Enhancing FEC Application in LTE Cellular Networks

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***Abstract*—3rd Generation Partnership Project's (3GPP) Long Term Evolution (LTE) is focused on enhancing the Universal Terrestrial Radio Access (UTRA). Evolved-Multimedia Broadcast and Multicast Service (e-MBMS) uses Multimedia Broadcast over a Single Frequency Network (MBSFN) operation in order to improve its performance. In MBSFN operation, data are transmitted simultaneously over the air from multiple tightly time-synchronized cells. Raptor codes have been standardized as the main application layer Forward Error Correction (FEC) method for e-MBMS due to the advanced error protection they offer and their overall performance. In this study, we investigate the application of FEC in MBSFN-enabled LTE cellular networks and we propose a new scheme that takes into account the properties of MBSFN in order to provide a more efficient operation of FEC during e-MBMS transmissions. The proposed scheme is compared with other file recovery methods and is evaluated against various network parameters in a realistic simulation environment.**

Keywords-long term evolution; cellular networks, forward error correction; raptor codes; reliability; single frequency network, multimedia broadcast and multicast;

I. Introduction

The Long Term Evolution (LTE) is one of the latest steps in an advancing series of mobile telecommunications systems. A new key feature of LTE is the exploitation of the Orthogonal Frequency Division Multiplexing (OFDM) radio interface to transmit multicast or broadcast data as a multicell transmission over a time-synchronized single frequency network: this type of transmission is known as Multimedia Broadcast Single Frequency Network (MBSFN). MBSFN transmission enables a more efficient operation of the Multimedia Broadcast and Multicast Service (MBMS) [1], allowing over-the-air combining of multi-cell transmissions towards the User Equipments (UEs). MBMS service, defines two delivery methods: download and streaming delivery. Our work investigates the application of FEC on download delivery method, so the rest of our analysis focuses on this MBMS delivery method.

Forward Error Correction (FEC) is an error control method that is used to improve or replace other methods for reliable data transmission. In FEC, the sender adds redundant information in the data transmitted to the receiver(s) allowing the reconstruction of the source data. In multicast protocols the use of FEC techniques has very strong motivations. The encoding eliminates the effect of independent losses at different receivers, while simultaneously the dramatic reduction in the packet loss rate largely reduces the need to send feedback to the sender. This is the reason why 3GPP recommends the use of FEC for MBMS and, more specifically, adopts the use of Raptor FEC code in the application layer [2].

It should be noted that all the existing related work covers research either on the application layer FEC for prior to LTE cellular networks or FEC for the LTE physical layer. The study presented in [6], investigates the impact of FEC use for MBMS and examines whether it is beneficial or not and how the optimal FEC code dimensioning varies based on the network conditions. In [7], the applicability of FEC via Raptor code in the multicast data transmission is studied while focusing on power control in the Radio Access Network (RAN). The evaluation considers the properties of point-to-point (p-t-p), point-to-multipoint (p-t-m) as well as hybrid transmission mode that combines both p-t-p and p-t-m bearers in RAN. The authors of [10] present an investigation on MBMS download delivery services in UMTS systems considering a comprehensive analysis by applying a detailed and complex channel model and simulation setup. The trade-off between the overhead added by the application layer FEC and the overhead added by the physical layer Turbo codes is examined. It is concluded that the optimal operating point in this trade-off uses low transmission power and a modest amount of Turbo FEC coding that results in relatively large radio packet loss rates. The use of a substantial amount of Raptor coding can then compensate for this packet loss. In the work presented in [9], the same authors have addressed the reliable file delivery over mobile broadcast networks, using Raptor codes as specified for MBMS services by 3GPP. They propose two algorithms that can enhance the regular raptor coding process when performed at the receiver side. The simulation results verify the efficient performance of the whole process. Finally, in study [8], an analytical approach is proposed for evaluating the performance of an MBSFN LTE network. It presents an estimation of the total telecommunication cost of an MBSFN transmission which we use in this paper for the evaluation of our proposed scheme.

The contribution of this paper is an innovative file recovery scheme for the transmission of the FEC redundant information

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during MBMS download delivery. This innovative scheme takes advantage of the MBSFN properties and performs an adaptive generation of redundant symbols for efficient error recovery. The redundant encoding symbols are produced continuously until all the multicast receivers have acknowledged the complete file recovery. In order to present the efficiency of the proposed scheme, we evaluate its performance in terms of telecommunication cost and compare it with existing error recovery methods.

The paper is structured as follows: a detailed description of error recovery in MBMS is presented in Section II. In Section III we describe our scheme and in Section IV the evaluation results of the conducted experiments are presented. Finally, in Section IV our conclusions and some possible future steps are provided.

II. Error Recovery in e-MBMS

A. *Application Layer FEC*

3GPP has standardized Turbo codes as the physical layer FEC codes and Raptor codes as the application layer 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 [5]. 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. This code can be viewed as the concatenation of several codes. The most-inner code is a non-systematic Luby-Transform (LT) code with l input symbols F, which provides the fountain property of the Raptor codes. This non-systematic Raptor code is not constructed by encoding the source symbols with the LT code, but by encoding the intermediate symbols generated by some outer high-rate block code. This means that the outer high-rate block code generates the F intermediate symbols using k input symbols D. Finally, a systematic realization of the code is obtained by applying some pre-processing to the k source symbols C such that the input symbols D to the non-systematic Raptor code are obtained. The description of each step and the details on specific parameters can be found in [1].

The study presented in [9] 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 modelled by (1) [10]:

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

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 failure probability when $m = k$, the failure for Raptor code is still about 85%. However, the failure probability decreases exponentially when number of received encoding symbols increases.

B. *File Repair Procedure*

The purpose of file repair procedure is to repair lost or corrupted file segments that appeared during the MBMS download data transmission [2]. At the end of the MBMS download data transmission each multicast user identifies the missing segments of the transmitted file and sends a file repair request message to the file repair server. This message determines which exactly the missing data are. Then, the file repair server responds with a repair response message. The repair response message may contain the requested data, redirect the client to an MBMS download session or to another server, or alternatively, describe an error case.

One of the main problems that should be avoided during file repair procedure is the feedback implosion in the file repair server due to a potential large number of MBMS clients requesting simultaneous file repairs. Another possible problem is that downlink network channel congestion may be occurred due to the simultaneous transmission of the repair data towards multiple MBMS clients. Last but not least, the file repair server overload, caused by bursty incoming and outgoing traffic, should be avoided. The principle to protect network resources is to spread the file repair request load in time and across multiple servers. The resulting random distribution of repair request messages in time enhances system scalability.

III. Proposed Scheme

Our scheme proposes the exclusive sending of redundant encoding symbols instead of using the file repair process during the MBMS download delivery of a given file. It is important to clarify that the transmission of all the encoding symbols is performed over the MBSFN infrastructure. The scheme takes advantage of the fact that the Raptor FEC decoder, based on a fountain code, is able to recover the source blocks from any set of encoding symbols only slightly more in number than the number of source symbols. Therefore, it is proposed that the Raptor FEC encoder in the sender generates redundant symbols until it takes an acknowledgement from all the receivers that all the initial source symbols have been recovered.

In order to describe our proposed scheme in more detail, we present it against existing error recovery methods specified by 3GPP for the download delivery [2]. Depending on the error recovery scheme used, the following three different methods should be assumed:

- Method M1: Retransmission of the lost file's segments.
- Method M2: Prefixed FEC overhead during the e-MBMS service transmission combined with retransmission of lost file's segments.
- Method M3: Exclusive transmission of redundant symbols for file recovery (proposed scheme).

Assuming that an MBMS download delivery of a file is performed using MBSFN operation, then based on the error recovery method used (M1, M2 or M3), the transmission process proceeds as described in the rest of this section. The same description is also illustrated in Figure 1.

Initially, we examine the case where no FEC is used (Figure 1, M1). In this case, the single error recovery scheme used is the packet retransmission and thus the receivers request the retransmission of the lost file's segments at the end of the process. Since MBSFN operation is used, the lost segments are transmitted to all the users in the area irrespectively of whether they have requested them or not. On the other hand, in case FEC is used (Figure 1, M2 and M3), then the file to be downloaded is partitioned into one or several so-called source blocks. As mentioned above, for each source block, additional repair symbols can be generated by applying Raptor encoding.

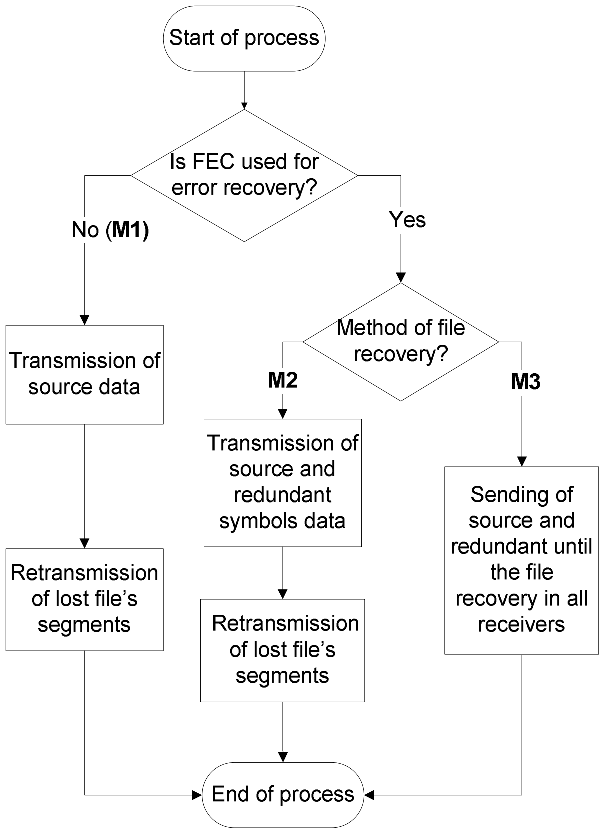

Figure 1. Flowchart of error recovery methods.

The ideal situation in an MBMS session is that all the multicast receivers have collected the source blocks from the file and therefore the complete file recovery is possible. Nevertheless, the above occasion rarely happens. In most of cases, due to miscellaneous network conditions receivers cannot recover all the source blocks or some of the received blocks are corrupted. In order to solve this situation and repair lost or corrupted file segments, we can use the standardized method defined by 3GPP in [2] (Figure 1, M2). According to this method, the complete error recovery may be achieved through the transmission of source and redundant data in combination with the file repair procedure, i.e. the selective retransmission of lost file's segments that takes place at the end of the transmission.

On the other hand, the scheme that we propose introduces the exclusive use of FEC for efficient error recovery during MBMS transmission over MBSFN. In more detail, redundant symbols are produced continuously by the sender until the sender has received acknowledgment messages from all the receivers participating in the multicast group (Figure 1, M3). On the MBMS receiver's side, each receiver sends back to the sender an acknowledgment message upon collection of the encoding symbols that are sufficient for the complete file recovery. The sender keeps track of which receivers have acknowledged and continues to send redundant encoding symbols until all receivers have acknowledged the file recovery.

IV. PERFORMANCE EVALUATION

The system simulation parameters that were taken into account for our simulations are presented in Table I. The typical evaluation scenario used for LTE is macro Case 1 with 1.4 MHz bandwidth and low UE mobility. The propagation models for macro cell scenario are based on the Okamura-Hata model [4].

TABLE I. SIMULATION SETTINGS

Parameter	Units	Value
Cellular layout		Hexagonal grid, 19 cell sites
UE drop location cells		7
Inter Site Distance (ISD)	m	500
Carrier frequency	MHz	2000
System bandwidth	MHz	1.4
Channel model		3GPP Typical Urban
Path loss	dB	Okumura-Hata
BS transmit power	dBm	46
BS # Antennas		1
UE # Rx Antennas		2
UE speed	Km/h	3

During our simulation experiments, we compare the proposed scheme (M3) with the existing error recovery methods (M1 and M2) presented above. The performance of the above methods is evaluated through a realistic simulation scheme that incorporates all the network parameters and is consistent with the corresponding 3GPP specifications. In this framework, we consider the performance of our scheme under different error rates, user populations and FEC configurations.

As already mention, the evaluation of the above methods is performed from telecommunication cost perspective. The estimation of each factor of the cost is based on the metrics for telecommunication cost for MBSFN transmission given by equation (2) [8]. In brief, the total telecommunication cost for the delivery of the MBSFN consists of the transmission cost over Uu (air) interface, the transmission costs over M1 and M2 interfaces, the processing cost for synchronization and the cost of polling procedure in each e-Node B (base station). For more information over the above procedures and the corresponding costs, we refer the reader to the analysis presented in [8].

$$C_{MBSFN} = C_{Uu} + C_{M1} + C_{SYNC} + C_{Polling} = \left(D_{Uu} + D_{M1} + \frac{D_{M1}}{N_{p\_burst}} \right) \cdot N_p \cdot N_{eNB} + \left(D_{p\_eNB} \cdot N_{cell} + D_{M2} \cdot N_{eNB} \right) \tag{2}$$

Finally it should be clarified that the calculated cost for each method is the sum of the cost for the initial file transmission, the cost for the transmission of the additional packets due to FEC encoding and the cost for the selective retransmission of lost packets:

A. Cost vs. Packet Loss

Having mentioned the distinct error recovery methods that are studied in this work, we evaluate the total costs for different packet loss rates assuming: a) MBSFN retransmission of lost packets (M1), b) application of a fixed amount of FEC for the recovery of lost packets (M2) and c) exclusive transmission of redundant symbols for packet recovery (M3).

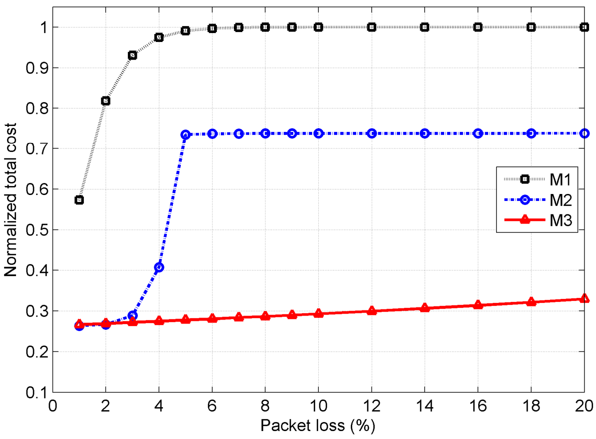

Figure 2. Cost vs. packet loss rate
(UE population = 100, fixed FEC overhead = 5%).

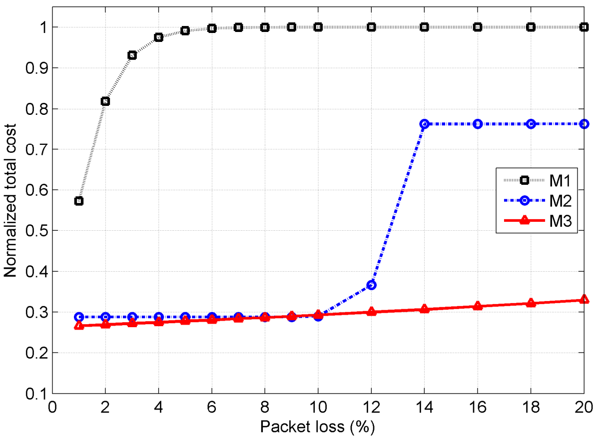

Figure 3. Cost vs. packet loss rate
(UE population = 100, fixed FEC overhead=15%).

In the first instance of the experiment (Figure 2), the fixed overhead used by the FEC encoding has been set to 5%. In Figure 2, the normalized total telecommunication cost, i.e., the value that varies between 0 and 1 and equals to the current cost divided by the corresponding maximum one, is plotted against the packet loss probability. As Figure 2 presents, the conventional retransmission of lost segments (method M1) is the most inefficient method compared to the two other methods that use FEC, irrespectively of the packet loss percentage. Furthermore, in this figure, we observe that method M2 has nearly the same total telecommunication cost with the proposed method (M3) until the packet loss percentage reaches 3%. However, as the packet loss percentage increase, the cost of method M2 increases exponentially. On the other hand, an increase in the packet loss percentage increases the cost of method M3 linearly.

From Figure 3, the first observation is that for higher fixed FEC overhead (15%) method M1 presents the highest total telecommunication cost among the three methods. Figure 3 also reveals that methods M2 and M3 show very close behaviour until packet loss approaches 10%. In method M2 however, higher values of packet loss percentage increase the total telecommunication cost drastically. Therefore, it is worth mentioning that a further increase in FEC overhead of M2 will just increase the total cost without actually improving the overall performance of the FEC scheme. To sum up, the proposed method ensures the lowest total cost irrespectively of the network conditions in terms of packet loss percentage.

B. Cost vs. FEC Overhead

This paragraph presents the impact of the prefixed FEC overhead on the total telecommunication cost for the three methods under investigation. More specifically, Figure 4 presents the normalized total cost of the three methods as a function of the applied FEC overhead percentage when the packet loss rate is equal to 5% and the total number of MBSFN users in the topology is 100. It is worth mentioning that the total telecommunication cost for methods M1 and M3 is constant and does not depend on the prefixed FEC overhead percentage (Figure 4).

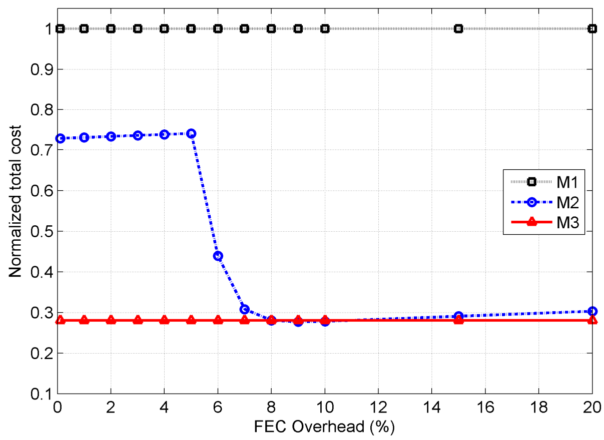

Figure 4. Cost vs. fixed FEC overhead
(packet loss rate = 5%, UE population =100)

On the other hand the prefixed FEC overhead percentage has a direct impact on the performance of method M2. Indeed, when method M2 is applied and the additional information introduced by FEC remains low enough (0%-5%), the unreliable redundant retransmissions keep the total cost in unacceptable high levels. On the other hand, if the percentage of the applied FEC overhead is high enough (in the specific scenario higher than 10%) the total cost increases without actually improving the system's performance. The smaller values of total cost are achieved when the percentage of redundant information introduced by M2 is around 8%.

It is important to mention that the amount of the prefixed FEC overhead is a matter of argument in FEC schemes. Sometimes a small amount does not have any effect to the transmission and, consequently, the need for packets' retransmission and the total telecommunication cost increase. On the other hand, a large amount of a fixed FEC overhead may cause the same results. In any case, as depicted in Figure 4, the proposed scheme (M3) ensures the lowest cost and proves a stable behaviour when network condition changes occur.

C. Cost vs. Multicast User Population

In this paragraph we attempt to analyze the impact of the multicast user population on the total telecommunication cost for the transmission of a multicast MBSFN service. Figure 5 presents the normalized total cost of the three methods as a function of the number of users in the MBSFN area when the packet loss rate is equal to 5% and prefixed FEC overhead introduced by M2 is 5%. One important result is that the conventional retransmissions of lost segments (M1) and the application of a prefixed FEC overhead (M2) may keep the total cost in acceptable levels only for small number of users. As the number of users becomes large, it is evident that methods M1 and M2 do not perform well. This occurs because an increase in the number of users results in an increase of failure probability. This in turn indicates that there is an extra need for retransmission of the lost segments.

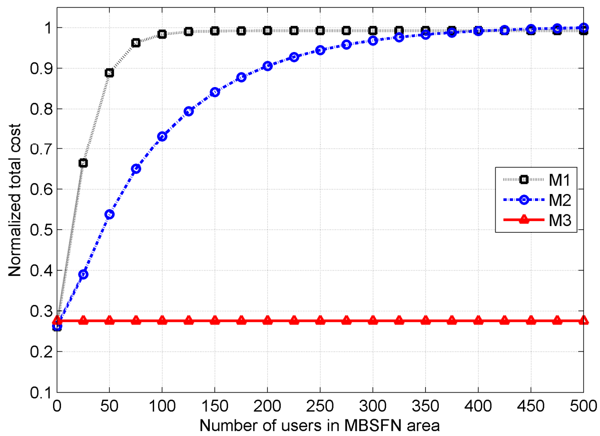

Figure 5. Cost vs. multicast user population
(packet loss rate=5%, fixed FEC overhead = 5%).

On the other hand, Figure 5 reveals that the normalized total cost of the proposed scheme is independent of the number of users and also remains in very low levels. Therefore, sending redundant symbols is proved to be the most efficient way to ensure the reliable reception of MBSFN data among the three methods.

V. Conclusions and Future Work

In this paper we have presented an efficient error recovery scheme for the MBSFN operation over LTE mobile networks. This scheme is based on the Raptor codes standardized by 3GPP for FEC use in cellular multicasting. The scheme that we propose uses exclusively the FEC method for the complete file recovery. The sender generates symbols, through a Raptor FEC encoder, and sends the redundant encoding symbols until it receives an acknowledgment message from all the receivers that participate in the multicast group that the file recovery has been completed. In order to evaluate our approach, we have conducted extensive simulation experiments. Also a direct comparison of our approach with other existing approaches is considered. The simulation results have shown the improved performance of our scheme during MBSFN operation. The reason is that our scheme takes advantage of the properties of MBSFN operation and instead of selectively transmitting lost segments that are probably different among the receivers (due to different packet losses), it transmits redundant information that is necessary to all receivers for the error recovery.

The step that follows this work may be the investigation of the proposed scheme against a p-t-p file repair session. Another idea could be the modelling and the implementation of a mechanism that makes efficient Raptor code selection for LTE networks. This mechanism could monitor the network conditions and use them as input in order to forecast the appropriate amount of redundant symbols for FEC encoding.

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