Reliable Multicasting over LTE: A Performance Study

Antonios Alexiou[2], Konstantinos Asimakis[1,2], Christos Bouras[1,2], Vasileios Kokkinos[1,2],
Andreas Papazois[1,2], Georgia Tseliou[1,2]
[1] Research Academic Computer Technology Institute, Patras, Greece
[2] Computer Engineering and Informatics Dept., Univ. of Patras, Greece
alexiua@ceid.upatras.gr, asimakis@cti.gr, bouras@cti.gr, kokkinos@cti.gr, papazois@ceid.upatras.gr, tseliou@cti.gr

***Abstract*—With the booming of multimedia services, the 3rd Generation Partnership Project (3GPP) has introduced the evolved Multimedia Multicast/Broadcast Service (e-MBMS) feature for LTE systems. The main objective of MBMS is to introduce real broadcast distribution capabilities into cellular systems. This purposed 3GPP to introduce the MBMS over a Single Frequency Network (MBSFN) operation. In this work we investigate the provision of MBMS service over a combination of MBSFN and PTM transmission schemes. We focus on the file repair procedure, because the distribution of binary data via MBMS must result in 100% error-free downloaded files. In order to achieve this goal, MBMS offers a Forward Error Correction (FEC) mechanism. Our simulation results show that there are some file repair schemes that achieve better performance as far as different network configurations are concerned. Furthermore, we compare all the file recovery methods and evaluate them against various network parameters in a realistic simulation environment.**

Keywords—long term evolution; multimedia broadcast and multicast; single frequency network; forward error correction;

I. INTRODUCTION

The evolved Multimedia Broadcast/Multicast Service (e-MBMS) in 3rd Generation Partnership Project (3GPP) Long Term evolution (LTE) is characterized by the MBMS Single Frequency Network (MBSFN) operation. The MBSFN operation requires that the identical signals are transmitted from all the base stations at the same time and in the same frequency resources. The key motivation for integrating multicast and broadcast extensions into mobile communication systems is to enable efficient group related data distribution services, especially those which are related to the radio interface [1]. In the rest of this work we use the term MBMS when referring to e-MBMS, without any loss in accuracy.

Multicast delivery can be implemented through a single Point-To-Multipoint (PTM) transmission with MBMS service. Reliable delivery of files is a quite challenging task, as an error-free reception of the files is required. In order to increase the robustness of MBMS transmission an additional Forward Error Correction (FEC) mechanism has been introduced. It is found at the application layer and it is based on Raptor coding. Moreover, users not able to receive the file after the initial MBMS transmission can complete the download in a post-delivery repair phase, where it is possible to perform PTM or MBSFN connections over MBMS service.

FEC mechanisms rely on the transmission of additional parity data that allow recovering the original information when transmission errors occur. For file download services, as it cannot be guaranteed that each and every user will be able to recover the file after the MBMS transmission, since some users might have experienced bad network conditions, a secondary delivery repair phase can be performed in order to complete the file download. In this work we analyze how crucial the choice of FEC overhead is, so as to minimize the telecommunication cost that is introduced.

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 [2], 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. The authors of [3] present an investigation on MBMS download delivery services in UMTS systems considering a comprehensive analysis by applying a detailed and complex channel model. The trade-off between the overhead added by the application layer FEC and the overhead added by the physical layer Turbo codes is examined and it is concluded that the use of a substantial amount of Raptor coding can compensate for the packet loss. In the work presented in [4] 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 that using only a PTM file repair scheme is not efficient, since the sender does not know the amount of repair data that is needed.

The goal achieved by this work is the investigation of several error recovery methods. The investigation is performed through a new mechanism that estimates the total telecommunication cost based on the network configuration for multicast transmission. Apart from the various deployments of MBSFN operation during a transmission, we also examine the PTM operation. The examination of these two schemes is a matter of great importance because in practice, LTE systems will be able to employ both of them to achieve a successful multicast transmission. Moreover, this paper discusses the trade-off between FEC protection and successive file repair procedure. Therefore, the major

978-1-4577-0681-3/11/$26.00 ©2011 IEEE

contribution of our work is the performance evaluation of combinations of different error correction methods with a variety of LTE network configurations.

The rest of the paper is structured as follows: Section II presents an overview of the LTE multicasting. All the examined file repair schemes and the proposed file repair algorithm are presented in Section III. Our simulation experiments and the obtained results are described in Section IV. Finally, in Section V we draw our conclusions and propose ideas for future work.

II. Overview of LTE Multicasting

The distribution of mobile multimedia services requires an efficient transmission system for the simultaneous delivery of content to large groups of mobile users. Multicasting in LTE offers a downlink connection from the network to a managed group of terminals; the content is only transmitted once to the whole group, and only users belonging to the managed user group can receive it.

A. *Transmission Schemes*

In this paper, we examine how the optimal network configuration varies with respect to the estimated telecommunication cost. Due to the fact that typically, a topology served by MBSFN does not produce the sufficient power for transmission, the term assisting cells is defined [5], [6]. By this term we refer to the external cells of the center blue area assist the service and transmit the same MBSFN data (Figure 1). These are called assisting cells formulating assisting rings and are painted with cyan color. Moreover, PTM transmission scheme is indicated with red color. The same convention is used in the rest of this work.

The reason for MBSFN transmission in the assisting cells is that the performance of the MBSFN transmission scheme increases rapidly when assisting cells that transmit the same MBSFN data are added to the topology. More specifically according to [5] and [6], even the presence of one assisting ring can significantly increase the overall spectral efficiency and the total telecommunication cost. Moreover, we assume that a maximum of 3 neighboring rings outside the center cells can transmit in the same frequency and broadcast the same MBSFN data (assisting rings), since additional rings do not offer any significant additional gain in the MBSFN transmission [5], [6].

Throughout our work we define the following configurations that have been analyzed in [7]:

- MBSFN area deployment with AII (one assisting ring and two interfering rings),
- MBSFN area deployment with AAI (two assisting rings and one interfering),
- MBSFN area deployment with AAA (three assisting rings),
- PTM only transmission (no MBSFN is used).

In Figure 1, we present some examples of different network configurations for a specific user distribution. We assume that the belonging cells can be served either with MBSFN operation or with PTM. The MBSFN area consists of cells marked with blue or cyan color. In case of MBSFN transmission the users are located in the blue cells. Whereas in the case of PTM transmission the corresponding cells are marked with red color.

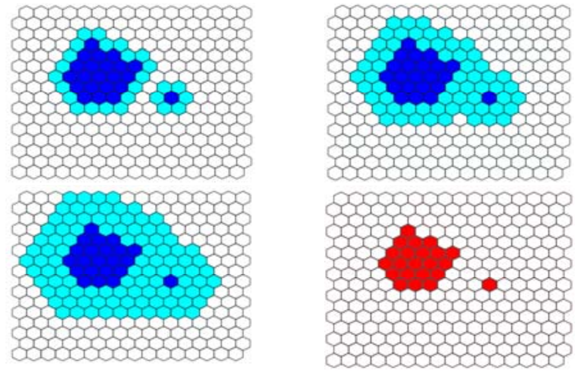

Figure 1. Different network configurations for a given user distribution.

B. *Application Layer FEC*

The systematic Raptor Code developed by Digital Fountain is chosen for MBMS error correction [7]. The Raptor Code belongs to the class of fountain codes. It can generate an arbitrary number of FEC redundant symbols out of one source block. Raptor Codes produce as many encoding symbols as needed for the file repair procedure. Using them wastefully, can add huge transmission cost during a session. However, in multicast protocols their use has really strong motivations since they take advantage of all the properties of multicasting such as the elimination of the effect of independent losses at different receivers. This makes these schemes able to scale irrespectively of the actual loss pattern at each receiver. Furthermore, the dramatic reduction in the packet loss rate largely reduces the need to send feedback to the sender.

This special property of the Raptor Code fits exactly the needs for file repair method. A broadcast of newly created FEC packets benefits all the receivers, which have not successfully reconstructed the original source block. The Raptor encoder can generate as many encoding symbols as desired on the fly from the source symbols of a source block of data [8]. Raptor codes subdivide files into a number of source blocks and the FEC repair symbols are generated for each source block.

Ultimately the most important parameter is FEC overhead (i.e., amount of parity data transmitted), since on the one hand very little overhead may result in a low robust transmission not allowing most users to recover the file, but on the other hand a very robust transmission consumes resources that could be used for other services.

C. *File Repair Procedure*

The purpose of file repair procedure is to repair lost or corrupted file segments that appeared during the download of the MBMS service [9]. At the end of the MBMS data transmission each 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.

This procedure has several important drawbacks. 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. FILE REPAIR AND COST ESTIMATION

The following three different methods are considered, depending on the utilized error recovery scheme:

- Approach A1: Retransmission of the lost file's segments.
- Approach A2: Prefixed FEC overhead during the e-MBMS service transmission combined with retransmission of lost file's segments.
- Approach A3: Exclusive transmission of redundant symbols for file recovery.

Initially, we examine the approach where no FEC is used (A1). In this case, the single error recovery scheme used is the packet retransmission and thus the receivers request the retransmission of the 1st file's segments at the end of the process. Since MBSFN and PTM operations are 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 (A2 and A3); the file to be downloaded is partitioned into one or several source blocks. As mentioned above, for each source block, additional repair symbols can be generated by applying Raptor encoding.

Ideally, in an MBMS session, 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, the standardized method defined by 3GPP in [9] (A2) can be used. 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 exclusive use of FEC for efficient error recovery during MBMS transmission over MBSFN. In more detail, the sender produces redundant symbols continuously until it has received acknowledgment messages from all the receivers participating in the multicast group (A3). Therefore, each receiver sends to the sender an acknowledgment message upon collection of the encoding symbols that are sufficient for the complete file recovery.

Below, we present the main algorithm for the calculation of the telecommunication cost for each error correction approach. The main idea starts with the creation of the MBSFN deployment (in case of PTM transmission there is no MBSFN deployment). According to the selected deployment, we choose a certain file repair procedure, among the existing approaches that are presented in Section III, and calculate the normalized telecommunication cost for the certain file repair scheme. The value of the normalized cost varies between 0 and 1 and equals to the current cost divided by the corresponding maximum one.

```
% Cost Estimation Mechanism for
File Repair Schemes and Deployments

deployment = create_deployment( )
switch(file_recovery_approach)
case (retransmission)
        identify_missing_file_segments( )
        r=retransmit(packet_num, deployment)
        calculate_cost(r)
case (prefixed_FEC_overhead)
        break_file_into_source_blocks( )
        identify_missing_file_segments( )
        define_prefixed_FEC_code( )
        while(FEC>=0)
        {
                a1=recover_with_FEC(packet_num,deploment)
                calculate_cost(a1)+= calculate_cost(a1)
        }
        a2=retransmit(rest_packet_num, deployment)
        calculate_cost(a2)
        total =calculate_cost(a1)+ calculate_cost(a2)
case (redundant_symbols)
        break_file_into_source_blocks( )
        identify_missing_file_segments( )
        create_raptor_coder/decoder( )
        while(receive_acknowledgment)
        {
                for(i=0;i<MAX_SYMBOLS;i++)
                {
                        send_symbols(i)
                        calculate_cost(i)+=calculate_cost
                }
        }
end
```

The pseudo-code distinguishes three cases that represent the three file repair approaches. The implementation of the first case includes the identification of missing file's segments, the simple retransmission of them and the calculation of the total normalized telecommunication cost. In the second case we declare the amount of the prefixed FEC coding in the algorithm. The file repair procedure uses symbols depending on the amount of FEC coding and when this amount is consumed, simple retransmission starts. In this case, two parts of cost are calculated and summed. When the file repair scheme consists only of Raptor coding, we keep track of which receivers have acknowledged and continue to send redundant encoding symbols until all receivers have acknowledged complete file recovery.

IV. Experimental Results

The three error correction approaches presented in Section III are applied over each one of the configurations presented in Section II. For each case we calculate the total telecommunication cost concerning different factors such as packet loss and number of users in each cell that requests MBMS service. The system simulation parameters that are 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. All the experiments are carried out for 100 multicast users. The propagation models for macro cell scenario are based on the Okamura-Hata model [7].

TABLE I. Simulation Settings

Parameter	Units	Value
Cellular layout		Hexagonal grid
Inter Site Distance (ISD)	m	500
Carrier frequency	MHz	2000
System bandwidth	MHz	1.4
Channel model		3GPP Typical Urban
BS transmit power	dBm	46
UE speed	Km/h	3

It is important to clarify that the evaluation of the above file repair 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 (1) [10]. In brief, the total telecommunication cost for the delivery of the MBSFN consists of the transmission cost over air interface [1], the transmission costs over core interfaces ([11], [12]) the processing cost for synchronization (only for the MBSFN transmission scheme) 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 [10].

$$C_{MBSFN} = C_{Uu} + C_{M1} + C_{SYNC} + C_{Polling} = \left(D_{Uu} + D_{M1} + \frac{D_{M1}}{N_{p\_burst}} \right) \cdot N_p \cdot N_{eNB} + \left(D_{p\_eNB} \cdot N_{cell} + D_{M2} \cdot N_{eNB} \right) \quad (1)$$

The estimation of the PTM cost takes into account the air interface and core network telecommunication cost. Taking this into account, it can be assumed that the below equation shows the total cost for PTM transmission scheme:

$$C_{PTM} = C_{Uu} + C_{M1} + C_{Polling} = \left(D_{Uu} + D_{M1} \right) \cdot N_p \cdot N_{eNB} + \left(D_{p\_eNB} \cdot N_{cell} + D_{M2} \cdot N_{eNB} \right) \quad (2)$$

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. *Telecommunication Cost for Different Parameters*

In this paragraph we evaluate the total cost for file recovery for the configurations of Figure 1.

1) *Telecommunication Cost vs. Number of Multicast Users*

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 MBMS service. Figure 2 presents the normalized total cost of the three approaches as a function of the number of users in the MBSFN area. The packet loss rate is 5% and the amount of the prefixed FEC overhead is 5%.

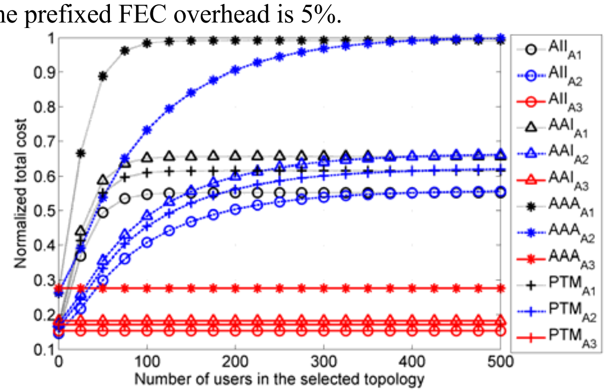

Figure 2. Total cost vs. Number of Users.

One important result is that the conventional retransmissions of lost segments (A1) and the application of a prefixed FEC overhead (A2) may keep the total cost in acceptable levels only for small number of users. As the number of users becomes large, approaches A1 and A2 do not perform well because the increase in the number of users results in an increase of failure probability. This in turn means that there is an extra need for retransmission of the lost segments. Approach A3 (sending redundant symbols) is proven to be the most efficient way to ensure the reliable reception of MBSFN data among the three methods. Moreover, the cost for file repair in PTM transmission scheme is between the cost for AII (MBSFN with one assisting ring) and AAI (MBSFN with two assisting rings) and remains in acceptable levels as the multicast population increases. Deployment AII appears to be the optimal one among the others.

2) *Telecommunication Cost vs. Packet Loss*

As presented in Figure 3, the conventional retransmission of lost segments (approach A1) is the most inefficient method compared to the other two methods that utilize FEC,

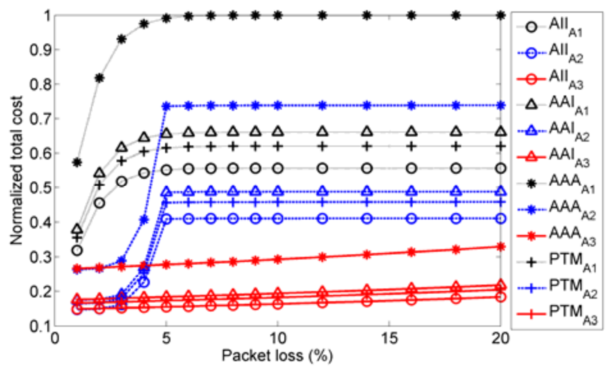

Figure 3. Total Cost vs. packet loss.

irrespectively of the packet loss percentage. The fixed parameters in this experiment are the number of multicast users (100) and the prefixed FEC overhead (5%). It is interesting to observe that deployment AII is the most cost efficient as the packet loss is augmented.

Furthermore, in Figure 3, we observe that approach A2 has nearly the same total telecommunication cost with A3 until the packet loss percentage reaches 3%. However, as the packet loss percentage increases, the cost of approach A2 increases exponentially. On the other hand, an increase in the packet loss percentage causes a linear increment of the cost of A3.

3) Telecommunication Cost vs. FEC Overhead

This paragraph presents the telecommunication cost concerning the amount of prefixed FEC overhead, which is a really controversial issue in FEC schemes. It has been observed that a small amount of FEC overhead does not affect the transmission and, consequently, the need for packets' retransmission remains high. In this case, the total telecommunication cost increases. The experiments presented below have been carried out with the application of 5% packet loss and 100 multicast users.

In Figure 4, the approach A3 ensures the lowest cost and proves a stable behavior when network conditions change. Another observation is that, the prefixed FEC overhead percentage has a direct impact on the performance of approach A2. While the additional information introduced by FEC remains low enough (until 5%), the unreliable redundant retransmissions keep the total cost in unacceptable high levels. After this limit, the approach A2 shows the same results as those of approach A3. The smaller values of total cost are achieved when the percentage of redundant information introduced by A2 is around 8%. Therefore, a general conclusion is that deployment AII shows the optimal behavior among all the proposed deployments, for the examined parameters.

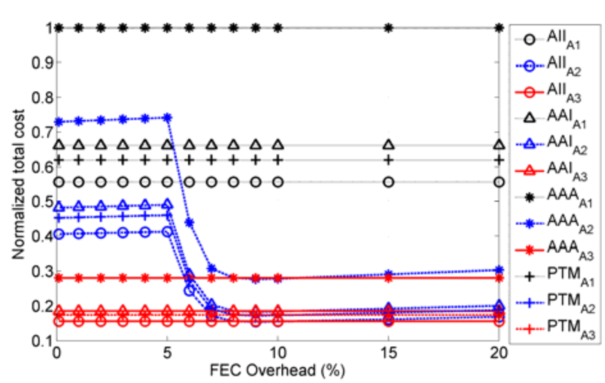

Figure 4. Total cost vs. FEC overhead.

B. Telecommunication Cost for a Scalable Topology

This experiment calculates the total cost for file recovery, while the topology that the users appear increases from 1 to 21 cells (Figure 5). The final topology is constructed in 14 steps sequentially by adding cells, neighboring to the first cell. The experiment takes into account the following variables: 100 multicast users, 5% prefixed overhead and 5% packet loss.

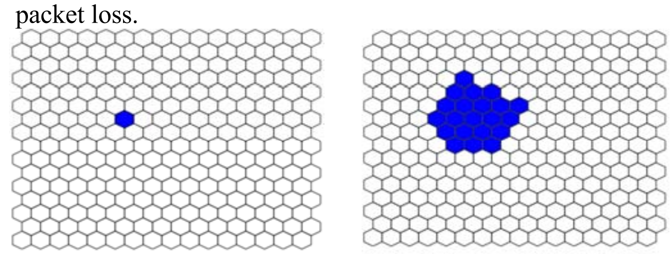

Figure 5. First and final snapshot of the created topology.

As Figure 6 to Figure 8 present, the MBSFN operation (AII, AAI and AAA) does not always appear as the most cost efficient deployment. Indeed, when the topology consists of a small number of cells, the PTM transmission scheme results in the lowest telecommunication cost. On the other hand, for larger number of cells, deployments that use MBSFN operation show a better performance since it is more cost-efficient to transmit data over MBSFN when the set of adjacent cells where multicast users roaming increases.

In Figure 6, we observe that the highest telecommunication cost for file recovery using simple retransmission of the lost files' segments, appears in the topology that uses MBSFN operation with three assisting cells. Moreover it is quite interesting to mark that conventional retransmission seems more cost-efficient for the deployment that uses PTM. Especially for a small number of cells (1-16), PTM deployment achieves smaller values of cost.

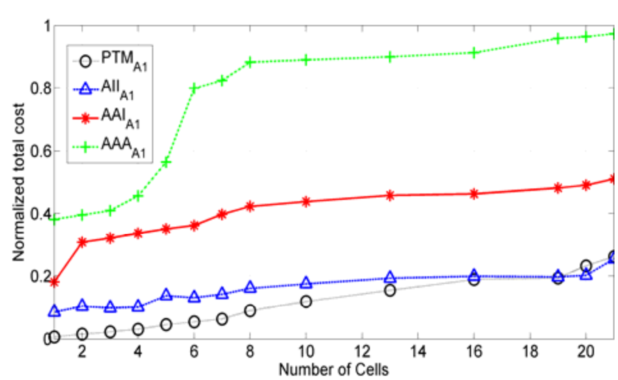

Figure 6. Total cost for Approach 1 (Retransmission).

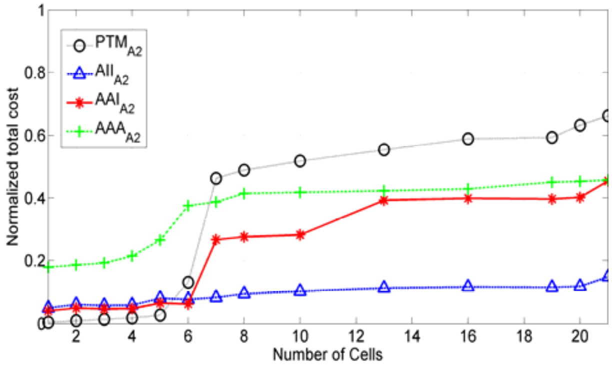

Figure 7. Total cost for Approach 2 (Prefixed Overhead).

As far as Figure 7 is concerned, PTM transmission scheme seems to be more cost efficient than the others, only for a small number of cells (1-5). For larger number of cells, the corresponding cost increases radically due to the fact that the prefixed number of FEC coding has been consumed and also retransmission of repair symbols is necessary. Deployment AII shows similar behavior with AAI for a small number of cells (1-6) but for larger number of cells cost for AAI increases rapidly. The overall conclusion is that AII shows generally a stable and cost efficient behavior.

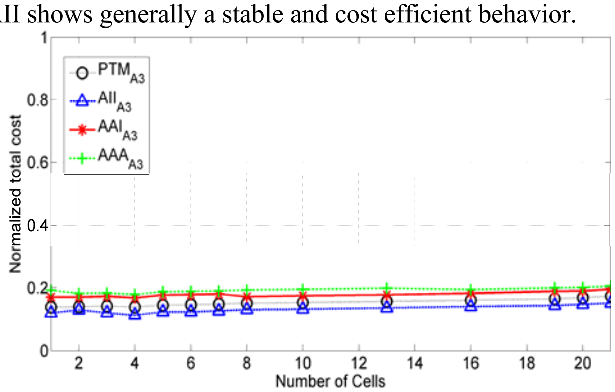

Figure 8. Total cost for Approach 3 (Redundant Symbols).

Finally, by observing Figure 8 we notice that Approach 3 proves a stable behavior for all the concerning deployments and results in low cost independently of the number of cells.

The three figures depicted above, can be compared to draw some general results. None of the file repair approaches can be considered optimal for all the network configurations. It is interesting to observe that for a small number of cells retransmission and the approach that uses prefixed overhead seems to have better results compared to Approach 3. So, depending on the network configuration and the file transmission scheme we can choose the optimal file repair scheme.

V. CONCLUSIONS AND FUTURE WORK

In this paper, we have presented a complete evaluation study on the provision of reliable MBMS service through MBSFN and PTM transmissions. The error recovery schemes that we have examined include the approaches standardized by 3GPP and a proposed one that employs exclusively FEC for the file repair. The evaluation of the different transmission schemes, MBSFN deployments and error recovery methods, has been performed using a metric that reflects the total telecommunication cost for the MBMS service provision. The conducted experiments have led to some important results concerning the reliable multicast data delivery over MBSFN and PTM transmission schemes. We have observed that the total telecommunication cost is strongly related with the network configuration in terms of transmission scheme, MBSFN deployment and error recovery method. Our quantitative analysis can define the optimal network configuration that minimizes the total cost based on the multicast user distribution.

The step that follows this work could be the investigation of the proposed file repair approach and the modeling and 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 to decide on the appropriate amount of redundant symbols for FEC encoding.

REFERENCES

[1] 3GPP TS 36.300, V9.1.0. "Technical Specification Group Radio Access Network; E-UTRA and E-UTRAN; Overall description; Stage 2 (Release 9)", 2009.

[2] Alexiou A., Bouras C., and Papazois A., "Adopting Forward Error Correction for Multicasting over Cellular Networks", in Proc. EW 2010.

[3] Luby M., Gasiba T., Stockhammer T. and Watson M., "Reliable Multimedia Download Delivery in Cellular Broadcast Networks", IEEE Trans. on Broadcasting, 53 (2), 2007, pp. 235-246.

[4] Luby M., Watson M., Gasiba T., Stockhammer T., and Xu W., "Raptor codes for reliable download delivery in wireless broadcast systems", in Proc. CCNC 2006, pp. 192-197

[5] 3GPP TS 23.246 V9.0.0, "Technical Specification Group Services and System Aspects; MBMS; Architecture and functional description (Release 9)", 2008.

[6] Rong L., Haddada O., and Elayoubi S., "Analytical Analysis of the Coverage of a MBSFN OFDMA Network", in Proc. of IEEE Global Communications Conference (GLOBECOM 2008), 2008.

[7] 3GPP TSG RAN WG1 R1-070051, "Performance of MBMS Transmission Configurations", 2007.

[8] Rummler R, Chung Y, Aghvami H. "Modeling and Analysis of an Efficient Multicast Mechanism for UMTS", IEEE Transactions on Vehicular Technology; 54(1), pp. 350-365, 2005.

[9] 3GPP TS 26.346 V7.8.0, "Technical Specification Group Services and System Aspects; MBMS; Protocols and codecs (Release 7)", 2008.

[10] Alexiou A., Bouras C., Kokkinos V. and Tsichritzis G. "Communication Cost Analysis of MBSFN in LTE", in Proc. of the 21th Annual IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC'10), Istanbul, Turkey, 2010.

[11] Holma H, Toskala A. "LTE for UMTS - OFDMA and SC-FDMA Based Radio Access", JohnWiley & Sons: Chichester, 2009. ISBN 9780470994016.

[12] 3GPP TS 36.201, V8.3.0. "Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); LTE Physical Layer - General Description (Release 8)", 2009.