AL-FEC for Streaming Services over LTE Systems

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Abstract—**The Third Generation Partnership Project (3GPP), recently introduced the evolution of the third generation (3G) cellular networks, the Long Term Evolution (LTE) telecommunication system. A key aspect of LTE specifications is the enhancement of Multimedia Broadcast/Multicast Services (MBMS), where the same content is transmitted to multiple users located in a specific service area. A significant point of the demanding multimedia services is the enhancement of the robustness against packet losses. To this direction, in order to support the efficient point-to-multipoint download and streaming delivery, 3GPP has included an Application Layer Forward Error Correction (AL-FEC) scheme in the MBMS standard. The standardized AL-FEC scheme is based on the systematic, fountain Raptor codes. In this paper, we investigate the application of AL-FEC over the MBMS streaming delivery method. We consider the benefits of AL-FEC for a seamless multimedia streaming transmission to multiple mobile users and we examine how the amount of FEC overhead can be adjusted under different packet loss conditions. For this purpose, we present a variety of realistic simulation scenarios for the performance evaluation of FEC considering several network and FEC encoding parameters. Furthermore, we provide suggestions in order to achieve efficient use of Raptor codes over LTE MBMS streaming services.**

Keywords—forward error correction; long term evolution; raptor codes; streaming; multimedia broadcast and multicast

I. INTRODUCTION

Third Generation Partnership Project (3GPP) Multimedia Broadcast and Multicast Service (MBMS) was firstly standardized as a new feature in 3GPP Release 6, in order to broadcast and multicast multimedia content to mobile terminals via MBMS radio bearer. The MBMS provides two different delivery methods, the download method providing delivery of discrete objects and the streaming method providing delivery of continuous media [1].

Forward Error Correction (FEC) is a method for error control that is used to augment or replace other reliability methods. In FEC, the sender introduces redundant information in the data transmitted, providing the ability to overcome packet losses at multiple receivers without the retransmission of lost data. In MBMS, Application Layer FEC (AL-FEC) can address the problems not dealt by physical layer FEC, in order to provide reliability and scalability against different packet loss rates. Consequently, 3GPP recommends the use of AL-FEC for MBMS. More specifically, Raptor codes [1] have been selected due to their high performance in comparison with other FEC schemes.

To the best of our knowledge, related works cover research on AL-FEC for the Long Term Evolution (LTE) MBMS download delivery method or for MBMS streaming services over prior to LTE cellular networks. In [2], a file recovery scheme for the LTE MBMS download delivery method is presented. The authors propose the exclusive sending of redundant packets, using AL-FEC, i.e., Raptor codes, instead of using the retransmission-based error recovery scheme, until all the receivers recover the file. The authors of [3] present an evaluation of MBMS download services in UMTS cellular networks. This work investigates the optimal dimensioning of Raptor codes based on a probabilistic method that models the multicast user distribution. The work presented in [4] evaluates the trade-off between AL-FEC and physical layer FEC over MBMS download delivery in UMTS systems. The authors investigate the benefits of FEC on user experience and radio resource consumption through a system level simulator. The study in [5] includes an investigation of Raptor codes as a method to provide QoS in the MBMS streaming framework over 3G networks by adjusting the AL-FEC parameters in order to maximize the amount of satisfied users who receive a video stream. Finally, the authors of [6] introduce a method, where partly erased data can be utilized to the decoding process enhancing the performance of Raptor codes in MBMS streaming applications over predecessor of LTE systems.

Since related work is dedicated to the investigation of AL-FEC over LTE MBMS download delivery method or MBMS streaming services over prior to LTE networks, our vision is to cover the evaluation of AL-FEC over LTE multicast streaming services. To this direction, in this work we study the application of AL-FEC for the streaming delivery method over LTE networks. Since the redundancy of FEC aims to overcome packet losses, we investigate how the amount of FEC overhead varies at multiple receivers using realistic simulation scenarios. We investigate the performance of AL-FEC overhead considering different cell deployments, user mobility models and FEC encoding parameters.

The rest of this paper is organized as follows: in Section II an overview of the AL-FEC MBMS streaming framework is presented and we provide a detailed description of Raptor codes. Section III describes the simulation framework we use and in Section IV we present the simulation results. Finally, in Section V we provide our conclusions and some possible future steps.

II. Overview Of FEC for MBMS Streaming

The purpose of the MBMS streaming delivery method is to deliver continuous multimedia data (i.e., speech, audio, and video) over an MBMS bearer. The protocol stack used by MBMS streaming delivery is illustrated in Figure 1 [1]. MBMS makes use of the most advanced multimedia codecs such as H.264 for video applications. Real-time Transport Protocol (RTP) is the application layer protocol for MBMS streaming delivery and provides means for sending real-time or streaming data over UDP transport layer. 3GPP recommends the use of FEC mechanism by the sender before RTP flows are mapped onto UDP. Thereafter, the resulting UDP flows are generally mapped on the MBMS IP multicast bearers.

A key functionality of the MBMS streaming delivery method is the provision of reliability control in the transmission by means of FEC for RTP flows. The AL-FEC mechanism consists of three components: the construction of an FEC source block from the source media packets belonging to one or several UDP packet flows, the modification of source packets to indicate the position of the source data from the source packet within the source block and the definition of repair packets, sent over UDP, which can be used by the FEC decoder to reconstruct missing portions of the source block.

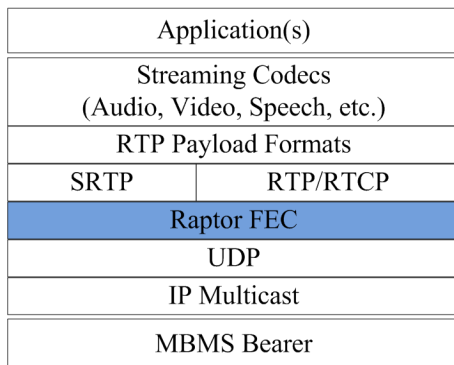| Application(s)	
Streaming Codecs (Audio, Video, Speech, etc.)	
RTP Payload Formats	
SRTP	RTP/RTCP
Raptor FEC	
UDP	
IP Multicast	
MBMS Bearer	

Figure 1. MBMS streaming services protocol stack.

At the sender, the mechanism begins by processing original UDP packets to create a stored copy of the original packets in the form of a source block, and FEC source packets for transmission to the receiver. After constructing the source block from the original UDP payloads to be protected, the FEC encoder generates the desired amount of FEC protection data, i.e., encoding symbols. These repair symbols are then sent using the FEC repair packet format. The receiver recovers the original packets directly from the FEC source packets. If any FEC source packets have been lost, but sufficient FEC source and FEC repair packets have been received, FEC decoding can be performed to recover the FEC source block. Consequently, if a UE that supports MBMS streaming services receives a mathematically sufficient set of encoding symbols, then the decoder shall recover the entire source block of data.

3GPP has standardized Raptor codes as the AL-FEC codes for MBMS aiming to improve service reliability [1]. The use of Raptor codes in the application layer of MBMS has been introduced to 3GPP by Digital Fountain [7]. Raptor codes are fountain codes, meaning that as many encoding symbols as desired can be generated by the encoder on-the-fly from the source symbols of a source block of data. The decoder is able to recover the whole source block from any set of FEC encoding symbols only slightly more in number than the number of source symbols. The Raptor code specified for MBMS is a systematic fountain code producing n encoding symbols E from $k < n$ source symbols C. The description of each step and the details on specific parameters can be found in [1]. The study presented in [8] shows that Raptor codes have a performance very close to ideal, i.e., the failure probability of the code is such that in case that only slightly more than k encoding symbols are received, the code can recover the source block. In fact, for $k > 200$ the small inefficiency of the Raptor code can accurately be modeled by (1) [9]:

$$ p_f(m,k) = \begin{cases} 1 & if\ m < k, \\ 0.85 \times 0.567^{m-k} & if\ m \geq k. \end{cases} \qquad (1) $$

In (1), $p_f(m,k)$ denotes the failure probability of the code with k source symbols if m symbols have been received. It has been observed that for different k, the equation almost perfectly emulates the code performance. While an ideal fountain code would decode with zero p_f when $m = k$, the failure for Raptor code is still about 85%. However, p_f decreases exponentially when number of received encoding symbols increases.

III. Simulation Framework

In order to evaluate the performance of Raptor codes for streaming services over MBMS environment we use an open source simulation platform introduced in [10]. This framework of LTE networks simulates both the evolved Universal Terrestrial Radio Access Network (eUTRAN) and the evolved packet system (EPS). It is a fully functional simulator that provides several traffic flows at the application layer through the implemented LTE protocol stack. It supports, among others, multi-user scenarios in single-cell and multi-cell environments, simulating different user mobility models, handover procedures, different scheduling algorithms and a variety of physical layer models. In order to simulate single-cell MBMS mode of LTE networks we extend the already provided functionalities of this framework.

The network architecture of our simulation framework is illustrated in Figure 2. In eUTRAN, the evolved Node Bs (eNB) are the collectors of the information that has to be transmitted to User Equipments (UE) over the air interface. Within evolved packet core (EPC), as specified in [11], an MBMS specific functional entity, the Broadcast Multicast Service Center (BM-SC) serves as an entry point for content provider used to initiate the modeled MBMS bearer service and deliver IP multicast traffic. Also the BM-SC is responsible to provide protection against errors to the transmitted data through AL-FEC. The content provider is the multimedia multicast source and provides discrete and continuous media to the BM-SC. Furthermore, the MBMS Gateway (MBMS GW) has been modeled. This functional entity exists at the edge between eNBs and the BM-SC and its main functionalities are to forward the protected packets to each eNB transmitting the streaming service and to control the multicast session start/stop via the Mobility Management Entity (MME).
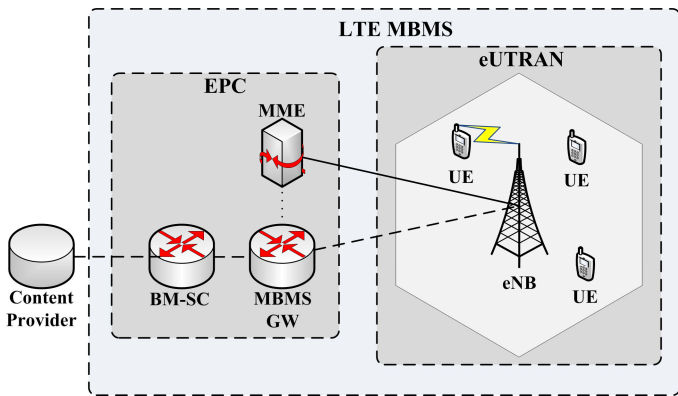
Figure 2. LTE MBMS simulator network architecture.

Our simulation scenarios provide real time video traffic models at the application layer, which are encapsulated in RTP and forwarded in lower layers (Figure 1). The application of FEC protection scheme to the multimedia stream is introduced at the BM-SC, using Raptor codes as described above. The modeled FEC encoder generates the additional packets according to the desired protection. More specifically, n encoding symbols are produced from k source symbols, therefore the overhead added from the Raptor encoding, i.e., the number of FEC repair symbols divided by the number of FEC source symbols, is equal to the fraction $(n - k) / k$. This fraction, in terms of percentage indicates the Raptor overhead that the FEC protection technique introduces to the transmission. After the applied FEC framework, the resulting UDP flows are mapped on the MBMS IP multicast bearers. The modeled multicast bearers require only a few modifications of the existing LTE user plane protocol stack of packet-switched services, to support MBMS mode.

The presented simulation framework allows us to evaluate a variety of streaming flows encoded at different source rates for different simulation duration. The modeled streaming flows are transmitted in realistic multicast environments with variable density of mobile users in the MBMS service area as well as different user mobility models. Furthermore, since our simulations concern about the single-cell MBMS mode, we can simulate different deployments selecting the number of adjacent cells acting as intercell interference and the cell radius. On system parameters we can evaluate the performance for different values of the system bandwidth and a variety of channel models. At the modeled AL-FEC layer the parameters that can be selected is the Raptor overhead and the number of symbols protected in a source block.

At the receiver side we examine the user satisfaction, in the sense of successful decoding the FEC protected stream, depending on the amount of overhead that Raptor encoding adds to the transmitted flow. The theoretical performance of the Raptor FEC code depends on the amount of data received by each user in the multicast area. If less data has been received than the size of the block to which FEC protection has been applied then recovery of the original block is obviously impossible. If an amount of encoding symbols has been received which is not less of the number of source symbols, then the probability of successful decoding the media stream can be extracted by (1).

IV. EXPERIMENTAL RESULTS

This section provides the experimental results of the evaluation that we conducted based on the framework presented in the previous section.

A. Simulation Setup

Our simulation setup is able to provide results for variable and realistic network conditions. The LTE system simulation parameters that are taken into account for the experiments are presented in TABLE I. The macrocell propagation model for urban area, proposed in [12], is selected for our simulation scenarios. The selected single-cell MBMS deployment simulates a MBMS center cell and adjacent cells acting as intercell interference. For this evaluation we use a H.264 video flow, encoded at different source rates, that is transmitted in a point to multipoint way to the users using the MBMS bearer. Furthermore, each user receives, simultaneously with the multicast content, one best effort flow through unicast bearers. Therefore our setup provides simulations results for realistic, high load network conditions.

For the FEC encoding process we assume that the symbol size is fixed and each resulting packet contains one FEC symbol. The simulation experiments evaluate the performance of Raptor codes, according to the introduced overhead to the transmission for different parameters from the user satisfaction perspective. We assume that a user is satisfied if the amount of received encoding symbols is sufficient to successful decode all the source blocks of the transmitted multimedia. More specifically, we demand that the probability of decoding failure for each source block of the stream is less than 10^{-2} as proposed in [13]. It is worth mentioning that this assumption does not imply that a user with decoding failure probability higher than this value will fail to reconstruct the encoded data, but it is a sufficient practical threshold.

TABLE I.   SIMULATION SETTINGS

Parameter	Units	Value
Cell layout		Hexagonal grid, 3 sectors per site
Simulation duration	sec	120
Carrier frequency	MHz	2000
System bandwidth	MHz	5
Channel model		3GPP Typical Urban (TU)
Propagation model		3GPP macrocell – urban Area
Path loss	dB	L= 128.1 + 37.6 $\log_{10}$d
UE Rx antennas		2
BS # antennas		1
BS transmit power	dBm	43
BS antenna gain	dBi	14

B. AL-FEC Overhead vs. Cell Range

In the first part of the experiments we examine the AL-FEC overhead in function of the cell range and we present how the average Raptor overhead varies against different cell deployments. For this evaluation we use a H.264 video flow, encoded at 128 kbps and transmitted to multicast users in the MBMS service area. We simulate 200 mobile users moving at 3 and 30 km/h speed, corresponding to pedestrian and vehicular mobility models, respectively, based on the random walk model [10]. In the FEC encoder, the source block configuration is fixed at 400 symbols per source block and the

decoding failure probability target is set to 10^{-2}, based on the assumption described in the previous section. In Figure 3 we illustrate the impact of the cell range growth on the average AL-FEC overhead.
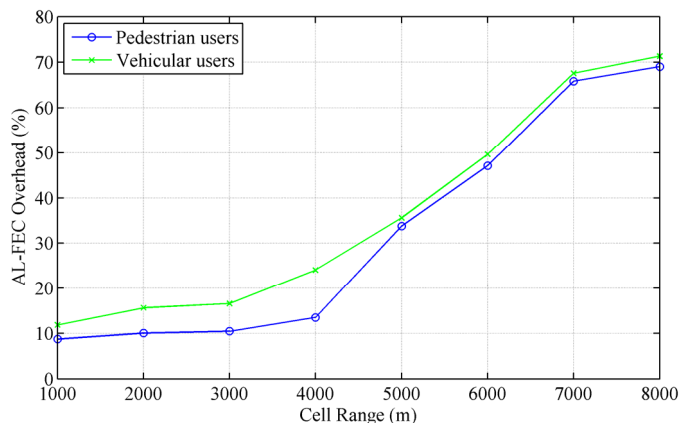

Figure 3. AL-FEC overhead against cell range for pedestrian and vehicular mobility model.

From the two plotted curves, we notice that the required average AL-FEC overhead increases as the cell range increases. For low values of cell radius the necessary overhead is low for both pedestrian and vehicular users. When the cell range is less than 5000 meters the difference between the average AL-FEC overhead of the two mobility models is around 5%. On the other hand, when the cell range exceeds the 5000 meters limit, we notice that the necessary overhead of the vehicular mode is very close to that of the pedestrian mode. This happens since, as the cell radius increases, users moving at higher speed can better exploit the multi-user diversity gains that LTE provides. In general, the required average overhead increases as the cell range increases, leading to high values of AL-FEC overhead. This is reasonable in a multi-user environment, where different users experience variable packet loss rates because of different radio channel conditions and given that as the cell size increases, even more users experience poor reception conditions.

C. Satisfied Users vs. AL-FEC Overhead

In this part of experiments we try to investigate in depth the performance of Raptor codes considering the impact of the introduced FEC overhead on the fraction of satisfied users. The cell range is now fixed at 2000 meters. The FEC encoding is applied on a video flow with source rate 128 kbps and the source block length is fixed at 400 symbols. Figure 4 depicts the AL-FEC performance from the perspective of satisfied users percentage, as the Raptor overhead introduced in the transmitted stream increases. This has been performed for three different values of mobile users population, simulating different network load instances. Figure 4a illustrates how the FEC performance varies for the pedestrian mobility mode and Figure 4b for the vehicular mode.

When the user density in the MBMS service area is relatively low (i.e., 50 and 100 users), the introduction of 5% overhead results in satisfying over 95% of mobile users, both for pedestrian and vehicular modes. During the simulation of 200 mobile users in the MBMS service area, we observe that in the case of pedestrian users, the overhead that is necessary to achieve that 90% of users are satisfied is 20%. On the other hand, when simulating vehicular users and in order to achieve the same performance in terms of user satisfaction, the necessary overhead is about 30%.
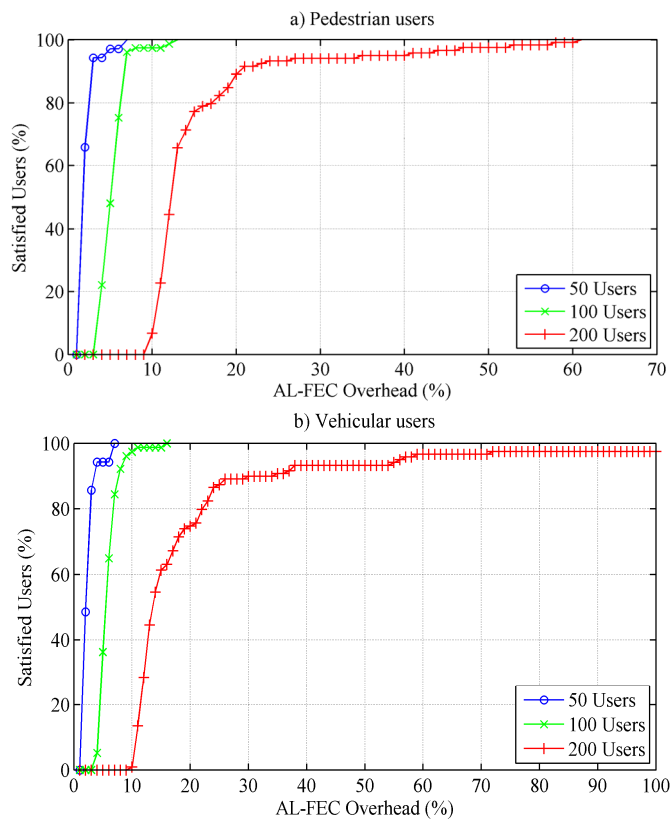

Figure 4. Percentage of satisfied users vs. AL-FEC overhead for different user population for: a) pedestrian users and b) vehicular users.

A very interesting notice from both plots is the existence of a point, beyond which a further increment in AL-FEC overhead is not efficient. This means that the additional gains on the decoding performance are minimized. Thus, by observing each plotted curve, we can determine a point of efficient selection the Raptor overhead that a sender should introduce to the transmission, aiming to satisfy a large proportion of users. Indicatively, when the multicast content is transmitted to 100 vehicular users and assuming that the satisfactory performance is when 90% of terminals are satisfied, the required overhead is 6%. It is clear from the results that there is an optimal value of Raptor overhead in each curve, in terms of the trade-off between transmission redundancy and satisfied users.

D. Satisfied Users vs. Source Block Length

In the last part of experiments we evaluate the impact of the modeled FEC encoder parameters on the performance of the decoding of the protected stream. In more detail, we present results on how the percentage of satisfied users varies for different number of FEC symbols per source block concerning different fixed values of AL-FEC overhead. Figure 5a and Figure 5b illustrate the results for a video stream encoded at

128 kbps and 440 kbps respectively. We simulate 200 pedestrian users dropped in the MBMS service area with cell range 2000 meters.
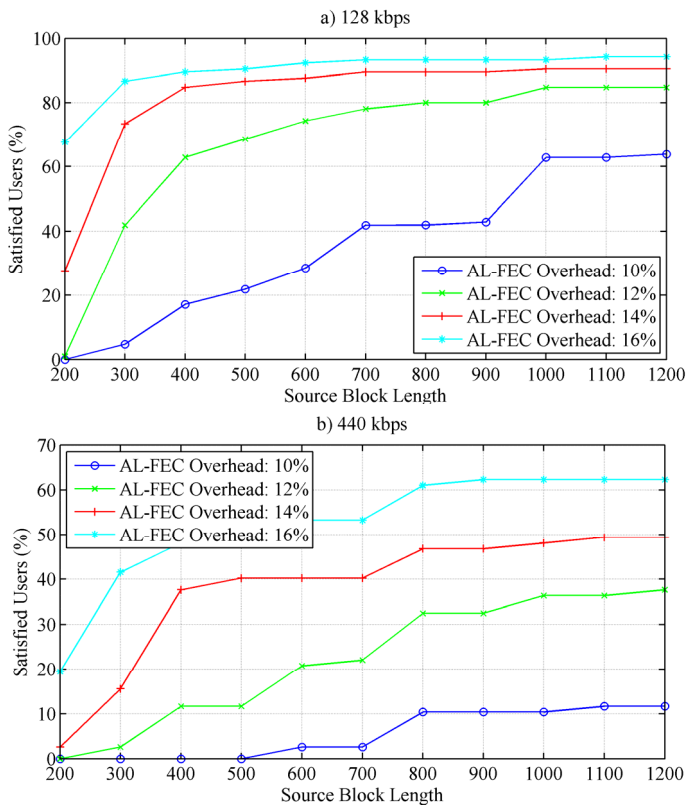

Figure 5. Percentage of satisfied users vs. source block length for: a) 128 kbps and b) 440 kbps video source rate.

As we can observe from both plots, the increment of the number of protected symbols in a FEC source block is beneficial for the performance of the decoding procedure. This behavior directly results from the operation of the Raptor codes described previously. Especially for some certain values of source block length, the gains during the decoding procedure are remarkable high. Another observation is that in the case of 440 kbps source video rate, the percentage of satisfied users is significantly lower than the case of 128 kbps for the same setup of AL-FEC overhead and source block length. This is reasonable since the number of packets to be protected for the same transmission interval in the case of 440 kbps is considerably higher than the case of 128 kbps. To conclude, the overhead and the source block length of the FEC encoder should be carefully selected based on the amount of protection to apply and on different streaming constraints (e.g., delay), in order to achieve efficient use of AL-FEC.

V. CONCLUSIONS & FUTURE WORK

In this paper, we have evaluated the performance of AL-FEC based on the Raptor codes in order to provide error protection in 3GPP LTE MBMS streaming services. We have examined how the Raptor overhead varies during different network conditions and which is the optimal overhead that a multicast sender should introduce to the transmission, in order to achieve successful delivery of the multimedia content in a point-to multipoint manner. Our method for the evaluation of the benefits that FEC protection provides is based on a realistic MBMS simulation environment, where an AL-FEC protection scheme is modeled over video streaming services. From the experimental results we have extracted valuable conclusions on the performance of Raptor codes considering different network deployments and encoding parameters.

Some possible future steps that could follow this work may be the design of a cross-layer mechanism for FEC protection over multicast streaming delivery services. We could further evaluate the AL-FEC benefits for streaming services concerning both physical layer aspects as well as advanced multimedia codecs. Another possible consideration is the design and the evaluation of an adaptive algorithm that computes the optimal FEC overhead. This mechanism could be based on a feedback-reporting scheme about network conditions and based on this reporting the amount of the introduced FEC overhead to the transmission could be adjusted.

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