Adopting FEC for Reliable Multicasting over LTE Networks

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ABSTRACT
The key feature for the provision of Multimedia Broadcast/Multicast Services (MBMS) in Long Term Evolution (LTE) networks is the Multimedia Broadcast over a Single Frequency Network (MBSFN). On the other hand, the use of Forward Error Correction (FEC) in mobile multicast transmission has significant advantages and the 3rd Generation Partnership Project (3GPP) has adopted the application layer FEC in the MBMS standard. In this paper, we investigate the impact of the application layer FEC over the MBSFN delivery method.

Categories and Subject Descriptors
C.2.1 [**Computer-Communication Networks**]: Network Architecture and Design – *Wireless communication*;

General Terms
Measurement, Performance, Reliability, Standardization.

Keywords
Forward Error Correction, Long Term Evolution, Cellular

1. INTRODUCTION
In Multimedia Broadcast over a Single Frequency Network (MBSFN) operation, evolved Multimedia Broadcast/Multicast Service (e-MBMS) data are transmitted simultaneously over the air from multiple tightly time-synchronized cells. A group of those cells which are targeted to receive the broadcast MBSFN data constitute a so called MBSFN area [1].

Forward Error Correction (FEC) is an error control method that can be used to augment or replace other methods for reliable data transmission. The main attribute of FEC schemes is that the sender adds redundant information in the messages transmitted to the receiver. This information allows the receiver to reconstruct the source data. Such schemes inevitably add a constant overhead in the transmitted data and are computationally expensive. In wireless multicasting however, the use of FEC techniques has very strong motivations. This is the reason why 3rd Generation Partnership Project (3GPP) recommends the use of FEC for e-MBMS and adopts the use of Raptor FEC code [2].

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In this paper, we study the application of FEC for MBSFN transmissions over Long Term Evolution (LTE) cellular networks. Since the performance of a FEC scheme mainly depends on the conditions in the LTE network, we consider its performance under different MBSFN deployments, user populations and error rates. Based on these parameters, we calculate the total telecommunication cost that is required for the transmission of the MBSFN data to end users. In this framework, our main target is to investigate the impact of FEC use in e-MBMS. We examine whether the use of FEC is beneficial, how the optimal FEC code dimensioning varies based on the network conditions, which parameters affect the optimal FEC code selection and how they do it. Another aspect that we examine from FEC perspective is the estimation of how many neighbouring cell rings should be included in the same MBSFN area in order to achieve high SFN gains with the lowest possible cost. It is important to mention that the use of FEC for the multicast transmission over LTE networks has not been studied yet. Therefore, it is our belief and the motivation behind our work that the impact of FEC in MBSFN transmissions is a new area of study in the LTE research community.

The paper is structured as follows: Section 2 presents the standardized FEC codes for the reliable transmission of data over e-MBMS service. In Section 3 we present the evaluation results and in Section 4 the conclusions and planned next steps are briefly described.

2. RAPTOR CODES FOR E-MBMS FEC
3GPP standardized Raptor codes as the application layer FEC codes for e-MBMS aiming to improve service reliability [2]. Apart from the provision of improved system reliability, Raptor codes offer a large degree of freedom in parameter choice. Files are mapped to so-called source symbols and the FEC encoder uses the set of source symbols as input in order to produce the encoding symbols. 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. The decoder is able to recover all the source symbols from any set of encoding symbols only slightly more in number than the number of source symbols. Hence, the Raptor codes operate very closely to an ideal erasure code which would require only the exact number of source symbols for recovery.

The Raptor code specified for e-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 *F* is itself code symbols generated by some code with *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 can be found in [5], whereas details on specific parameters are listed in [2].

The simulation results presented in [5] show that Raptor codes have a performance very close to ideal, i.e., the failure probability of the code is such that in case is only slightly more than *k* symbols are received, the code can recover the source block. In fact, for $k > 200$ the small inefficiency of the Raptor code can quite well be modelled by the following equation [5]:

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

In the above equation, $p_f(m,k)$ 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 with increasing number of received symbols.

3. PERFORMANCE EVALUATION

The system simulation parameters that were taken into account for our simulations are presented in Table 1. The typical evaluation scenario used for LTE is macro Case 1 with 10 MHz bandwidth and low User Equipment (UE) mobility. The propagation models for macro cell scenario are based on the Okamura-Hata model [1].

Table 1. Simulation parameters

Parameter	Units	Case 1
Inter Site Distance (ISD)	m	500
Carrier Frequency	MHz	2000
Bandwidth	MHz	10
Penetration Loss (PL)	dB	20
Path Loss	dB	Okumura-Hata
Cell Layout		Hexagonal grid, 3 sectors per site, Infinite rings
Channel Model		3GPP Typical Urban (TU)
# UE / # BS Antennas		2 / 1
UE speed	Km/h	3
BS transmit power	dBm	46
BS Ant. Gain	dBi	14

As already mention, the evaluation is performed from telecommunication cost perspective. The estimation of each factor of the cost is based on the telecommunication cost for MBSFN transmission given by equation (2) [4]. 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 [4].

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

3.1 Simulation Scheme

As it is specified by 3GPP in [2], both techniques of FEC with Raptor codes and selective retransmission of lost segments may be employed by the BM-SC in order to provide reliable data download delivery. The scheme that we have designed and have implemented is consistent with the 3GPP specifications and includes both of the fundamental repair processes. Therefore, it combines the application layer FEC and selective retransmission of lost data. The above recovery processes are both provided via MBSFN transmissions. Our simulation scheme incorporates all the properties of a typical Raptor code defined for data delivery over e-MBMS as they are defined by 3GPP in [3].

Our goal of is the calculation of the total cost for a complete file reception. This cost 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. The estimation is based on (2).

During the decoding procedure in each UE, there is a failure probability given by (1). When a packet loss rate $p_{loss} > 0$ is applied over the e-MBMS bearer, the number of the received symbols *m* may become less that the *n* symbols initially transmitted. As a result of the packet losses, $p_f(m,k)$ increases. If the recovery of the *k* source symbols fails in a UE, then selective retransmission is invoked by the UE for the recovery of the lost packets. This retransmission procedure creates an additional cost which is also taken into account by our scheme.

3.2 Cost vs. MBSFN Deployment

This section evaluates the total cost of each of the MBSFN deployments (AAA, AAI, AII) for different user distributions with and without the application of FEC. Figure 1 depicts the total cost of the SFN transmission with and without FEC for the 3 different deployments (AII, AAI, AAA) as the number of UE drop location cells increases. We observe that for the first 3 user distributions (cases of 1, 7, 19 UE drop location cells), the AII deployment ensures the lowest cost for the delivery of the MBSFN data. On the other hand, for UE drop location cells 37, 61, 91 and 721 cells, AAI is the most cost efficient deployment. For the case of the MBSFN transmission where the users are residing in infinite cells, AAA deployment is more efficient than the other two deployments since it results in a lower overall cost.

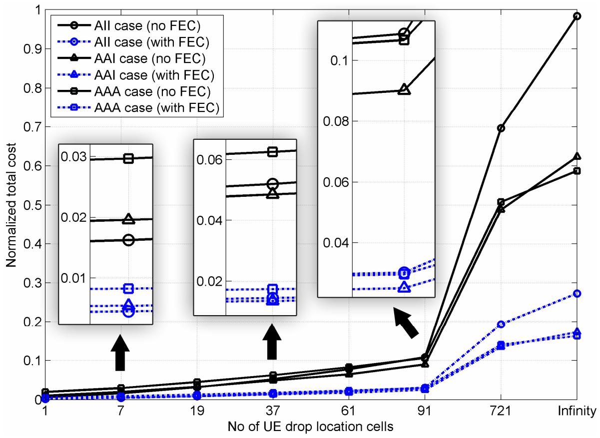

Figure 1. Cost vs. MBSFN Deployment (Packet loss rate = 5%, FEC overhead = 10%, UE population = 100).

Generally, it is necessary to switch between the 3 MBSFN deployments, when the number of UE drop location cells increases, so as to achieve the lowest possible transmission cost. More specifically, as the number of UE drop location cells increases, the most efficient deployment for the delivery of the MBSFN data, switches from AII, to AAI and finally to AAA when the number of cells that have users interested in the MBSFN service approaches infinity (number of cells >> 721). This switching can save resources both in the core network and the air interface. For example, in the case of 721 UE drop location cells, we observe that the normalized total cost without FEC application is 0.6967 when AII is used. However, when AAI is used the total cost is 0.4879. Therefore, the usage of AAI instead of AII can decrease the total telecommunication cost by (0.6967-0.4879) / 0.6967 = 29.96%.

3.3 Cost vs. Multicast User Population

This paragraph presents the impact of multicast user population on the total cost for the transmission of a multicast service via MBSFN. Figure 2 depicts the normalised total cost in function of user population for the three MBSFN deployments, with and without FEC. It is worth mentioning that Figure 2 corresponds to the case of 5% packet loss and 5% FEC overhead. Moreover, the “UE drop location cells” area consists of 7 cells. The examination of Figure 2 leads to the following three observations:

- **Shape of the curves:** The normalized total cost increases as the number of users in the MBSFN area increases; however, the increase when FEC is not applied is more abrupt. Furthermore, the total cost in all cases is converged in a value that depends on the number of MBSFN users in each case. The stabilization of total cost declares that the failure probability is equal to 1 and therefore the retransmission of MBSFN packets is certain. As an aftermath, an additional increase in the number of users will not change the total cost.
- **MBSFN deployment:** The case of AII ensures the lowest total cost, both when FEC is applied or not. This fact constitutes a first confirmation for the correctness of results, since the results are in accordance with work [1]. Indeed, according to [1] for the examined “UE drop location cells” area the case of AII is the most efficient deployment.

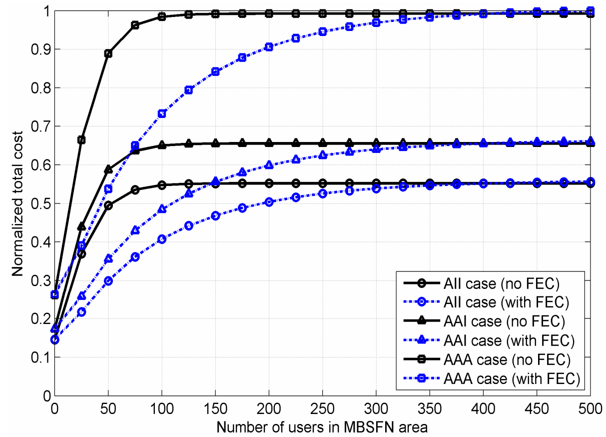

Figure 2. Cost vs. Multicast User Population (Packet loss rate = 5%, FEC overhead = 5%).

- **FEC application:** The most important observation from Figure 2 is that the application of FEC may lead to total cost reduction. Independently of the MBSFN deployment, the application of FEC may lead to reduction of total cost that reaches up to 41% compared to the case where FEC is not applied (this reduction takes place for 25 users in the MBSFN area). However, the application of FEC seems not to influence the total cost when the number of users becomes very large.

The last observation indicates that the amount of redundant information is one of the most critical issues in FEC schemes. Indeed, a small amount may result in unreliable transmissions and therefore in need for packets’ retransmissions and increased total cost. On the other hand, a large amount of redundant information increases the total cost without actually improving the overall performance of the FEC scheme.

3.4 Cost vs. FEC Overhead

This section presents the impact of FEC overhead to the total telecommunication cost for the three different MBSFN deployments under investigation. In Figure 3 the normalized total cost is presented as a function of the percentage of applied FEC overhead when the packet loss rate is equal to 5% and the total number of MBSFN users in the topology is 100.

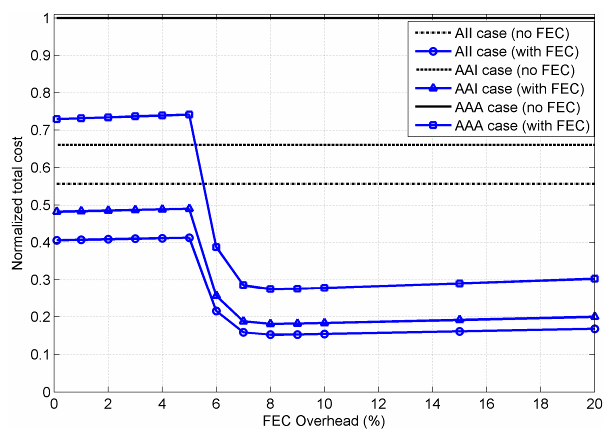

Figure 3. Cost vs. FEC Overhead (Packet loss rate = 5%, UE population = 100).

The most important observation that comes from Figure 3 is that the application of FEC reduces the total telecommunication cost for each of the three different MBSFN deployments. Additionally, we can say that in this simulation scenario, the application of FEC is always preferable to the case that no FEC is applied (for all MBSFN deployments) since the total cost (when FEC is applied) is always smaller than cost of the case which FEC is deactivated.

In the case where FEC is applied, when the additional information introduced by the application of 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 our case around 8%) the total cost increases without actually improving the system's performance. The smaller values of total cost are achieved for all MBSFN deployments when the percentage of redundant information introduced by the application of FEC is around 8%.

3.5 Cost vs. Packet loss

The last part of our experiments is the evaluation of the cost during MBSFN transmission versus the packet loss with and without FEC for various MBSFN deployments. Figure 4 and Figure 5 illustrate the simulation results for different values of FEC overhead.

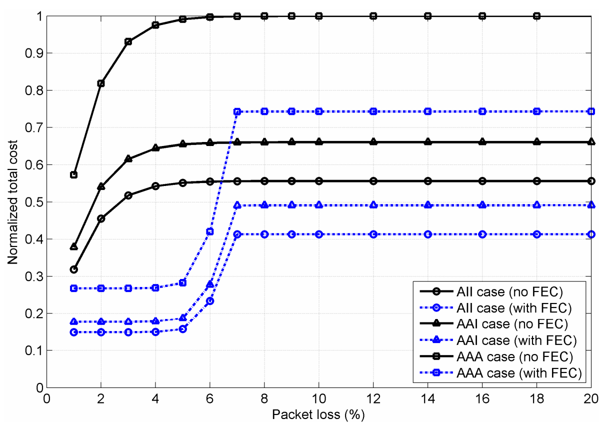

Figure 4. Cost vs. Packet loss rate (UE population = 100, FEC overhead = 7%).

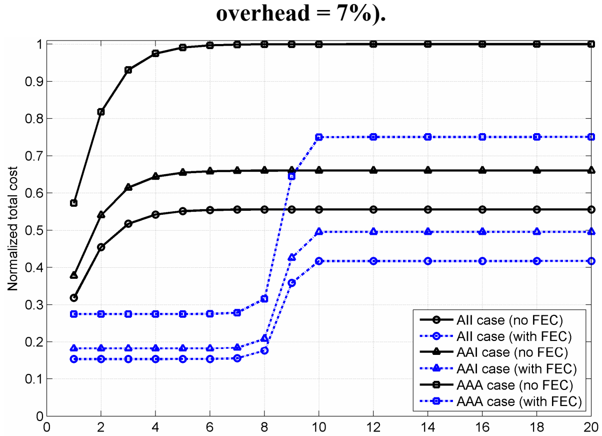

Figure 5. Cost vs. Packet loss rate (UE population = 100, FEC overhead = 10%).

In the first instance of this experiment, the overhead used by the FEC encoding has been set to 7%. In Figure 4, the normalized total telecommunication cost is plotted against the packet loss probability. In this figure, we observe that in order to have a low total cost for MBSFN with FEC overhead 7%, the average packet loss at the MBSFN transmission should not exceed 5%. On the other hand, for packet losses greater than 5%, the cost of MBSFN with FEC is increased exponentially.

For higher values of packet loss and in order to keep the total cost low, the value of FEC overhead should properly increase. As depicted in Figure 5, an increment in FEC overhead from 7% to 10% could cover situations where packet loss reaches 8%. However, a further unnecessary increase in FEC overhead will just increase the total cost without actually improving the overall performance of the FEC scheme are clearly illustrated in Figure 3.

4. CONCLUSIONS AND FUTURE WORK

In this paper, we have investigated the performance of the FEC mechanism which is standardized by 3GPP for the multicast data delivery via e-MBMS service. Our simulation results have shown how the optimal FEC code dimension varies depending on the different network conditions. In more detail, we have determined the efficient working point in the trade-off between the FEC code overhead and the retransmission cost. We have concluded that parameters like the MBSFN deployment, the multicast user population and the packet loss probability affect this trade-off and we have investigated how they do it. It is important to mention that all the above results have been qualitatively assessed and explanations for the model behaviour have been given. A general conclusion is that an appropriate selection of FEC redundant symbols makes the FEC use beneficial. Actually, the amount of redundant information is one of the most critical issues in FEC schemes. A small FEC overhead may result in unreliable transmissions and therefore in packets' retransmissions. As an aftermath, the total cost is increased. On the other hand, a large amount of redundant information increases the total cost without actually improving the overall performance of the FEC scheme. The step that follows this work may be the investigation of the FEC schemes from power control perspective.

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