Performance Evaluation of ATSC 3.0 DASH over LTE eMBMS

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***Abstract*— Enhanced TV (enTV) features introduced into *Long Term Evolution* (LTE) *Evolved Multimedia Broadcast/Multicast Service* (eMBMS) have attracted TV broadcasters to offer their services also over eMBMS to enable service continuity and greater coverage. Considering the usual service quality offered by these content providers, an important question becomes how to deliver the offered services also over eMBMS while achieving an acceptable level of quality. In this paper, the results of an investigation that was performed for ATSC 3.0 *Dynamic Adaptive Streaming over HTTP* (DASH) TV broadcasting service are reported. While adequate service quality was achieved through LTE *carrier aggregation* (CA), additional error robustness schemes, and a flexible service configuration framework, crucial input for 5G design considerations, are derived.**

***Keywords*— LTE eMBMS; ATSC 3.0; mobile TV**

I. Introduction

Evolving mobile network technologies have led to the trend of consuming services on mobile devices anywhere and anytime. In this context, multimedia services—especially video among all services—have stood out as the most demanded by the mobile end users [1].

One such multimedia service gaining increasing attention is TV distribution, which has resulted in broadcasters being faced with the problem of reliably reaching the mobile users. At this point, *Long Term Evolution* (LTE) *Evolved Multimedia Broadcast Multicast Service* (eMBMS) is considered to be the enabler for the broadcasters to extend their reach and offer services to their mobile users. Its employment by service providers has especially been forecasted to grow even stronger after the newly-introduced *Enhanced TV* (enTV) features in *3rd Generation Partnership Project* (3GPP) Release 14, by which efficient and flexible service delivery and management are provided [2].

All the advantages aside, however, a crucial question on how to provide sufficient service quality arises. Considering that content providers have optimized their delivery systems for broadcasting such that the service quality is maximized whereas eMBMS has been built upon LTE that is primarily optimized for low latency communications, delivery over eMBMS can encounter problems when providing expected service quality [3-5]. Therefore, understanding the broadcasting capabilities and possible limitations of eMBMS is of utmost importance. In this context, examining the requirements of the services, determining the relevant *Quality of Service* (QoS) parameters, and observing their relations to *Quality of Experience* (QoE) play important roles for this assessment.

In light of the discussed open issue, this paper focuses on a specific service that is provisioned according to the *Advanced Television Systems Committee* (ATSC) 3.0 services specification. ATSC 3.0 can offer a variety of services with different formats and delivery methods; however, our focus is on *Dynamic Adaptive Streaming over HTTP* (DASH)-based TV broadcasting [6].

The aim of this work is to design and analyze a system for the delivery of the aforementioned service over eMBMS by exploiting the related enTV features, provision its delivery accordingly to achieve the expected service quality, as well as to benchmark eMBMS broadcasting capabilities for this purpose and hence provide input for multimedia delivery design considerations for 5G.

II. System Background

In this section, a brief overview of the key components of the realized service delivery is provided.

A. LTE eMBMS

LTE eMBMS has been introduced as the enabler of the delivery of services over multicast and/or broadcast connections. It has been built upon LTE with as minimal change as possible to the existing structure, resulting in overall cost minimization and easy adoption by operators. In addition to this, with recent 3GPP Release 14, eMBMS has been extended with enTV features. These have enabled TV broadcasters to deliver their services also over eMBMS, by which TV broadcasters can extend their user reach [2][4].

Some of these features relevant for TV broadcasting organizations are transport-only mode delivery, receive-only mode device support, and *Extended MBMS* (xMB) interface introduced between *Broadcast/Multicast Service Center* (BM-SC) and content provider.

In transport-only mode delivery, content providers send application data to the 3GPP network and the BM-SC simply forwards the data in a transparent fashion to the user device defined by a destination address and a destination port number. This in turn enables the content providers to offer their services over eMBMS as pass-through and allows such services to be delivered to mobile users in their native format [7].

Receive-only mode mobile devices are the closest ones to the traditional television broadcast receivers; and by receive-only mode device support, these receivers are being provided with a subset of eMBMS services without any (U)SIM card or 3GPP subscription. Therefore, eMBMS enables not only higher coverage of mobile equipment in service providing, but also the Free-to-Air content broadcasting [7].

Content providers can offer their mobile users with different services, each of which might require different service parameters to be met. The xMB interface allows them to satisfy their service needs and user expectations. Furthermore, it provides the network with the optimum use of resources [8].

B. ATSC 3.0 ROUTE/DASH

ATSC 3.0 is designed to be all IP-based with the aim of increased interoperability and service and device variety. It provides for various applications with different packaging and transportation techniques over either or both of broadcast and broadband connections. Among these offers, this paper focuses on linear TV service delivered via ROUTE/DASH over eMBMS [5][6].

1) MPEG DASH [9] is the attempt for interoperability in media delivery by the use of a common manifest file format, called MPD. This file provides information about and points to the available content. It consists of a hierarchical structure and the actual media is contained in DASH segments.

2) ROUTE (Real-Time Object delivery over Unidirectional Transport) [6] is the object-based delivery and reception of a service in real-time. Objects are media components further fragmented into smaller chunks whereas the packaging and delivery are performed through the use of *Layered Coding Transport* (LCT) and *Asynchronous Layered Coding* (ALC) protocols, respectively. ROUTE has been developed as a variant of *File Delivery over Unidirectional Transport* (FLUTE) with real-time object delivery capability and further optimizations regarding the handling of multiple session deliveries and error protection, which make ROUTE well-suited for linear TV and other real-time applications.

In ROUTE/DASH, the components correspond to DASH media components composed of segments, which can be divided into smaller objects, wrapped according to ALC packet format and transmitted and received through one or more LCT channels, packed together to generate the original segments for playback.

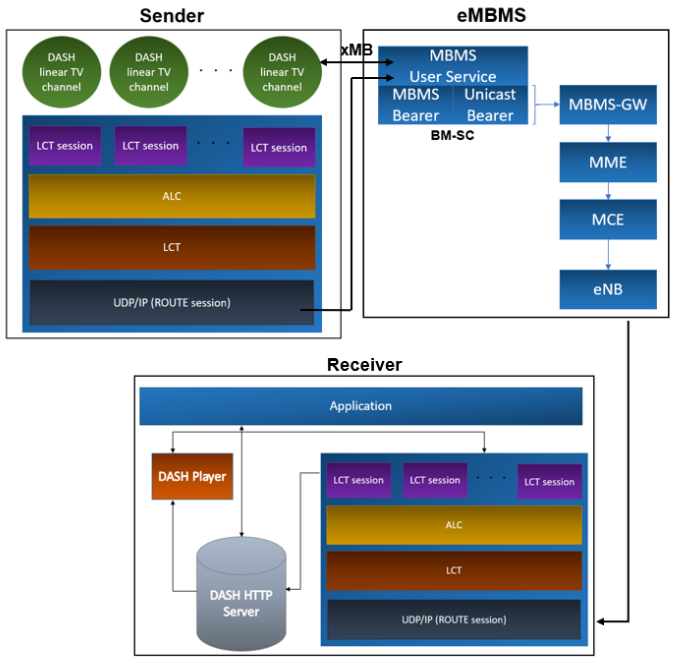

Fig. 1. Representative system architecture.

III. Service Delivery

In this section, first, an overview of the system architecture is provided. Considered service quality parameters, possible issues that can be encountered during the service delivery and how they can be solved are further discussed. Subsequently, service delivery configuration and observed results are presented.

A. Architecture

The service delivery architecture can be illustrated as in Fig. 1. An ATSC 3.0 content provider first provisions its offered service and ingests the content through the xMB interface. Via the provisioning eMBMS configures the bearers and initiates the user service. The ingestion includes the preparation of the offered DASH content into ROUTE objects and the delivery of the objects to the eMBMS network. Thereafter, eMBMS provides the multicast and/or broadcast forwarding of the received data flow using the transport-only mode of delivery. The ATSC 3.0 receiver which is interested in receiving the service initiates the object-based data reception procedures via ROUTE and packs them accordingly into DASH segments. Each segment is then stored in a local cache and sent to the DASH-compatible player to be consumed at the respective time points.

B. Considerations and Issues

Service requirements and user expectations from mobile linear TV service are: 1) low end-to-end latency, 2) low channel switching or tune-in time, 3) high error robustness, and 4) high quality content display [10].

In accordance with the service requirements, some issues can arise during service delivery and service provisioning evaluation; therefore, determining such issues and proposing solutions constitutes an important part of this work.

- *Bandwidth:* Since the service consists of UHD content in linear channels, high transmission capacity needs to be provided from the network such that smooth and timely display at mobile receivers can be observed.
- *Packet loss:* In the case that the provided robustness is insufficient for providing satisfactory perceived user experience, additional means of robustness needs to be used. Also, since additional resilience techniques cannot guarantee a complete recovery from losses, client application should have an appropriate mechanism to handle these unrecoverable errors.
- *Performance Evaluation:* For performance evaluation of the service delivery regarding the provided user perceived quality, a suitable assessment method needs to be determined.
- *Service Configuration and Management:* Flexible service configuration before the service delivery initiation is necessary not only for the content provider to meet the respective requirements but also for the network to efficiently manage the available resources. Hence, advanced techniques enabling this functionality need to be exploited.

C. Tools and Techniques

The solution for possible issues in the service delivery, reception and content playback resides in the employment of advanced tools and techniques on each part of the system architecture.

1) Carrier Aggregation (CA): In this feature, more than one and up to five carriers are aggregated to carry the data. Each aggregated carrier can have different bandwidth of 1.4, 3, 5, 10, 15 or 20 MHz, which means a maximum of 100 MHz of bandwidth is available. It should be noted that while CA solves the possible bandwidth issues, it introduces additional complexity both in the network and end devices. However, it is well-known that every newly-introduced technology poses this same issue. Also, since its release, more and more operators and device manufacturers around the globe have been deploying this technology successfully. Therefore, the complexity drawback can be discarded and CA can be employed in eMBMS for increasig the capacity for the investigated service [11].

2) RaptorQ Application-Layer Forward Error Correction (AL-FEC): LTE transmission channels, just like other communication channels are prone to errors. Knowing that errors in received data greatly affect the perceived quality, it is crucial to employ certain techniques to increase the robustness of the system. While for unicast LTE employs error correction techniques that rely on feedback mechanisms from the client devices, these are impractical and inapplicable for broadcast connections. In the latter case, feedback-less robustness techniques are necessary. Among many options, the latest member of fountain codes, RaptorQ AL-FEC [12] is chosen due to its high flexibility, efficiency and error recovery performance with little redundancy [13][14].

RaptorQ encodes and decodes the original data in blocks, called source blocks defined by an identification number. Each source block is composed of equal-sized smaller chunks, called source symbols. The source symbol size and the length of the source block (SBL) depend on the provided service requirements. Additional recovery data, called repair symbol(s), are of the same size as the source symbol, and are computed for each source block independently from the other source blocks [12].

3) DASH Resilience: Apart from providing an excellent solution for error robustness for point-to-multipoint delivery in LTE networks via AL-FEC RaptorQ, erroneous reception will still occur depending on the provided solution and the network conditions during the delivery. In this case, the properties of the delivered service in error handling also plays an important role in ensuring a certain degree of error resilience at the client device by the content provider for the specific service offer. Since the DASH players do not have a mechanism to handle such situations, when the timeline presents the play-out of the lost segment, they will immediately terminate the content playback even though the client application decodes the subsequent segments successfully. Therefore, additional errror resilience mechanisms for the application need to be integrated and they should account for the player capabilities, service requirements and user expectations. In this regard, the three proposed techniques are: 1) Black screen display, 2) Repeating the last sucessfully received segment, and 3) Freezing the last frame of the last successfully received segment [15]. Which one to deploy in DASH depends on their provided user experience.

4) Multi-Scale Structural Similarity Index (MS-SSIM): For quantifying the QoE of the provided service as accurately as possible without RaptorQ employment, in the presence of RaptorQ recovery and in the presence of each error concealment methods for DASH resilience, a novel approach needs to be identified. It is well-known that the most accurate way is the subjective video quality assessment (VQA), since it directly reflects the user opinion on the displayed content. As this method is time consuming, an objective VQA (OVQA) technique that is well-suited for packet loss scenarios needs to be employed. In this regard, the current research suggests the use of MS-SSIM due to its good correlation with subjective scores in packet loss scenarios and reasonable computational cost [16]. Knowing that MS-SSIM is essentially an image quality metric, for its applicability to video sequences, the simple mean algorithm was used as suggested in [17], which provides the sufficient comparable result.

5) xMB Application Programming Interface (API): As mentioned before, the xMB interface has been introduced for content providers to flexibly configure the delivery-related parameters in LTE eMBMS depending on the individual service needs. These mentioned service configuration and management procedures can be performed via defined xMB

API using HTTP message exchanges between the content provider and BM-SC [18]. A representative API for the investigated service is also integrated into the system in the course of this work.

D. Framework

In light of the abovementioned considerations, the service setup was performed with the ATSC 3.0 software and a real-time LTE emulator with eMBMS configuration.

Two linear channels, each carrying 4K-resolution UHD content encoded at an average data rate of 16Mbps and segmented at 1 second granularity, were offered. At this point, it should be noted that ATSC 3.0 supports the delivery of 4K UHD channels through its own physical layer; so, the delivery analysis over eMBMS for the same scheme is investigated.

The LTE system was configured according to typical urban deployment scenarios where each user equipment moves at a pace of 3km/h. The carrier frequency was selected as 2GHz, which results in a coherence time of the fading channel in the order of 70ms, which leads to significant burst-like packet losses. Although 3GPP Release 14 allows even higher resource allocation, taking into account the possible unicast service requests in the same geographical area for the same and/or different services, 60% of the network resources were allocated for eMBMS delivery. To maximize the available transmission rate, network bandwidth and modulation and coding scheme (MCS) index were set to 20 MHz and 24, respectively. Overall, this provides a maximum available capacity of around 32Mbps for the eMBMS services. An illustration of the cell with initial positions of the live user used for consecutive simulations can be seen in Fig. 2.

E. Initial Results and Observations

After the environment setup, preliminary results were collected to address the possible issues related to available network capacity and network losses, respectively.

Without enabling network losses in the network, the preliminary evaluation indicated that this LTE configuration did not provide sufficient capacity and latency, which resulted in a very unstable content playback. Delivering two channels with high quality content, the varying DASH segment sizes of the offered content and the selected resource allocation for eMBMS service play a significant role in this observation. However, the logic behind these settings is provided in the previous subsection. Therefore, to increase the available capacity and decrease the latency, the proposed CA technique is employed.

For the network loss analysis, CA of 2 carriers, each of 20 MHz is employed. In the presence of packet losses, it was observed that the error robustness in the service delivery was not adequate; for the typical IP packet loss rates in the network, the resulting DASH segment loss rate was extremely high as can be seen from Fig. 3 in blue circles, which greatly affects the user perceived quality. This result stems from the selected MCS as well as large segment sizes and the nature of the ROUTE protocol, in which loss of an object causes a complete segment loss. Consequently, the discussed RaptorQ AL-FEC and DASH resilience schemes are integrated.

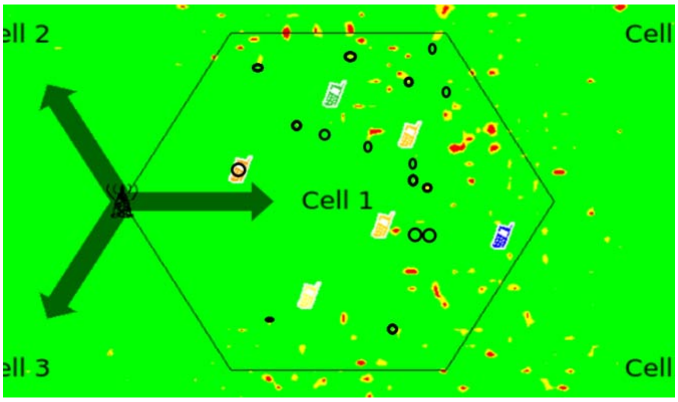

Fig. 2. Cell with varying live user positions shown in black circles.

F. Proof-of-Concept Results via Advanced Techniques

Considering that loss rates are mostly less than 10% and the linear behavior of RaptorQ overhead and protection, 10% of recovery data is provided. Additionally, for further exploration of the service delivery, a RaptorQ repair data flow size of 20% is introduced. Because of varying segment sizes and the fact that in live broadcasting data is consumed directly after its reception at the client device, the size of the minimum-sized segment is used as the source block size and to further partition the larger segments to form the source blocks. The decoding failure probability threshold, on the other hand, is determined as 10^{-4}. For almost 15-minute content with each second corresponding to a segment, this means an error-free decoding at the client device in case that enough encoding symbols are received.

The provided protection is not free of charge in terms of offered transmission capacity, which means that delivered content along with the introduced overhead needs to employ the same amount of transmission rate and allocated resources. Therefore, the original content encoding bitrate is reduced by 10% and 20% for each RaptorQ repair flow employment, respectively.

As for DASH resilience, testing each of the proposed mechanisms in terms of provided user experience via MS-SSIM, frame freezing technique outscored the other approaches. This was expected since it provides the closest temporal and spatial imitation of the lost scenes. Hence, frame freezing technique for the losses that could not be recovered by RaptorQ is used.

The results when using these advance techniques are as follows:

1) Error Robustness: Remarkable improvement was achieved in error robustness. On average, the segment loss reduction of 58% was achieved with introduction of only 10% recovery data, whereas it was further reduced by 71% with 20% protection. The reason behind these high values resides in the mentioned nature of the ROUTE protocol, where a single object loss causes the corresponding segment to be lost completely. Also, the randomness of where the burst packet loss occurs greatly affects the recovery performance of RaptorQ. Related results are provided in Fig. 3.

2) Latency parameters: Providing error robustness has the trade-off of increased end-to-end latency and tune-in delay. Essentially in RaptorQ scheme, the repair flow of the associated source block flow is sent along with the next source block flow. When combined with that ROUTE protocol waits until the last object of the complete media segment to be received to initiate the recovery and object packing procedure, the introduced increase in the latency parameters can have tremendous effect on the service reception and the QoE. An illustration of this is provided in the middle part of the Fig. 4. It was derived that in the worst case scenario, on average the end-to-end latency doubled whereas the tune-in delay increased by more than 50%. With the proposed method of transmitting the repair flow right after its associated source block flow in burst, the introduced increase in end-to-end latency and tune-in delay are reduced to around 10-20% and 6-12%, respectively. An illustration of this approach can be observed in the lower part of the Fig. 4.

3) QoE: The improvement on the overall user perceived quality was computed as 20% in 10% RaptorQ repair usage and 21.25% in 20% RaptorQ repair usage. The small increase from 10% case to 20% case recovery rates is because of the random burst packet loss occurance along with the reduced content encoding bitrate as a consequence of higher recovery data transmission. Examplar results can be seen in Fig. 5.

IV. CONCLUSIONS

In this paper we studied the service delivery for ATSC3.0 DASH over eMBMS. It is observed that LTE did not provide sufficient transmission capacity. Although a solution, like CA exists to compensate for this, facing this problem by the delivery of only two linear UHD channels raises the concerns on the possibility of delivering a variety of services, simultaneously. This result is considered to be of high importance for the design considerations in 5G multimedia delivery networks. It is also derived that additional error resilience techniques are essential in ensuring acceptable service quality. The xMB API is also important for efficient resource allocation in the network. Furthermore, optimal provisioning can be performed based on the targeted parameter values.

An extension to this work would be to study more features introduced into eMBMS, such as MBMS Operation On Demand (MOOD) that utilizes a hybrid of broadcast delivery and unicast delivery. Although this feature is not applicable for receive-only mode devices, i.e. it reduces the device type coverage, the investigation of the resulting QoS and QoE can provide an important input on the current eMBMS broadcast delivery performance status. Additionally, depending on the performance differences, a more efficient way of service delivery switching between broadcast and unicast can be employed, by making use of the counting procedure introduced in eMBMS.

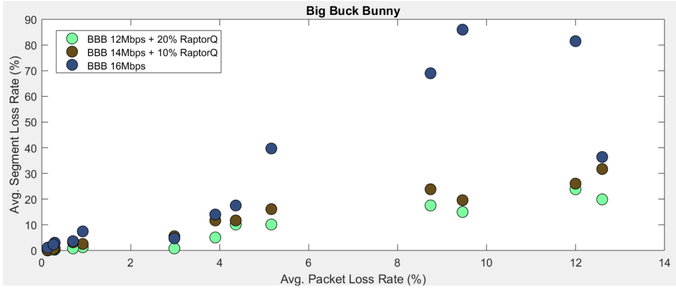

Fig. 3. Segment loss rate comparison of original source without RaptorQ data (blue) and introduced 10% (brown) and 20% (green) RaptorQ data at observed IP packet loss rates in the network.

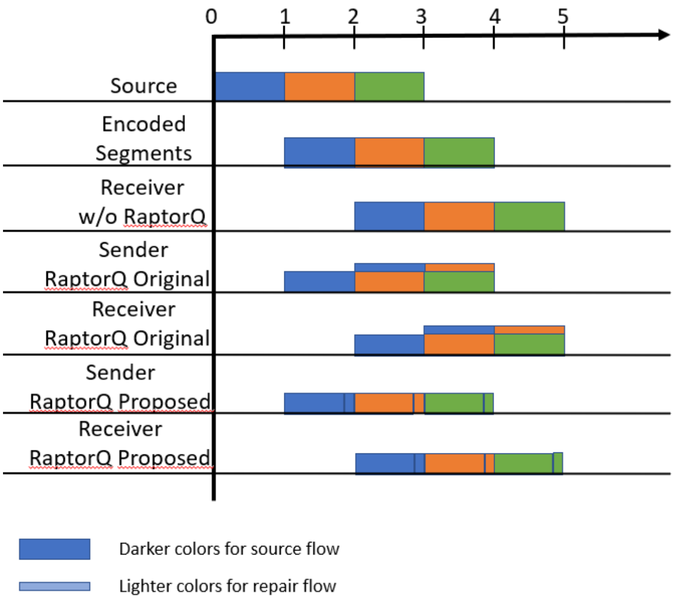

Fig. 4. Illustrative RaptorQ source flow and repair flow transmissions: no RaptorQ (top), original (middle) and proposed (bottom). Note that the content encoding bitrate is reduced according to the introduced RaptorQ protection amount.

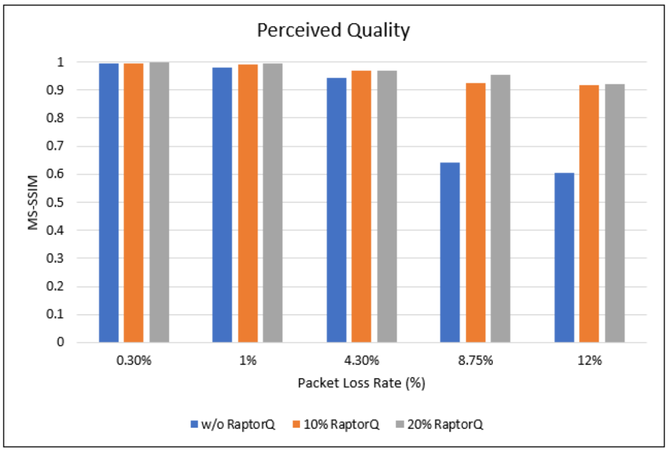

Fig. 5. Perceived quality results under different IP packet loss rates in the network with the introduced 10% and 20% RaptorQ repair data compared to no RaptorQ employment.

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