XML donnant les informations de ces segments. Cette information se compose de caractéristique de média (résolution vidéo, la durée et le débit, l'adresse ou URL pour obtenir le segment et le calendrier correspondant. Dans MBMS Télécharger Livraison Méthode, un ou plusieurs objets sont livrés par MBMS porteur à plusieurs récepteurs. Nous pouvons prendre avantage de la méthode de téléchargement de livrer les segments de DASH et fichier MPD aux clients utilisant le protocole FLUTE.

Le MPD, qui fournit l'information pour obtenir les segments de DASH, joue le même rôle avec la Table Fichier de livraison (FDT) dans FLUTE qui décrit les attributs des objets transportés dans une session. Pour adapter le DASH eMBMS, l'adresse URL correspondant à un segment de fichier MPD est associé à un objet de la livraison dans le FDT. Le MPD pourrait être envoyé aux utilisateurs via la description du service de l'utilisateur (USD), tandis que les segments de DASH sont transférés sous forme de fichiers FLUTE (objets) utilisant le protocole UDP / IP. Au côté du récepteur (ce est à dire du terminal), FLUTE est capable de cartographier les objets reçus dans les caches HTTP. De telle manière, la partie client DASH dans le terminal mobile examinera ces objets / fichiers sont fournis sur le protocole HTTP et il peut récupérer ces fichiers en utilisant le fichier MPD. Ce point conduit à l'idée de combiner le DASH et DASH eMBMS traditionnelle sur HTTP pour permettre une transition transparente entre la diffusion et d'une connexion unicast.

Allant plus bas dans la pile de protocoles, deux nouvelles voies logiques sont définis pour soutenir eMBMS : la voie de commande MBMS (MCCH) pour eMBMS signalisation informatioin et le canal de trafic MBMS (MTCH) pour les données de l'utilisateur eMBMS. Dans une région MBSFN, toutes les informations de contrôle liés aux services de eMBMS dans ce domaine de MBSFN est donnée dans un message. Ce message de contrôle est effectué sur le canal MCCH tandis que les données de l'utilisateur sont transférés sur les chaînes de MTCH. Ces deux canaux logiques sont mappés sur un canal de transport appelé Multicast Channel (MCH).

A.3 La continuité du Service

Pour offrir un meilleur service eMBMS, le soutien la mobilité des utilisateurs dans les réseaux LTE/LTE-Advanced devient une nécessité. En raison de la caractéristique de la transmission MBSFN, il pourrait y avoir de multiples types de transfert intercellulaire comme ci-dessous :

1. Le handover intra zone MBSFN : le terminal se déplace vers une nouvelle cellule qui appartient à la même zone MBSFN avec la cellule actuelle.
2. Le handover interzone MBSFN : les zones MBSFN soutenu par la cellule de source et la nouveau cellule sont différents.
3. Le handover inter fréquence : le terminal passe à une autre fréquence ou un autre porteur (peut-être dans le même ou différent eNB).
4. Le handover inter Technologie d'Accès Radio (RAT) : l'utilisateur passe à un autre système de diffusion pour continuer à recevoir le service.

Actuellement, la norme 3GPP fournit seulement la continuité de service pour l'eMBMS dans le cas du handover inter fréquence. En outre, nous avons également constaté certains travaux présentés par d'autres chercheurs dans [47–49]. Ces travaux soutiennent aussi bien le handover interzone MBSN que le handover inter fréquence mais aucun d'entre eux prend en charge tous les cas énumérés ci-dessus. Cette partie vise à introduire une solution complète pour la continuité de service eMBMS dans tout type de handover.

L'idée principale de notre méthode est prise en compte des informations des services diffusés par les cellules voisines lors de la sélection des candidats pour le transfert intercellules ou de la procédure de resélection de cellule. Sachant où les services souhaités sont disponibles aidera l'eNB source à choisir la bonne eNB cible afin de remettre l'UE ou de l'aide pour connecter à une cellule appropriée. La différence clé de notre méthode en comparaison avec les autres, c'est que nous concentrons sur les cellules voisines et les services eMBMS qu'ils soutiennent au lieu des services transmis sur d'autres fréquences. Notre solution proposée va orienter l'UE vers les cellules voisines qui ont ses services intéressés à la même fréquence avec la cellule actuelle avant de chercher sur les autres fréquences. Pour être plus précis, nous proposons qu'une station de base diffuse l'identité de toutes les zones MBSFN et services eMBMS (ServiceID ou TMGI) dont elle prend en charge ainsi que ceux pris en charge par ses voisins. Cette information est appelée *eMBMS Mobility Support Information* et elle contient la correspondance entre l'ID de la cellule voisine, la fréquence, l'ID de la zone MBSFN et l'ID du service MBMS ou TMGI. La cellule actuelle peut recueillir cette information soit d'une entité de réseau soit de ses voisins, puis l'attacher à SIB13 ou SIB15 avant leur diffusion aux utilisateurs.

En recevant le SIB13 / SIB15 modifié, un terminal veille (en mode Idle) va comparer l'ID du service fourni par les cellules voisines et celui de son service intéressé. S'il y a plus d'une cellule voisine en charge de ce service, celle qui travaille à la même fréquence avec la cellule actuelle et qui a une meilleure signal sera dans la première priorité.

Pour la mobilité en mode connecté, une procédure d'handover sur réseau contrôlé est appliquée, c'est-à-dire l'eNB servant décidera quand et où remettre terminal mobile. Si la cellule de desserte veut assurer la continuité des eMBMS pour un utilisateur mobile, il doit sélectionner la cellule cible qui fournit les services de eMBMS étant reçus par cet

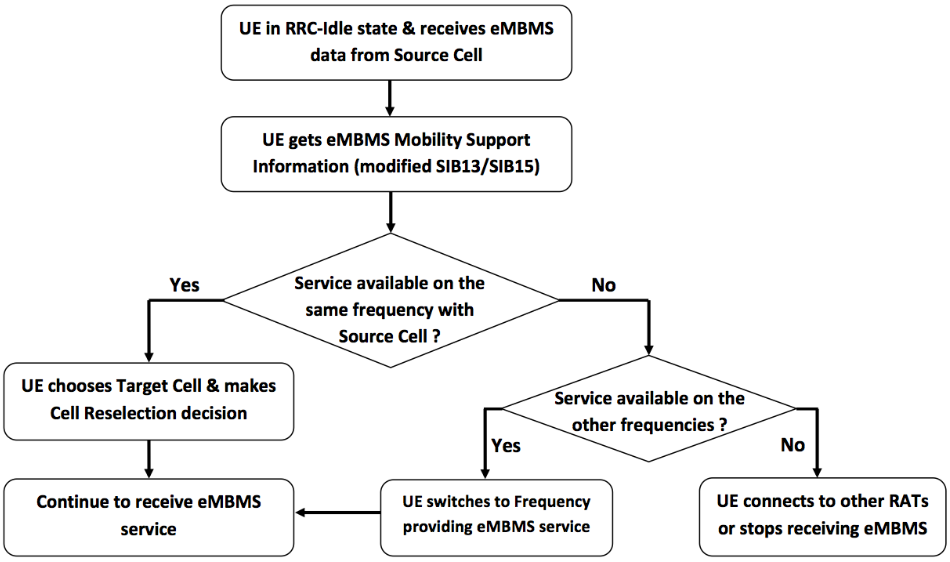


FIGURE A.2 – eMBMS Mobility Procedure for RRC-Idle Users.

utilisateur. Afin de choisir le bon candidat dans la décision de transfert, la cellule actuelle a besoin de savoir deux choses :

1. Les services pris en charge par les cellules voisines (*l'eMBMS Mobility Support Information*).
2. Les services eMBMS que l'UE reçoit ou intéressé à recevoir (dénommé *l'eMBMS Service Interest*)

La cellule source a déjà le premier élément après l'acquisition de ses voisins via l'interface X2 ou d'une autre entité du réseau que nous avons proposé plus tôt. Ce dernier est toujours manquant ; donc l'UE devrait le fournir à la cellule de desserte, peut-être dans un message RRC comme l'indication d'intérêt MBMS (le MBMS Interest Indication message). Ce service d'intérêt eMBMS transmet simplement une liste d'identifications des services que l'UE reçoit ou dont l'UE est intéressé à recevoir et les zones MBSFN correspondant. Ceci pourrait être envoyé à l'eNB servant en même temps que les rapports de mesure quand un événement déclencheur se produit ou lorsque l'UE modifie son intérêt.

En utilisant *l'eMBMS Mobility Support Information*, *l'eMBMS Service Interest* et les rapports de mesure de l'UE, l'eNB source peut choisir la cellule soutenant les services nécessaires pour les utilisateurs. Un point à noter dans notre méthode est que les candidats qui travaillent sur la même fréquence avec la cellule courante ont une priorité plus élevée que ceux de la fréquence différente. Dans le cas où l'eNB cible est dans une zone MBSFN différente que celle de la cellule source, afin d'éviter la nécessité de lire le message MCCH dans le nouveau eNB, le message MCCH peut être envoyé de l'eNB cible à l'UE via l'eNB servant.

Pour résumer, nous avons présenté la solution qui assure la continuite de service eMBMS pour les utilisateurs par le biais des cellules différentes, dans les zones MBSFN différentes et sur des fréquences différentes. En outre, notre méthode apporte également la possibilité pour les utilisateurs d'eMBMS de se connecter à d'autres technologies d'accès radio (RAT)

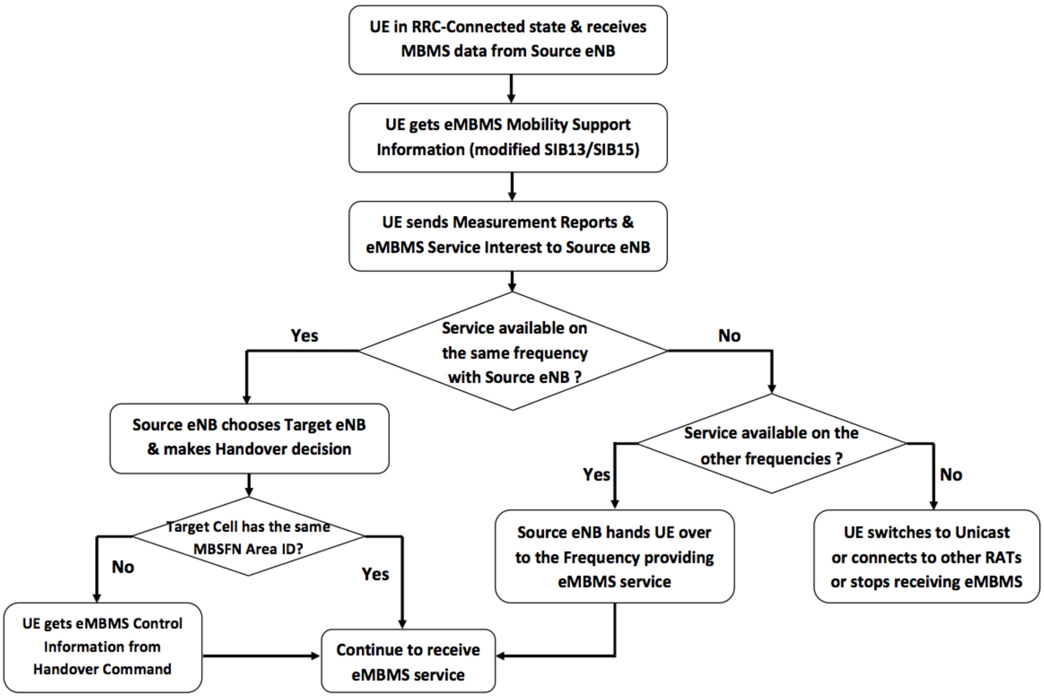


FIGURE A.3 – eMBMS Mobility Procedure for RRC-Connected User.

tels que le DVB ou système de satellite afin que les utilisateurs puissent toujours obtenir le service MBMS même en dehors de la couverture du réseau cellulaire. Imaginons une situation où un service eMBMS est diffusé sur le réseau LTE, sur le satellite et sur le système DVB-NGH en même temps, le mobile a également la capacité de recevoir des contenus multimédia à partir de l'ensemble des technologies ci-dessus. Au cas où cet appareil reçoit les données vidéo et de passer à une région éloignée où il n'y a pas de signal cellulaire disponible, il va perdre la connexion et le service sera arrêté. Heureusement, les signaux des satellites ont une très bonne couverture extérieure et si l'utilisateur peut en quelque sorte savoir que le même service est également diffusé par le satellite, il peut passer à ce système pour continuer à recevoir son service intéressé. La question ici est de savoir comment les utilisateurs savent quelle technologie est capable de fournir son service requis ? Avec notre méthode, le réseau peut donner cette information à des mobiles lors de la transmission de l'information sur le support de la mobilité eMBMS avec un petit modification : d'autres technologies de diffusion seront représentées par une valeur prédéfinie "cell ID'" de sorte qu'ils sont considérés comme les cellules voisines « spéciales ».

A.4 La continuité du flux média

Quand la continuité est assurée, un autre aspect important doit être envisagé, c'est la qualité de service pendant la période de transition. Une mesure couramment utilisée pour évaluer la performance des services multimédia au cours de la transition est le temps d'interruption. Dans la transmission unicast, pendant la procédure de transfert intercellules, l'eNB source peut transmettre les données à l'eNB cible, donc le terminal peut continuer à recevoir ces données une fois connecté à la nouveau eNB. Cependant, il n'y a pas de mécanisme de transmission dans l'eMBMS et les terminaux doivent écouter les informations de signalisation après avoir connecté à une nouvelle cellule. Le flux multimédia est donc peut être interrompu un certain temps lorsque l'UE se transforme en une nouvelle cellule. Notre objectif est de proposer un mécanisme pour réduire le temps d'interruption du service eMBMS pendant le transfert. Pour ce faire, nous devons d'abord identifier les facteurs qui influent la perturbation.

Lorsque l'équipement de l'utilisateur se déplace vers une nouvelle station, qui fonctionne sur la même fréquence avec la station de base actuelle mais qui appartient à une zone MBSFN différente, il doit effectuer la procédure resélection de cellule (dans l'état de idle) ou la procédure de transfert intercellulaire (dans l'état connecté). Après, les informations de signalisation pour le service eMBMS doit être prélevé avant que l'utilisateur continue la réception de service. Par conséquent, le temps d'interruption est à peu près égale à la durée de resélection de cellule / transfert intercellulaire plus le temps pour récupérer des informations d'eMBMS.

Dans le cas où la fréquence de l'eNB cible est différente de celle de l'eNB source ou les UEs changent à un autre porteur , la synchronisation doit être effectuée avant tous les autres acquisition. Il est clairement observé que le temps d'interruption de service est composé de la durée de synchronisation et le temps de collecter d'information de contrôle.

En bref, nous pouvons en déduire que l'acquisition des informations de signalisation d'eMBMS impacte le temps d'interruption de service dans la plupart des scénarios de mobilité. De ce fait, une solution pour diminuer le temps d'interruption est réduire du temps de récupération des informations d'eMBMS. Mais quelles sont ces informations ?

Dans le service eMBMS, avant de recevoir les données média réelles, les terminaux ont besoin d'obtenir les informations suivantes :

— Le bloc d'information du système type 13 - SIB13 : Il contient les informations des zones MBSFN supportées par cet eNB. Cependant, le rôle principal de SIB13 est d'apporter l'information la plus importante aux terminaux - le message MCCH. Ce SIB13 est diffusé avec une fréquence variant de 8 à 512 trames.
— Le message du canal de contrôle - message MCCH : Le contenu de ce message donne aux UEs la position des sous-trames qui sont attribuées pour chaque groupe de services eMBMS et le détail de chaque service dans ces groupes. L'un des messages MCCH correspond à une et une seule zone de MBSFN et il est transmis périodiquement tous les 32, 64, 128 ou 256 trames.
— L'élément de contrôle au MAC niveau de multidiffusion ordonnancée - MSI : Il est créé dans la couche MAC où plusieurs MTCHs et peut-être le MCCH sont multiplexés en un canal de transport. Le MSI montre la position exacte et l'ordre de chaque service eMBMS transférés au sein d'un canal de transport (ou dans un groupe). Il est muni des périodes de 8, 16, 32, 64, 128, 256, 512, 1024 trames radio.

A partir de ces éléments ci-dessus, la durée totale dont un terminal a besoin pour récupérer toutes les informations nécessaires pour accéder à un service eMBMS particulier, noté T_{eMBMS}, est exprimée par la formule suivante :

$$T_{eMBMS} = t_{SIB13} + t_{MCCH} + t_{MSI} \tag{A.1}$$

où t_{SIB13}, t_{MCCH} and t_{MSI} est le temps d'acquérir le SIB13, le message MCCH et l'élément de contrôle MSI, respectivement.

A partir de l'analyse que nous avons présentée, afin de minimiser l'impact du temps de récupération des signalisations d'eMBMS, choisir la configuration avec une valeur minimale pour tous les paramètres périodiques serait une solution. Cependant, avec cette solution, le T_{eMBMS} est encore long. Une idée intuitive pour réduire encore plus cette quantité est d'éliminer un ou plusieurs composants qui contribuent à la somme. Ceci est équivalent en quelque sorte à fournir les informations essentielles aux terminaux afin qu'ils les obtiennent avant la connexion à la nouvelle cellule. De manière classique, la cellule cible transfère ces messages de commande aux terminaux mobiles, dans notre solution ce travail est fait par la cellule servant.

Quand un événement déclencheur se produit, l'eNB source va commencer la procédure de handover pour les terminaux qui sont en mode connectée. Profitant de la connexion entre la cellule source et la cellule cible pendant le handover, nous suggérons de transférer l'information d'eMBMS soutenue par la cellule cible au terminal mobile. Pour être plus précis, lorsque la station de base actuelle envoie le message de Handover Request à une station de base cible pendant un transfert intercellulaire de X2, il doit indiquer l'identité des services que l'UE reçoit ou intéressées à recevoir et les zones MBSFN respectives. Cette information est *l'eMBMS Service Interest*. L'eNB source doit déjà obtenir cette information et l'insérer comme un nouvel élément d'information (IE) dans le message de Handover Request. Si cet IE est absent, cela signifie que l'UE n'est pas intéressé au service eMBMS.

En réponse, si la cellule cible accepte la demande d'Handover, en plus des paramètres requis pour la création de la connexion de monodiffusion normale, nous proposons l'eNB cible d'ajouter son SIB13 et MCCH dans le message de Handover(HO) Command de sorte que l'UE n'aient pas besoin de les recueillir une fois connecté à la cellule cible. De cette manière, le temps d'acquisition d'eMBMS peut être réduit considérablement. Mais la volonté de mettre ces données supplémentaires dans le message de Handover Request et le message d'acquittement de réception va-t-il allonger la durée de transfert ? La réponse est : il n'affecte guère la procédure parce que la taille de ces messages supplémentaires

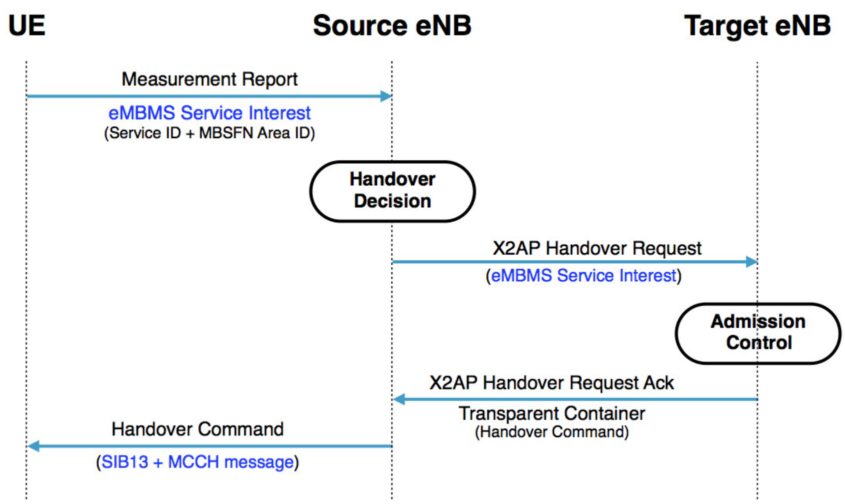


FIGURE A.4 – Modification in X2 Handover procedure.

sont assez petites par rapport au le message de Handover Request ou Handover Request Acknowledge (par exemple dans la mise en œuvre en vertu de notre plate-forme en temps réel, un message MCCH codé est inférieure à 12 octets tandis que l'Handover Command au normale 3GPP Rel-9 est environ 80 octets). Toutefois, avant d'envoyer la demande de remise, la source eNB doit vérifier cet eNB et l'eNB cible sont dans la même zone MBSFN qui fournit les services dont ils sont intéressés ou non. S'ils sont dans la même zone MBSFN, l'UE ne se rend pas compte de la mobilité en terme de services eMBMS et donc, la source n'ajoutera pas le nouveau IE dans le message de Handover Request pour empêcher l'eNB cible d'inclure MCCH et SIB13 dans le message de Handover Command.

En éjectant l'ID de la zone MBSFN et le service utilisateur requis dans la demande, la cellule cible sait quel message MCCH (une cellule peut appartenir à plus d'une zone MBSFN, c'est-à-dire la cellule cible pourrait avoir plusier messages MCCH), qui convient d'insérer dans la réponse. Avec cette conception, seul le message approprié MCCH est transféré à l'équipement utilisateur nécessaire et donc, il est optimisé en termes d'économie d'énergie.

La stratégie similaire pourrait être appliquée lorsqu'il n'y a pas de connexion l'X2 entre le station de base de source et de cible. Dans la procédure de transfert basé sur S1 [56], l'eNB source envoie tout d'abord le message de Handover Required à MME qui permettra de transférer la demande de Handover à l'eNB cible avec les informations de contexte UE. Puis comme dans le transfert de X2, l'eNB cible contrôle l'admission et répond à la demande par un accusé avec le message de Handover Command. Ce message arrive à l'équipement utilisateur après le passage à travers la cellule source.

Pour soutenir le service eMBMS, le même concept est utilisé, ce qui signifie que la nouvelle IE avec l'identifiant de service MBMS et l'ID de la zone MBSFN correspondant sera transférée de l'UE à la cellule source, puis à la cellule cible via l'MME. Dans l'autre sens, le message SIB13 et MCCH passerait de cible eNB (ou MCE) pour MME, l'eNB source et enfin l'UE tel que décrit dans Fig. A.5.

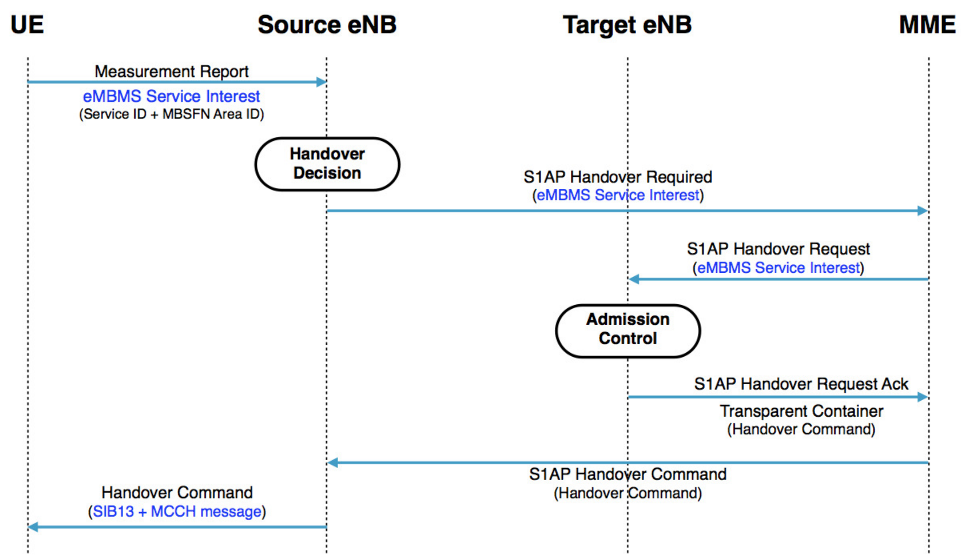


Figure A.5 – Modification S1 handover procedure.

Contrairement en mode RRC-connecté, le terminal inactif dans le réseau LTE n'a pas une connexion dédiée avec la station de base, il ne peut écouter que le canal de diffusion commun. Pour cette raison, afin de fournir les informations relatives d'eMBMS à l'UE avant qu'il campe à une autre cellule, la cellule actuelle doit diffuser l'information de ses voisins. Cependant, l'eNB courant ne sais pas s'il est un utilisateur eMBMS ou non, ni quand un utilisateur se prépare à la procédure de re-sélection de cellule. Par conséquent, il doit diffuser l'information d'eMBMS de ses voisins périodiquement en pleine puissance pour assurer que toute UE dans sa couverture peut obtenir ces informations quand ils ont besoin. En outre, le courant eNB ne sais pas quel service l'UE reçoit ou intéressé à recevoir, il doit donc diffuser les SIB13s et tous les messages MCCH soutenus dans toutes ses cellules voisines. En résultat, une grande quantité d'informations doivent être transférés fréquemment par une station de base, ce qui n'est évidemment pas une méthode efficace pour troquer le délai de quelques eMBMS utilisateurs. C'est la raison pour laquelle nous ne modifions pas la norme et laisser les utilisateurs inactifs recueillent l'informations d'eMBMS dans la cellule cible après avoir campé à elle.

A.5 L'implémentation de l'eMBMS sur un Système Temps Réel

A partir de l'absence d'une mise en œuvre réelle d'eMBMS et la nécessité d'un outil de simulation/émulation pour évaluer la solution proposée, nous avons mis en place le système eMBMS sur une plate-forme open-source qui est développée dans notre laboratoire - l'OpenAirInterface [21]. Les modifications et extensions suivantes ont été réalisées dans la mise en œuvre du système LTE standard pour soutenir le service eMBMS :

- Nouvel élément d'information qui indique les sous-trames de transmission des eMBMS est ajouté à SIB2.
- Les informations de contrôle d'eMBMS - SIB13 et message MCCH - ont été créés au niveau de RRC.
- Au niveau PDCP et à la sous-couche RLC, l'interface avec RRC et MAC a été ajusté pour soutenir le transport d'eMBMS.
- Dans la couche MAC, le planificateur a été modifié en tenant en compte des ressources allouées pour le service eMBMS. En plus, un nouvel élément de contrôle contenant les informations de planification MTCH est généré.
- À la couche physique, les exigences particulières pour l'eMBMS sont ajoutées ou modifiées, y compris le nouvel ensemble de symbole de référence, le nouveau générateur de séquence de brouillage et l'interface entre MAC et PHY.

Après avoir étudié à fond la norme, nous commençons à mettre en œuvre le service eMBMS sur la plate-forme OpenAirInterface. Nous avons choisi le modèle de déploiement MCE distribué, c'est-à-dire que l'MCE est considéré comme une partie de l'eNB. La raison principale du choix du modèle MCE distribué est que nous voulons réduire la complexité de l'implémentation et il est plus pratique pour nous de le mettre en œuvre dans la plate-forme de l'OAI pour étudier et évaluer la performance du système d'eMBMS. Le choix d'implementation dans un réseau LTE réel dépend des besoins des opérateurs et du type de déploiement du réseau.

A.5.1 Le niveau de contrôle des ressources radio (RRC)

Basé sur la structure de l'eMBMS, les nouveaux composants et fonctions pour le service eMBMS sont ajoutés à la plate-forme OAI. Dans le plan de contrôle, le bloc du système d'information SIB13 et le message MCCH sont générés à l'unité de contrôle des ressources radio (RRC) du côté eNB. D'autre part, un élément d'information (IE) en lien avec les sous-trames réservées à l'eMBMS est également ajouté dans le SIB2.

Dans le SIB13, en dehors des informations de notification de changement du MCCH, une séquence de composants contenant la configuration de la zone MBSFN est construite. Chaque composant correspond à une zone MBSFN avec les valeurs des paramètres spécifiées dans [41]. La chaîne de 6 bits indiquant la position du sous-trame transmet le message MCCH pour une zone MBSFN est représenté par une valeur hexadécimale dans la plate-forme. Dans notre plate-forme, le SIB2 et SIB13 sont mis dans la même fenêtre SI (avec le SIB3 ainsi), c'est-à-dire que ces blocks d'informations sont créés en même temps lors de la configuration d'une instance eNB.

Un nouveau IE nommé MBSFN-SubframeConfigList est ajouté à SIB2. Cette extension dans SIB2 est introduite pour informer les terminaux mobiles sur les sous-trames réservées pour la transmission de MBMS en liaison descendante. Cela aide le récepteur à ne pas se faire confondre par les transmissions de données eMBMS en essayant de décoder les signaux spécifiques de référence de la cellule et PDCCH. Il est à noter que les messages MCCH sont également transmis sur les sous-trames de MBMS, donc, une conformité a besoin d'être faite entre la position de MCCH dans SIB13 et le motif de sous-trame de MBMS dans SIB2.

Un ou plusieurs messages MCCH, l'information principale de signalisation du service eMBMS sont générés conformément à la norme 3GPP standard avec quelques remarques ci-dessous :

— Le MCCH est mis à jour chaque fois qu'un nouveau service / session vient ou un service existant se termine.
— Les ressources indiquées dans SIB2 sont pour toutes les zones MBSFN soutenues dans l'eNB correspondant, d'où le motif de sous-trame de MBMS dans chaque message MCCH devrait être une partie de celui de SIB2. Au cas où l'eNB appartient à une seule zone MBSFN, un seul message MCCH est créé et le modèle de sous-trame dans ce message doit être identique à celui dans SIB2.
— Les sous-trames admissibles pour MBMS en TDD et FDD sont différentes, donc la valeur d'une chaîne de bits représente généralement une sous-trame différente dans TDD et FDD (par exemple, la chaîne 010 000 en TDD signifie que la sous-trame # 4 est une sous-trame MBMS tandis que dans FDD, la sous-trame # 2 est réservée aux eMBMS).

Semblable à d'autres systèmes d'informations de transmission unicast, des informations de contrôle eMBMS sont transférées directement à partir de la RRC à la sous-couche MAC via le canal logique BCCH et MCCH comme décrit dans Fig. A.6 . Une autre tâche de l'unité RRC est configurer les porteurs de données pour les services d'eMBMS au PDCP et la sous-couche RLC en utilisant les paramètres indiqués dans les messages SIB13 et MCCH.

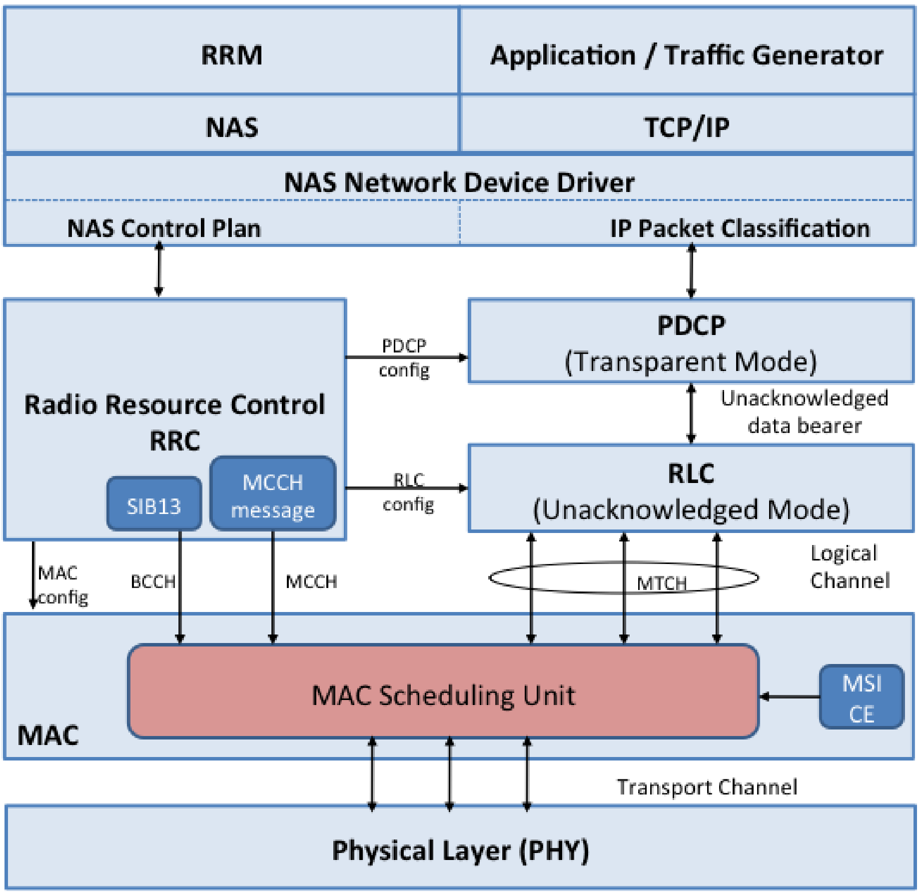


FIGURE A.6 – eMBMS protocol stack in OAI.

A.5.2 Le niveau PDCP et niveau RLC

Pour transporter les données de l'utilisateur d'eMBMS, nous avons implémenté la protocoles complète dans le plan de données selon la norme au niveau 2 y compris PDCP, RLC et la sous-couche MAC. Comme indiqué dans [41], le protocole des paquets de données convergentes (PDCP) n'est pas utilisé lorsque le service eMBMS est diffusé dans l'E-UTRAN. Le PDCP est utilisé pour la compression / décompression de l'entête (ROHC-Robust Header Compression) et le chiffrement / déchiffrement des données unicast, cependant, pour le trafic eMBMS, PDCP est juste une boîte vide qui reçoit les paquets de données de la couche supérieure (IP) et les transmet à la sous-couche inférieure. Dans la plate-forme OAI, le PDCP fonctionne en mode transparent (mode TM), ce qui signifie que l'unité de données de protocole (PDU) est remise directement à la sous-couche de contrôle de liaison radio (RLC) du côté eNB (ou à la couche supérieure du côté du récepteur) sans l'entête et bande-annonce annexées.

Au niveau du contrôle de liaison radio, eMBMS utilise le mode sans accusé de réception (UM) et une entité RLC-UM est créée pour un bearer de données (une session). Entité RLC met les paquets reçus de PDCP dans le tampon RLC. Une instance RLC est responsable de la segmentation de la SDU reçue en plus petits paquets en fonction de la demande de l'ordonnanceur MAC. La taille du paquet est déterminée par la valeur MCS utilisée pour ce canal de transport. Quelques bits pour l'entête RLC sont également ajouté dans la charge utile d'origine avant que l'instance RLC-UM les envoie à la sous-couche MAC par les canaux logiques MTCH au côté de l'émetteur. Une procédure inverse est appliquée du côté du récepteur afin de rassembler ces segments.

Pour différencier de la transmission unicast, un tableau d'entités eMBBMS RLC est spécialement créé sur l'OAI et il est indexé par l'identité du service et de la session. Comme cela, la longueur du champ de la séquence des nombres pour l'entité RLC d'eMBMS est égale à cinq bits.

A.5.3 Le niveau Contrôle d'accès au support (MAC)

Lorsque les paquets d'informations de contrôle et de données arrivent à la couche MAC de l'eNB, ils seront multiplexés en différents canaux de transport avant d'être transmis à la couche physique. Pour être plus précis, le MCCH et MTCHs seront projetés sur différents MCH à la sous-couche MAC. En fonction du nombre de canaux de MCH (groupes de services eMBMS), un ou plusieurs éléments de contrôle MSI (CE) est périodiquement créé pour ces canaux. Chacun de ces CEs contient les informations d'allocation des ressources pour tous les services dans le groupe correspondant telles que l'identité de canal logique (LCID) et la position de la dernière sous-trame pour chaque service.

Une nouvelle unité de planification pour multiplexer le MCCH et MTCHs est mise en œuvre dans ce niveau. Un point à remarquer, c'est qu'une simple Unité de protocole de données MAC devrait transporter des données d'un seul MCH. Cela signifie que les données de plusieurs services (MTCHs) qui ont la même exigence de qualité et peut-être que le message MCCH pourrait être transféré dans un PDU MAC. Un autre point est, en UETRAN, seules les cellules mixtes (transmettant à la fois unicast et broadcast/multicast) sont prises en charge pour eMBMS ; par conséquent, l'ordonnanceur MAC devrait être modifié afin que la planification pour eMBMS n'affecterait pas le trafic unicast. Pour ce faire, la fonction d'ordonnancement d'"eMBMS utilise les paramètres fournis par la CRR et vérifie si une sous-trame est réservée pour eMBMS ou non. Si cette sous-trame est allouée pour eMBMS, pas de données à diffusion individuelle peuvent être programmées à l'exception de la notification d'affectation de liaison montante qui est transportée sur PDCCH dans les deux premiers symboles OFDM de cette sous-trame.

Utilisant le résultat de la première étape, MAC va créer l'élément de contrôle MSI, recevoir le message MCCH de RRC ou requêter les données de l'utilisateur MTCH de RLC. La taille de bloc transport (TBS) et le système de codage et modulation (MCS) sont également calculés lors de la procédure de planification.

Les tâches suivantes sont effectuées par l'ordonnanceur eMBMS à la couche MAC de l'émetteur (c'est-à-dire du côté eNB) :

- Basé sur le nombre d'unités des données du service MBMS (SDU) qui sont transférées dans cette sous-trame, le MSI est créé en conséquence. Un MSI est constitué d'un ou plusieurs éléments de base, chacun d'entre eux représente un MTCH ou un MCCH. Dans un élément de base, il existe deux domaines, l'un pour l'identification du canal logique (en LCID) du MTCH ou MCCH, et l'autre désigne la dernière sous-trame contenant des données de ce canal.
- La TBS est calculée sur la base du schéma de codage et modulation (MCS) valeur

comme spécifié dans [61]. Si une MCH exprime à la fois le trafic utilisateur (MTCH) et le trafic de signalisation (MCCH ou MSI), le MCS du trafic de signalisation sera attribué. La TBS est utilisé pour demander la quantité de données à partir du tampon eMBMS RLC.

— Si MCCH est transmis dans cet sous-trame, le eMBMS SDU est demandée à partir du niveau RCC et se il ya MTCHs, les SDUs contenant les données qui viennent du RLC sont utilises. Le planificateur mettra ces SDU dans la mémoire tampon de PDU dans l'ordre comme indiqué dans MSI.
— - Avant d'envoyer la PDU de la couche PHY sur voie de transport MCH, MAC crée l'en-tête (header) en fonction du nombre de SDU reçues et des éléments de commande dans cette sous-trame. Pour le canal MCH, la PDU MAC utilise le même format que dans le canal DL-SCH.

La sous-couche MAC dans le côté récepteur (UE) n'a pas la tâche de planification, mais il n'a pas besoin de connaître la position des sous-trames MBMS commander couche PHY pour décoder le PMCH. Ces informations sont stockées à la fois MAC du terminal peut décoder le message et SIB13 MCCH.

A.5.4 Le niveau Physique

A la couche physique, la plupart des procédures PHY pour eMBMS sont identiques à celles de la transmission unicast en liaison descendante. Le calcul de redondance cyclique (CRC), le système de codage de canal (turbo codeur avec taux de codage égal tiers) et l'adaptation de débit pour MCH et le canal de transport DL-SCH sont identiques [62]. Dans le processus d'embrouillage, il existe une petite différence dans le calcul de la valeur initiale de séquence de brouillage pour brouiller eMBMS parce que la transmission de eNB participant est MBSFN dépend de la région ID MBSFN à la place de l'ID de la cellule comme d'habitude.

Comme dans le canal partagé de liaison descendante physique (PDSCH), trois schémas de modulation (QPSK, 16QAM et 64QAM) sont disponibles pour PMCH. Néanmoins, seulement quatre MCS (2, 7, 9 et 13) valeurs peuvent être utilisées dans la sous-trame portant un message MCCH ou élément de commande MSI tandis que le transport de sous-trame avec des données d'utilisateur eMBMS, toutes les valeurs de MCS (0-28) sont admissibles. La plus grande différence dans PHY pour eMBMS est les signaux de référence qui sont générés à des fins d'estimation de canal. Ces signaux de référence sont transmis à la zone MBSFN sur le port d'antenne 4 avec un motif spécial donné dans [5] et son générateur de séquence est également défini dans le même document.

A la sous-trame MBMS, le signal de référence spécifique à la cellule peut être généré à région non MBSFN (sur OAI, nous mettons en œuvre deux premiers symboles de la sous-trame pour cette région). Le PMCH peut être transmis dans la partie restante de la sous-trame. Le préfixe cyclique prolongé est toujours utilisé pour PMCH tandis que deux symboles de contrôle peuvent utiliser le préfixe cyclique normal. Dans ce cas, il y aura un trou dans la transmission de liaison descendante entre les symboles d'envoi individuel et MBSFN. En plus de l'espacement du sous-porteur de, un espacement du sous-porteur réduit $\Delta = 7{,}5$ kHz est, peut être utilisé pour la transmission MBSFN. Cependant, dans l'OAI, nous n'utilisons que le sous-porteur de 15 kHz pour MBMS.

A.6 L'expérimentation et les Résultats

A.6.1 La Validation de l'Implémentation

Pour évaluer la performance du système eMBMS mis en œuvre, nous utilisons l'outil d'émulation construit au-dessus de la plate-forme OpenAirInteface. La plate-forme matérielle utilisée pour l'émulation du niveau de liaison est un ordinateur portable équipé d'un processeur Core i7 Intel exécutant l'émulateur OAI et la pile de protocoles utilisant le système Linux/Ubuntu 12.04. Nous avons effectué des mesures en temps réel en mode souple pour l'exécution LTE dans la trame FDD pour une bande passante de 5MHz, dans une simple topologie de réseau cellulaire composé d'un eNB et un UE statique pour mesurer performance du meilleur scénario. Cette émulation utilise la couche physique complète (PHY) sur le canal de propagation spécifique à un environnement d'évanouissement par multi-trajets, comme indiqué dans [63].

Avec l'émulation au niveau du système, nous avons déployé OAI dans deux machines physiques équipées de processeur Intel (R) Core (TM) i3 3.1GHz exécutant la version Ubuntu 12.04 LTS : une machine est utilisée pour une instance OAI d'eNB tandis que l'autre machine héberge plusieurs cas OAI d'UE. Ces deux machines sont connectées via une liaison Ethernet. Pour le trafic d'eMBMS dans ces émulations, nous générons avec une des deux méthodes suivantes. Dans la première méthode, nous utilisons un outil appelé OpenAirInterface - générateur de trafic (OTG) [64]. Cet outil est un outil de génération de trafic réaliste au niveau des paquets pour les scénarios d'application émergeante. L'autre façon de générer les données de l'utilisateur est utiliser un application réelle. Plus précisément, on utilise l'application de transmission des flux VideoLAN (VLC) en continu pour transférer une vidéo d'une machine (dénommée l'émetteur) à l'autre (le récepteur) à travers la pile de protocole OAI. Dans la machine de l'émetteur, la vidéo est trans-codée au format H.264 et envoyé sur le protocole Real-time Transport (RTP) / User Datagram

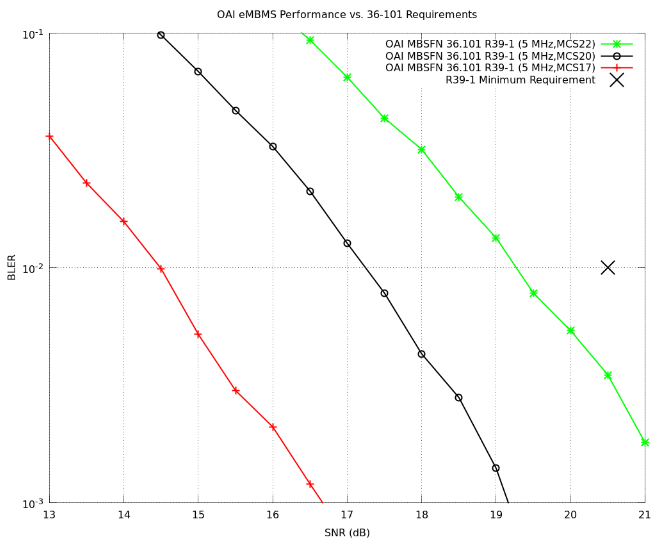


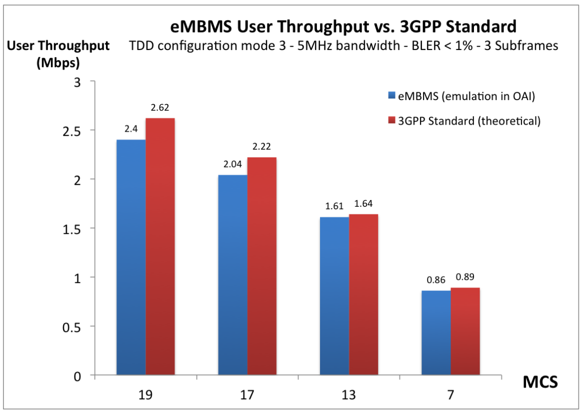
FIGURE A.7 – BLER for eMBMS Transmission in OAI.

Protocol (UDP) à une adresse multicast sur le bearer d'eMBMS.

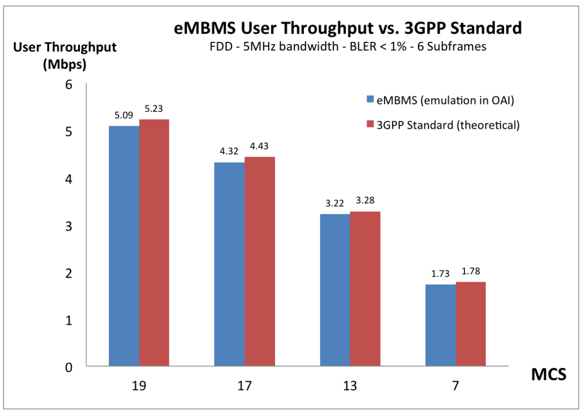
Selon [63], le minimale exigence de BLER pour la transmission eMBMS dans les deux configurations FDD et TDD est de 1% au SNR = 20,5 (dB) avec le canal de référence R.39-1 et la taille du bloc de transport (TBS) correspondante à la schémas de codage et modulation (MCS) est égale à 20. Avec cette émulation, le scénario avec un seul groupe de service (une SMI) et d'un service eMBMS (MTCH) est appliqué.

Nous avons fait la simulation avec la même condition que dans l'exigence standard (canal R.39-1) pour troisschémas de codage et modulation différente (MCS = 17, 20, 22). Comme nous pouvons observer dans la Fig. A.7, la transmission eMBMS dans l'émulation obtient un gain d'environ 3 dB au BLER = 1% par rapport à l'exigence standard (le point dans le graphe de x).

Un avantage majeur de l'utilisation de LTE pour eMBMS est que les débits binaires pour les services en temps réel tels que le streaming vidéo, vidéoconférence ou les jeux interactifs sont beaucoup plus élevés que pour MBMS dans le réseau 3G (UTRAN). Par conséquent le débit du terminal est un indicateur important lors de l'évaluation des performances eMBMS. À l'heure actuelle, en mode TDD, notre plate-forme de l'OAI prend uniquement en charge le mode de configuration de TDD 3 qui permet de transmettre



(a) TDD



(b) FDD

FIGURE A.8 – eMBMS User Throughput in OAI.

le maximum de données en trois sous-trames eMBMS (# 7, # 8 et # 9). Ainsi, quand nous exécutons l'émulation en mode TDD, seulement trois sous-trames sont allouées pour l'eMBMS tandis qu'avec FDD, toutes les six sous-trames admissibles peuvent être utilisées. Les résultats d'émulation pour le débit en mode TDD eMBMS avec la différence des valeurs MCS sont présentés dans Fig. A.8.

Dans la figure, les barres rouges représentent le débit du terminal du système eMBMS calculé par OTG sur le côté récepteur tandis que les barres bleues représentent le débit de transmission maximum pour l'eMBMS calculées à partir des spécifications 3GPP [61]. Il y a un peu de différences entre ces deux valeurs dans chaque configuration MCS qui peut être expliqué comme suit : tout d'abord, le débit théorique est la capacité de transmission de la couche physique alors que le débit du terminal est calculé après que données soient envoyées à OTG à partir de PDCP. Par conséquent, une petite quantité de ressources est utilisée pour les en-têtes à la couche 2. D'autre part, la perte de paquets lors de la propagation sur l'interface d'air (canal modélisé) affecte également le débit du terminal. Le résultat de BLER satisfait à l'exigence minimale de la norme 3GPP et les débits du terminal obtenus dans différentes valeurs de MCS sont très proche à la valeur théorique ont validé notre mise en œuvre des eMBMS dans l'OAI.

A.6.2 L'Évaluation de la Qualité d'Expérience

Au cours des dernières années, QoE est devenu la métrique la plus appropriée pour évaluer la qualité des services de vidéos. Par conséquent, nous voulons aussi utiliser cette métrique pour évaluer notre solution sur la continuité du service eMBMS. En raison de la limitation en temps et l'insoutenabilité de l'OpenAirInterface pour la procédure de handover base sur l'interface de X2, nous ne pouvons pas réaliser l'émulation dans OAI pour évaluer l'efficacité de notre méthode d'aide à la mobilité pour le service de broadcast en LTE. En plus, il n'y a toujours pas de framework d'eMBMS accessible qui nous permet d'intégrer et d'évaluer notre solution avec QoE.

Pour ces raisons, nous devons trouver une façon indirecte pour évaluer de la mise en valeur du service eMBMS pendant la période de transition de zone MBMS lors de l'application de notre méthode. L'expérimentation est décrite par deux étapes suivantes :

Étape 1 Dans la première étape, nous essayons de calculer le temps d'interruption d'un service eMBMS lorsqu'un terminal mobile effectue la procédure de handover. L'interruption de flux dans ce cas est principalement conduite par la procédure de transfert intercellulaire et le temps pour récupérer les informations de contrôle eMBMS. Puisque l'objectif est d'évaluer notre solution de soutien à la mobilité, nous nous concentrons sur la mesure de la perturbation qui est causée par le temps de récupération des messages de signalisation d'eMBMS. Avec notre méthode proposée, ces messages de contrôle de la cellule cible sont fournis à l'équipement utilisateur au cours de la handover, par conséquent, le temps d'interruption est réduit d'une quantité correspondant. Nous allons estimer cette quantité de temps grâce à l'émulation dans la plateforme OAI.

Étape 2 Pour voir comment la satisfaction d'un utilisateur est affectée par l'interruption du flux de médias pendant le transfert, nous lançons un essai dans un réseau cellulaire reel. Dans cette expérience, nous utilisons un modem USB 4G/LTE Huawei qui se connecter à un ordinateur portable comme un utilisateur mobile. Etant placé dans une voiture en mouvement avec la vitesse de 50-60 km/h, ce terminal mobile utilise le lecteur VLC pour demander une vidéo sur l'Internet. La voiture ira à la zone de chevauchement entre deux stations de base et le transfert sera déclenché. Pendant ce temps, le terminal mobile reçoit toujours le flux vidéo et l'impact de la procédure de handover sur la QoE du service de streaming est mesuré par la méthode d'Indication de qualité de la vidéo en streaming (VSQI) [35]. L'expérience est menée à Sophia-Antipolis, en sud de la France, en coopération avec Com4Innov, un société de télécommunications [67]. Le service de vidéo en streaming se fait grâce à des équipements de la société Com4Innov intégrés dans l'infrastructure de l'opérateur de réseau tandis que la mesure de QoE est donnée par l'outil d'enquête TEMS [36] dans la métrique de VSQI. Normalement, dans la procédure de transfert intercellulaire LTE, la transmission de données est appliquée pour transférer des paquets à partir de l'eNB source à l'eNB cible, puis vers le terminal mobile. Le but de la transmission de données est d'éviter la perte de paquets et modérer l'interruption de service. Dans le but d'imiter le service de diffusion, la fonction de transfert ne sera pas utilisée dans notre expérimentation.

Pour mesurer le temps pour récupérer des informations de contrôle d'eMBMS dans la plate-forme OAI, nous utilisons l'émulation avec deux machines physiques : la première héberge une instance eNB et dix instances d'UE sont générées dans la seconde machine. Dans cette expérimentation, nous recueillons le temps de récupération des messages SIB13, MCCH et MSI de toutes les instances d'UE et calculons le temps moyen pour recevoir chaque type d'informations de signalisation d'eMBMS. Le temps de récupération est calculé à partir du moment où un équipement utilisateur est actif (allumé) jusqu'au moment où il décode avec succès les informations de contrôle respectives. Avec une valeur de la période de répétition MCCH, nous faisons l'émulation pour 1000 fois et chaque fois, les UEs sont programmés pour être activés à un moment aléatoire suivant la distribution uniforme. Dans l'émulation, le SIB13 est répété toutes les huit trames de radio et la MSP est réglé sur 16 trames pendant que la période MCCH varie de 32 à 256 trames. Les résultats sont donnés dans le Tableau A.1.

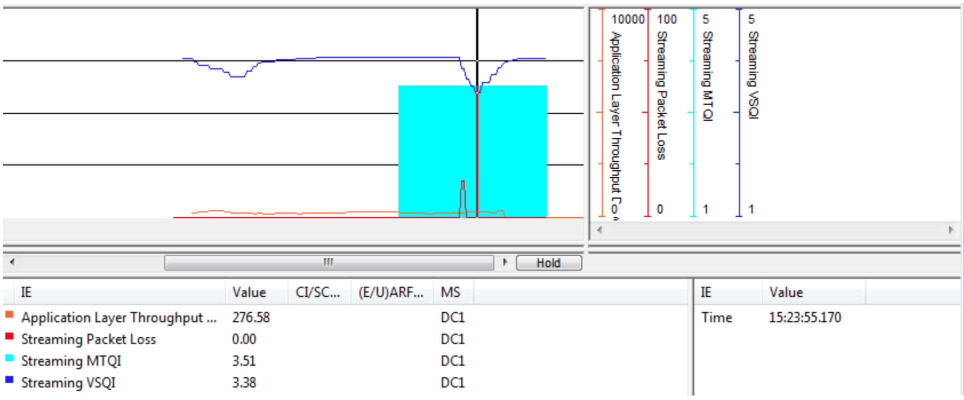
Table A.1 – Retrieving Time for eMBMS Control Information.

MCCH period	SIB13		MCCH		MSI	
	Average	Deviation	Average	Deviation	Average	Deviation
32 (RFs)	4.03	2.24	16.34	9.17	32.31	18.25
64 (RFs)	4.03	2.23	32.20	18.42	48.21	27.31
128 (RFs)	4.01	2.24	64.24	36.79	80.47	46.24
256 (RFs)	4.02	2.27	128.27	73.78	144.42	82.85

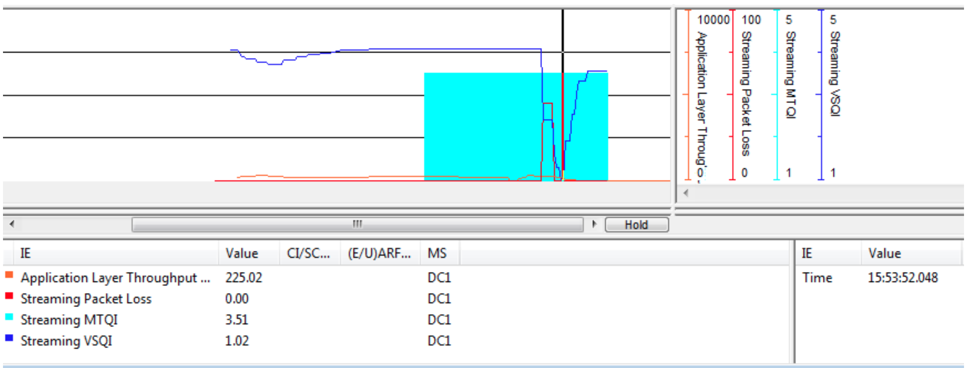
Regardez les résultats d'émulation, nous pouvons réaliser que le temps pour récupérer SIB13 et MCCH est environ la moitié de leurs périodes de répétition tandis que le MSI est obtenu environ un MSP après la réception du message MCCH. C'est parce que l'équipement utilisateur met en marche de façon aléatoire au cours de la période de SIB13 / MCCH et à la fin de la période, il peut décoder le message. Considérant que, nous programmons le MCCH et MSI dans la même sous-trame, par conséquent, l'UE doit attendre le prochain MSP pour obtenir le MSI.

A partir de ces résultats, nous pouvons en déduire que si les messages SIB13 MCCH sont transférés à l'UE qui est en mode RRC-Connecté au cours de la procédure de handover, en moyenne, l'UE peut économiser un temps égal à la moitié de la période MCCH (avec l'hypothèse que les informations ajoutées n'affectent pas le temps de décodage). En d'autres termes, le temps d'interruption de service peut être réduit d'une quantité équivalente à la moitié de la période MCCH. Par exemple, dans le cas où le système utilise la période de répétition de 256 trames radio pour les MCCH, avec notre solution, le temps de perturbation peut être réduit d'une quantité de $2560/2 = 1280$ ms ou 1,28 s. Cette quantité est assez importante pour un service de streaming et du résultat dans notre test sur le terrain avec un réseau 4G/LTE reel, nous verrons comment cela pourrait influencer la qualité d'un flux de diffusion en termes de QoE.

Nous avons effectué l'essai sur le terrain plusieurs fois avec deux scénarios. Dans le premier, le dispositif mobile demande un service de transmission en continu à partir d'un serveur sur Internet. Lors de la réception de la vidéo, l'appareil sort de la couverture de la cellule actuelle et le transfert se passe de la façon dont il devrait être. Dans le deuxième scénario, toutes les conditions restent les mêmes comme elles étaient dans le test précédent, sauf que nous avons mis un retard dans le plan de contrôle dans la procédure de transfert de sorte qu'une perturbation sera créé dans le plan d'utilisation avec une quantité



(a) No delay in C-plane (With our solution)



(b) With delay in C-plane (Without our solution)

FIGURE A.9 – QoE of the eMBMS Service during Handover.

correspondante à celle que nous recevons lors de l'émulation. Par exemple, avec le retard de 600 ms d'un aller-retour au plan de contrôle, le temps d'interruption est d'environ 1 seconde (approximativement égale à la perturbation donnée par l'émulateur OAI au cas où notre solution n'est pas appliquée et la période de répétition MCCH est 256 trames radio).

Avec les deux scénarios d'expérimentation, nous identifions le temps perturbé du flux multimédia par la mesure du débit utilisateur sur l'appareil mobile. L'enquêteur TEMS [36], l'outil leader de l'industrie pour le dépannage, la vérification, l'optimisation et la maintenance des réseaux sans fil, est utilisé pour faire la mesure. Intégré à la méthode VSQI, cet outil est également en mesure d'estimer la qualité du service et de générer la valeur QoE du service de streaming en temps réel. Cette valeur est réconfortante avec MOS (il prend la valeur de 1 à 5).

Au cours du handover, il y a un moment où le débit à couche physique du récepteur est tombé à zéro, ce qui signifie que l'utilisateur ne reçoit pas de données de la source à ce moment. L'intervalle où le débit reste à zéro correspond à l'interruption de flux dans le plan d'utilisation. D'après le résultat de la mesure dans le premier scénario, cette perturbation du flux vidéo dans le premier test est d'environ 90 à 100 ms et elle est à peine reconnue dans le lecteur vidéo. Cette quantité d'interruption correspondante au cas où notre méthode est appliquée avec la période de répétition de MSI est égale à 16 trames radios. La QoE, ou pour être plus exact, la valeur de VSQI du service pendant la période transfert a diminué un peu, mais reste encore au niveau acceptable (de 4 à 3,4) comme dans la figure A.9(a). Dans le deuxième scénario, lorsque nous ajoutons un retard au plan de contrôle, le temps d'interruption dans les plans d'utilisation augmente à une seconde (notre solution n'est pas utilisée). Et comme prévu, avec cette perturbation, la valeur VSQI a chuté dramatiquement de 4 à 1, ce qui est une très mauvaise qualité (la figure A.9(b)). Ce résultat prouve clairement que notre mécanisme peut réduire le temps de défaillances des eMBMS et peut améliorer la qualité perçue par les utilisateurs eMBMS durant la procédure de transfert intercellulaire.

A.7 Conclusion et Perspective

Conclusion Cette thèse donne l'introduction à la technologie de diffusion cellulaire et souligne sur la performance d'eMBMS dans le contexte de mobilité. Les deux aspects théoriques et pratiques du service de broadcast dans le réseau LTE sont mentionnés dans notre travail. La partie théorique décrit la figure complet du service eMBMS et adresse les problèmes que l'utilisateur pourrait rencontrer lors de l'utilisation de l'eMBMS dans un environnement à haute mobilité ; tandis que la partie pratique exprime les performances du système eMBMS dans une plate-forme en temps réel. Les principales réalisations de la thèse sont énumérées ci-dessous :

— **Identifier et analyser les problèmes liées à la mobilité du service eMBMS :** Dans cette thèse, nous avons étudié en profondeur le standard d'eMBMS et avons classé les situations qui affectent la réception du service de broadcast en LTE à cause du mouvement des terminaux mobiles. L'analyse détaillée a clarifié la limitation des procédures d'aide à la mobilité pour l'eMBMS dans la norme 3GPP et dans la littérature à ce moment. L'analyse nous permet également de reconnaître les informations manquantes qui provoquent l'interruption de service et suggère des idées pour résoudre ce problème.

— **Proposer une solution complète pour la continuité du service eMBMS sur le réseau LTE/LTE avancée :** Base sur les inconvénients des mécanismes de soutien de la mobilité existants, nous fournissons une méthode qui permet aux utilisateurs de continuer à recevoir leur service MBMS intéressé dans tous scénarios de mobilité possibles. Avec notre solution, la continuité de service est assurée à travers de différentes zones MBSFN et sur toutes les fréquences alors que la norme LTE actuelle prend en charge seulement lorsque le mouvement se produit dedans une zone MBSFN. En outre, même si la convergence entre les technologies de diffusion est actuellement un objet de la recherche, une méthode de signalisation est disponible dans notre proposition pour que le mobile peut connecter à un autre technologie d'accès radio et recevoir son service en-cours.

— **Présenter un mécanisme pour réduire le temps d'interruption des flux multimédia durant la période de transfert :** Le service eMBMS, avec sa fonctionnalité de streaming, devrait être transparent avec le mouvement des utilisateurs. Cependant, dans la norme actuelle, les utilisateurs devront faire face à une interruption de flux lorsque le transfert se produit. Afin de résoudre ce problème, nous avons conçu un mécanisme comprenant une méthode d'échange d'informations d'eMBMS entre l'eNB source et cible dans les procédures handover basées sur X2 ainsi que sur S1. Avec cette proposition, le terminal peut accéder rapidement aux données de médias réelles lors sa connexion à la nouvelle cellule. En utilisant notre mécanisme dans des expérimentations réelles, le temps d'interruption de service est réduit de manière significative et la qualité perçue par les utilisateurs est également améliorée.

— **Fournir une véritable implémentation du système eMBMS sur une plate-forme open-source :** Nous avons mis en place le service eMBMS sur la plate-forme en temps réel, l'OAI. Nos travaux répondent à la limite d'un outil de simulation/émulation pour le service de LTE broadcast dans la communauté des chercheurs. Cet outil non seulement nous a aidé à évaluer notre solution de soutien à la mobilité à travers des expérimentations avec un degré de confiance élevé, mais est également un simulateur/émulateur qui permet les autres chercheurs de faire des recherches avancée dans le domaine de l'eMBMS.

Perspectives En raison de la difficulté de l'implémentation dans le système en temps réel et de la contrainte de temps, cette thèse ne peut pas fournir un scénario de mobilité réaliste pour étudier le service eMBMS avec la pile de protocole complète (DASH avec flûte et le code Raptor pour FEC) et dans une interface X2 entre deux stations de base. Cela pourrait être une bonne direction pour étendre notre travail. En outre, la fonction d'agrégation de porteuse est en cours de développement sur notre plate-forme et quand cela sera fait, nous pouvons étudier l'impact de la procédure de changement de fréquence sur la qualité de service reçu par les utilisateurs d'eMBMS. Le but ultime de ces études est de construire un système de critères optimisé basé sur la métrique QoE pour la procédure de sélection du réseau en tenant compte de la réception de l'eMBMS.

Bien que la diffusions sur LTE est sur le point d'être commercialisée prochainement, de nombreux aspects sont potentiels pour la future recherche pour améliorer la performance du système eMBMS : dans la couche physique, un préfixe plus cyclique (33,3 μs au lieu des 16,7 μs actuelles) ou la technique MIMO pour la transmission eMBMS doit être étudié ;

Une liaison montante pour signaler la qualité et optimiser la transmission MBSFN ou un porteur dédié pour eMBMS sont également les objectifs de recherche potentielles.

Une autre direction serait la convergence des technologies de diffusion. Quelques études ont été réalisées dans le but de fusionner deux systèmes de diffusion terrestres : eMBMS et DVB-T2. Un tel système de diffusion commun permet d'augmenter la couverture et la disponibilité des services et assurer la bonne qualité de service pour les clients. Le réseau hybride LTE/Satellite devient aussi un sujet prometteur pour offrir un système de livraison de vidéo sans couture.

Dans un point de vue différent, nous pouvons exploiter l'utilisation de la technologie LTE broadcast dans autres applications plutôt qu'uniquement pour les services conventionnels comme téléchargement ou streaming. L'eMBMS peuvent être utilisés comme un moyen efficace pour transférer des messages de sécurité publique. Le réseau peut avoir besoin qu'une petite partie des ressources radio pour envoyer l'avertissement via le porteur l'eMBMS aux habitants concernés dans un domaine spécifique sur les catastrophes naturelles telles que le tsunami, tremblement de terre ou une éruption volcanique, etc. La demande de l'eMBMS peut apparaître dans le système de transport intelligent (ITS) comme les véhicules de nouvelle génération dont le système d'exploitation se connecte au smartphone et pouvant obtenir les informations de trafic à partir du réseau cellulaire par l'eMBMS puis informer les propriétaires.

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