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# Cost optimization of MBSFN and PTM transmissions for reliable multicasting in LTE networks

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**Abstract** Long Term Evolution (LTE) systems have been specified and designed to accommodate small, high performance, power-efficient, end-user devices. The evolved Multimedia Broadcast/Multicast Service (e-MBMS) feature is introduced by the 3rd Generation Partnership Project (3GPP) as a complement to the existing MBMS service in order to accommodate multicast groups that are interested in receiving the same data. MBMS service is provided by MBMS over a Single Frequency Network (MBSFN) and/or Point-To-Multipoint (PTM) transmission methods. One of the challenges of MBMS is the complete error recovery of the transmitted files, a matter of great importance since the distribution of binary data must result in 100% error-free download. To fulfill this tight requirement, Forward Error Correction (FEC) mechanism has been proposed by 3GPP. In this work, we investigate the reliable multicasting by introducing a transmission method that combines the advantages of MBSFN and PTM transmission methods. We compare several FEC-based file recovery methods and evaluate them against various network parameters in a realistic simulation environment. The comparison is based on a cost-oriented analysis of MBMS service that takes into account the transmission cost over all the interfaces and nodes of the LTE architecture. The simulation results are performed with the aid of a new simulation tool and show that the performance of the file repair schemes depend on the network configuration.

**Keywords** Multimedia multicasting · Cellular networks · Forward error correction · Reliability · Single frequency network · Optimization · Point to multipoint

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## 1 Introduction

The evolved Multimedia Broadcast and Multicast Services (e-MBMS) feature constitutes the evolutionary successor of MBMS for Long Term Evolution (LTE) systems. The key motivation for integrating multicast and broadcast extensions into mobile communication systems is to enable efficient group-related data distribution services, especially on the radio interface [1].

The available transmission methods for efficient multi-destination data delivery in cellular networks are the Point-To-Multipoint (PTM) and the MBMS over a Single Frequency Network (MBSFN) transmission method. The former has been proposed by the 3rd Generation Partnership Project (3GPP) and allows data to be transmitted from a single source entity to multiple recipients [1]. It improves the scalability of broadcast and multicast in cellular networks by utilizing a common channel to send the same data to multiple receivers, and thus minimizes the usage of network resources. However, its performance is poor, mainly because the performance of User Equipments (UEs) at the overlapping cellular regions could be affected by destructive interferences, i.e. Inter-Symbol Interference (ISI).

To improve the multimedia data delivery especially at the cell edge, LTE has exploited the Orthogonal Frequency-Division Multiplexing (OFDM) radio interface to transmit e-MBMS data as a multicell transmission over a synchronized Single Frequency Network (i.e. MBSFN). MBSFN transmission enables a more efficient operation of the e-MBMS service, allowing over-the-air combining of multi-cell transmissions towards the UEs [1]. The new standard aims to reduce delays, improve spectrum flexibility and reduce cost for operators and end-users. In the Single Frequency Network (SFN) technology, the base stations transmit to UEs the same signal at the same time and over the same frequency channel.

To support e-MBMS in LTE systems, 3GPP recommends the use of PTM transmissions and MBSFN [1]. In real conditions, rarely one transmission method is used. Commonly, a variety of methods are exploited in order to ensure an efficient transmission. The selection of the transmission method depends on various factors such as the topology, the deployment or the type of data. In this manuscript, we investigate among others, the provision of MBMS service over a combination of MBSFN and PTM transmission methods so as to increase the efficiency of multicast transmissions.

Reliable delivery of files is a challenging task, as an error-free reception of the files is required. In order to increase the robustness of the MBMS transmission, an additional Forward Error Correction (FEC) mechanism at the application layer based on Raptor codes has been introduced. FEC mechanisms rely on the transmission of additional parity data (overhead) that allow the recovery of the original information when transmission errors occur. For file download services, there is no guarantee that every user will be able to recover the file after the initial MBMS transmission. Therefore, a post-delivery repair phase can be performed 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.

Apart from FEC protection, MBMS offers two additional types of file repair procedures: the first uses interactive bearers and the second uses MBMS bearers. In case of file repair, the MBMS client waits until the end of files' or sessions' transmission and then identifies the missing data. Afterwards, it calculates a random back-off time and selects a file repair server randomly out of a list. The file repair server responds with a repair response message that either contains the requested data—redirecting the client to an MBMS download session or to another server—or alternatively, describes an error case. The performance of the post-delivery file repair procedures described above has been analyzed in [2, 3].

In this work, we try to optimize the telecommunication cost that occurs during multicast or broadcast transmission. A cost analysis of the MBMS service is presented based on the transmission cost over all the interfaces and nodes of the LTE architecture. During the evaluation, we take into account the total transmission cost that consists of the packet delivery cost at the network nodes and interfaces and the cost for control procedures.

Main goal of this work is to extend the research works [2] and [3] by evaluating the performance of an MBMS provision scheme that combines MBSFN with PTM transmissions. The examination of these two schemes is a matter of great importance because in practice, LTE systems can employ both of them to achieve a successful multicast transmission. Moreover, an end-to-end cost-based evaluation approach has not yet been studied and it is our belief that this approach contributes to more sophisticated results than other approaches that investigate only the efficiency over the air interface. Furthermore, we discuss the trade-off between FEC protection and successive file repair procedure. We focus on the performance evaluation of the file reliability that can be achieved by the combination of different error correction methods with a variety of LTE network configurations. For the experimental evaluation, we have designed and implemented a simulation tool that examines the various LTE system configurations and makes an optimal selection of the transmission method (MBSFN and/or PTM) over each cell of the LTE network in order to minimize the total telecommunication cost. The tool is available at [4].

The rest of this manuscript is structured as follows: Sect. 2 describes in detail the work related with our study and Sect. 3 describes the e-MBMS architecture. An overview of FEC in LTE is provided in Sect. 4. In Sect. 5 a cost analysis for PTM and MBSFN operation modes is described and in Sect. 6 we describe three FEC methods and an algorithm that estimates the cost for different file repair schemes and deployments. Section 7 describes the performance evaluation of the experiments that are carried out and includes the calculation of the telecommunication cost for different file recovery methods and for a scalable topology that combines MBMS transmissions and FEC. Finally in Sect. 8 our conclusions and some proposals for future work are drawn up.

## 2 Related work

The initial research in the area of multimedia transmission methods was considered in fixed networks and soon, moved to the wireless communication field. On the other hand, FEC in multicast transmission was a great matter of investigation. The standardization of MBMS by 3GPP triggered the research on the use of FEC for multicasting in the domain of mobile networks. Even though this research area is relatively new, a lot of solutions have been proposed so far.

In [5], an introduction to the Raptor code structure is presented. The Raptor codes are described through simple linear algebra notation. Several guidelines for the practical implementation of the relevant encoders and decoders are presented and the good performance of file broadcasting with Raptor codes is verified. The simulation results verify the efficient performance of the whole process. The same authors in [6] investigate the download delivery services in Universal Mobile Telecommunications System (UMTS) MBMS considering a comprehensive analysis by applying a detailed and complex channel model and simulation setup. 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.

In [7], the adoption of FEC is examined from another point of view. A potential bottleneck of the radio network is taken into consideration and the authors investigate which are the optimal operation points in order to save radio resources and use the available spectrum more efficiently. The conducted simulation experiments and the corresponding numerical results demonstrate the performance gain that Raptor code FEC offers in MBMS coverage. In more detail, the spectrum efficiency is significantly improved and resource savings are achieved in the radio network.

The study in [3] focuses particularly on the file repair procedure. The trade-off between FEC protection and successive file repair is discussed extensively. The authors propose a novel file repair scheme that combines PTM filer repair transmission with a Point-to-Point (PTP) file repair procedure. It is proved that the new scheme can achieve better performance than a PTP-only file repair procedure. The overall goal is the optimization of 3G resource usage by balancing the FEC transmission overhead with file repair procedures after the MBMS transmission.

It should be noted that the manuscript constitutes an extension of several previous studies by the same authors, which however focus on the application layer FEC for prior to LTE cellular networks or are limited to the standardized file recovery methods. More specifically, in the study presented in [8], the authors investigate the impact of application layer FEC on power control during mobile multicast transmission in UMTS cellular systems. Studies [9] and [10] present a cost analysis of the MBMS that is based on the transmission cost over all the interfaces and nodes of the LTE architecture. This analysis however, targets at defining the optimal MBSFN configuration; while, it does not take into consideration the file repair procedure that would result in error-free downloaded files. A similar analysis that investigates the performance of the FEC mechanism is presented in study [11]. However, this study only investigates the performance of the standardized (by 3GPP) methods in order to repair the lost or corrupted file segments. Moreover, it does not take into account the PTP transmission for the delivery of the multicast data.

This manuscript presents an extended analysis of the above studies, which is differentiated at several levels. More specifically, the contribution of this work includes the review of the current error recovery methods, an extensive cost analysis of the data delivery during MBMS transmissions (both MBSFN and PTM) in LTE cellular networks and the proposal of a new error recovery scheme, which the simulation experiments prove to be more cost-efficient than the existing standardized ones.

## 3 e-MBMS architecture

The e-MBMS architecture is illustrated in Fig. 1. Within evolved Universal Terrestrial Radio Access Network (e-UTRAN), the evolved Node Bs (e-NBs) or base stations are the collectors of the information that has to be transmitted to users over the air-interface. The new functionalities, which MBMS provides to operators and service providers, are grouped in a new functional node called evolved Broadcast/Multicast-Service Centre (e-BM-SC).

e-BM-SC can be regarded as a functional interface between content delivery services and the MBMS service offered by a cellular network. It is the entity in charge of introducing multimedia content into the 4G networks. For that purpose, the e-BM-SC serves as an entry point for content providers or any other broadcast/multicast source, which is external to the network. Towards the core network the e-BM-SC controls the set-up and release of the MBMS transport bearers and the scheduling of MBMS transmissions.

Within evolved UTRA Network (e-UTRAN), the evolved Node Bs (e-NBs) or base stations are the collectors of the information that has to be transmitted to users over the air-interface. The Multicell/multicast Coordination Entity (MCE) is coordinating the transmission of synchronized signals from different cells (e-NBs). Especially in PTM transmission method, MCE is responsible for the allocation of the same radio resources and can physically be part of the e-NB in the case of a flat architecture. In MBSFN operation MCE is used by all e-NBs in the MBSFN area for multi-cell MBMS transmissions. Besides allocation of the time/frequency radio resources, MCE is also responsible for the radio configuration e.g. selection of modulation and coding scheme.

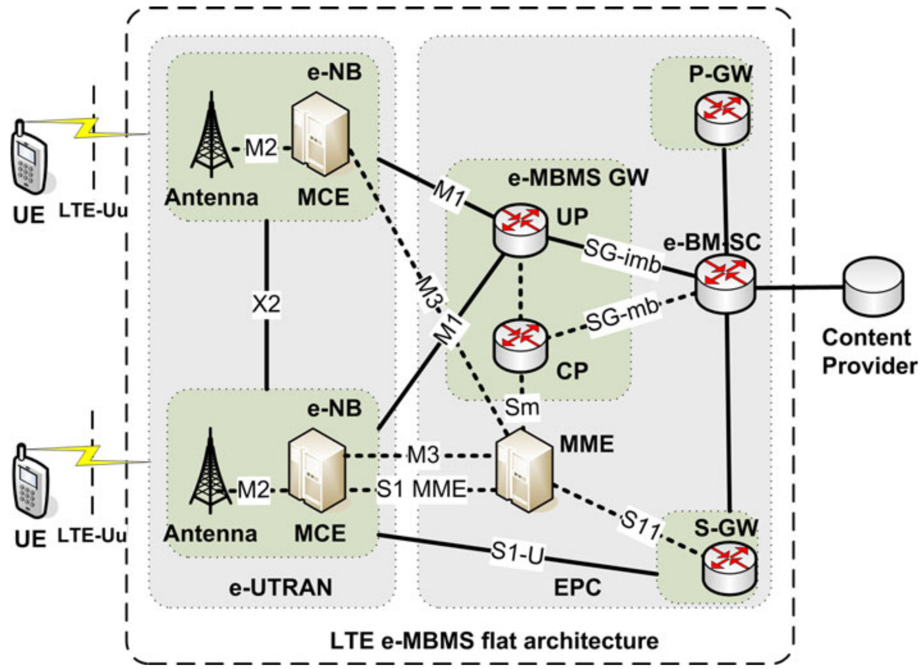


**Fig. 1** e-MBMS flat architecture

The e-MBMS Gateway (e-MBMS GW) is physically located between the e-BM-SC and e-NBs and its principal functionality is to forward the MBMS packets to each e-NB transmitting the service. Furthermore, e-MBMS GW performs MBMS Session Control Signalling (Session start/stop) towards the e-UTRAN via Mobility Management Entity (MME). The e-MBMS GW is logically split into two domains. The first one is related to control plane, while the other one is related to user plane. Likewise, two distinct interfaces have been defined between e-MBMS GW and e-UTRAN namely M1 for user plane and M3 for control plane. M1 interface makes use of IP multicast protocol for the delivery of packets to e-NBs. M3 interface supports the MBMS session control signalling, e.g. for session initiation and termination [1, 12].

In the air (or LTE-Uu) interface, MBMS uses two logical channels (in downlink), namely the Multicast Traffic Channel (MTCH) and the Multicast Control Channel (MCCH). MTCH is a PTM channel for transmitting data traffic to the UEs residing to the service area and enables PTM data distribution. On the other hand, MCCH is a PTM downlink channel used for transmitting MBMS control information from the network to UEs and is associated to one or several MTCHs. MCCH and MTCH are only used by UEs that receive MBMS traffic. Additionally, both MCCH and MTCH are mapped on the MCH, which is a transport channel at the Medium Access Control (MAC) layer. MCH is a broadcast channel that supports semi-static resource allocation with a time frame of a long Cyclic Prefix (CP). MCH is mapped to the Physical Multicast Channel of the physical layer [1, 13].

## 4 Overview of FEC IN e-MBMS

### 4.1 Application layer FEC

The systematic Raptor Code developed by Digital Fountain is chosen for MBMS error correction [14]. 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 need 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 [15]. Raptor codes subdivide files into a number of source blocks and the FEC repair symbols are generated for each source block.

The FEC overhead (i.e. amount of parity data transmitted), is ultimately the most important parameter, 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.

### 4.2 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 [15]. 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 part of the data. Then, the file repair server responds with a repair response message. The repair response message, which may contain the requested data, redirects the client to an MBMS download session or to another server, or alternatively, describes 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 occur 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 case is to protect network resources by spreading in time and across multiple servers the load of the file repair request, something that enhances system's scalability.

## 5 Cost analysis for e-MBMS

In this section, we present a telecommunication cost analysis method for the PTM and MBSFN transmission schemes. The evaluation of the performance of each transmission scheme and the selection of the optimal system configuration is based on this cost analysis. It should be noted that as far as the cost analysis is concerned, we distinguish the total cost for PTM and MBSFN transmission. Independently of the other parts of cost, in order to determine if there is an interested user in the given service, we assume that a polling procedure is taking place. PTM total transmission cost includes cost over the air interface and over the core interface. MBSFN includes the same parts of cost with an addition of the demanded synchronization cost.

The cost metric used in this study includes the telecommunication cost for both packet deliveries and control signal transmissions [16]. Based on the e-MBMS operation that was presented in Sect. 3, we perform an analysis for each type of cost that has to be taken into account for the calculation of the total telecommunication cost for the entire session. In this analysis, we apply the notations presented in Table 1.

### 5.1 Transmission schemes

In Fig. 2, the central dark-blue area consists of cells that contain users. By the term assisting cells, we refer to the surrounding cells of the centre dark-blue area. The assisting cells contribute to the service by transmitting the same MBSFN data [17, 18]. In Fig. 2, the assisting cells formulate assisting rings, which are painted with cyan colour. In case a cell contains users subscribed to the multicast service but is not included in the MBSFN area, the chosen method for transmitting the MBMS data is the PTM transmission method. Therefore, in Fig. 2, the dark-blue cells contain users that receive the service through MBSFN, whereas in the case of PTM transmission, the corresponding cells are marked with red colour. In the rest of this work, the same convention has been used.

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 [17] and [18], the presence of one assisting ring can significantly increase the overall spectral efficiency and the total telecommunication cost. Moreover, we assume that, except for the centre cells that contain users, a maximum of 3 neighbouring rings 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 [17, 18].

Throughout our work, we define the following configurations that have been analyzed in [19]:

- MBSFN area deployment with AII (one assisting ring and two interfering),
- 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 Fig. 2, we present some examples of different network configurations for a specific user distribution. We assume that the cells can be served either with MBSFN operation or with PTM.

### 5.2 Polling cost

In order to examine which cells contain users interested in receiving the MBMS service, we assume that a polling procedure is taking place. It should be noted that we differentiate the cost for MBMS polling from the cost for

**Table 1** Notations for cost analysis

| Abbreviations | Explanation |
|---|---|
| $D_{Uu\_PTM}$ | Transmission cost of single packet over air for PTM |
| $D_{Uu\_MBSFN}$ | Transmission cost of single packet over air for MBSFN |
| $D_{p\_eNB\_PTM}$ | Cost for polling procedure at each e-NB for PTM |
| $D_{p\_eNB\_MBSFN}$ | Cost for polling procedure at each e-NB for MBSFN |
| $C_{Uu\_PTM}$ | Total transmission cost over Uu (air) interface for PTM |
| $C_{Uu\_MBSFN}$ | Total transmission cost over Uu (air) interface for MBSFN |
| $C_{M1\_PTM}$ | Total transmission cost over M1 interface for PTM |
| $C_{M1\_MBSFN}$ | Total transmission cost over M1 interface for MBSFN |
| $N_{eNB\_PTM}$ | Number of e-NBs that participate in PTM (cells with users) |
| $N_{eNB\_MBSFN}$ | Number of e-NBs that participate in MBSFN |
| $N_{cell\_PTM}$ | Total number of e-NBs in the topology for PTM |
| $N_{cell\_MBSFN}$ | Total number of e-NBs in the topology for MBSFN |
| $D_{M1}$ | Transmission cost of single packet over M1 interface |
| $D_{M2}$ | Transmission cost of single packet over M2 interface |
| $N_p$ | Total number of packets of the MBSFN session |
| $N_{p\_burst}$ | Mean number of packets in each packet burst |
| $C_{polling}$ | Total polling cost over air and core interface |
| $C_{polling\_air}$ | Total polling cost over Uu (air) interface |
| $C_{polling\_core}$ | Total polling cost over core interface |
| $C_{SYNC}$ | Total cost for synchronization |
| $C_{PTM}$ | Total telecommunication cost of the PTM transmission |
| $C_{MBSFN}$ | Total telecommunication cost of the MBSFN transmission |
| $C_{TOTAL}$ | Total telecommunication cost of the whole session |

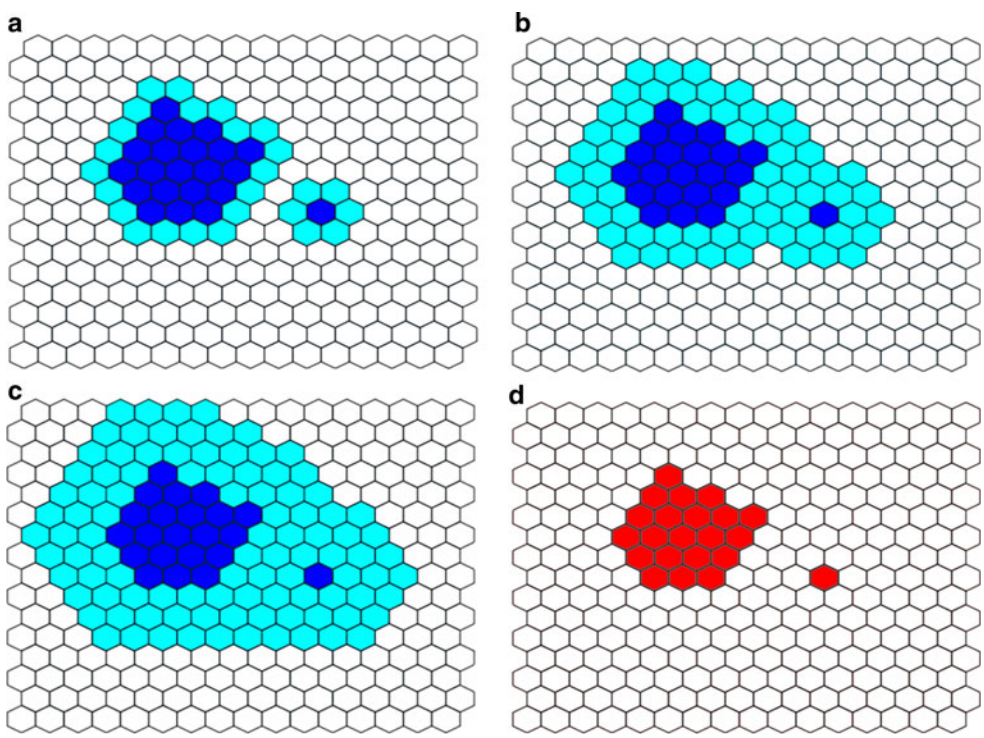


**Fig. 2** Different network configurations for a given user distribution

packet deliveries. In contrast to the counting procedure used for the provision of MBMS in UMTS systems, where the exact number of MBMS users was determined, polling just determines if the cell contains at least one user interested for the given service. The polling cost has a constant value contrary to the other parts of the total cost. Moreover, this cost is too small in comparison to the other parts of the total cost.

The e-NB receives the feedback from the UEs in the form of signature sequence. This information (packet) is sent to the MCE over M2 interface, which estimates which cells contain MBMS users interested in the given MBMS service [20].

$$C_{Polling} = C_{Polling\_air} + C_{Polling\_core} = D_{p\_eNB\_PTM} \cdot N_{cell\_PTM} + D_{p\_eNB\_PTM} \cdot N_{cell\_MBSFN} + D_{M2} \cdot (N_{eNB\_PTM} + N_{eNB\_MBSFN}) \quad (1)$$

The total cost associated to the polling procedure is derived from (1), where $N_{cell\_PTM}$ and $N_{cell\_MBSFN}$ is the number of e-NBs in the topology for PTM and MBSFN transmission schemes (since all e-NBs send a UE feedback request message), $N_{eNB\_MBSFN}$ represents the number of e-NBs that participate in MBSFN transmission and $N_{eNB\_PTM}$ those that participate in PTM transmission. Also the terms $D_{p\_eNB\_PTM}$ and $D_{p\_eNB\_MBSFN}$ represent the cost of polling procedure at each e-NB (equal to $D_{Uu\_PTM}$ and $D_{Uu\_MBSFN,}$ respectively) and $D_{M2}$ is the cost of the delivery of a single packet over the M2 interface (see Fig. 1).

### 5.3 Air interface cost

The transmission cost over the air interface is defined for different network topologies, user distributions and deployments. As shown in Fig. 1, the air interface is the interface Uu that connects the UE and the base station.

In order to estimate the telecommunication cost over the air interface, we define the term resource efficiency percentage (*RE_percentage*). This is the fraction of the current deployment resource efficiency to the maximum resource efficiency that can be achieved for the given user distribution and indicates the quality of the resource efficiency achieved by the examined deployment [19]. In the following analysis, we define the cost of packet delivery over the air interface ($D_{Uu}$) as the inverse of *RE_percentage*. This means that as the resource efficiency of a cell increases, the *RE_percentage* increases too. Thus, the cost of packet delivery over the air interface decreases. In [19], the maximum resource efficiency achieved is 2.4 bps/Hz (infinite topology with AAA MBSFN deployment). According to this, we define the cost of a single packet delivery over the air interface ($D_{Uu}$) as follows:

$$D_{Uu} = \frac{1}{RE\_percentage} = \frac{\max\_resource\_efficiency}{current\_resource\_efficiency} \quad (2)$$

Finally, the total cost for the transmission of the data packets over Uu (air) interface is derived from the following equation:

$$C_{Uu} = C_{Uu\_PTM} + C_{Uu\_MBSFN} \quad (3)$$

The above definition includes the air interface costs for both PTM and MBSFN transmission schemes. In order to make it explicit, the air interface cost for the PTM transmission scheme is derived from (4):

$$C_{Uu\_PTM} = D_{Uu\_PTM} \cdot N_p \cdot N_{eNB\_PTM} \quad (4)$$

The term $N_{eNB\_PTM}$ represents the number of e-NBs that participate in PTM transmission, $N_p$ the total number of packets of the session and $D_{Uu\_PTM}$ is the cost of the delivery of a single packet over the air interface.

Similarly, in (5), the equivalent terms are defined for the MBSFN transmission scheme.

$$C_{Uu\_MBSFN} = D_{Uu\_MBSFN} \cdot N_p \cdot N_{eNB\_MBSFN} \quad (5)$$

### 5.4 Core network cost

The cost over M1 interface is indicated as the core network telecommunication cost. M1 interface uses IP multicast protocol for the delivery of packets to e-NBs. The total cost for the transmission of the data packets over M1 interface for PTM and MBSFN transmission schemes is derived from (6) and (7). The term $D_{M1}$ is the cost of the delivery of a single packet over M1 interface. It is obvious that this cost depends on the number of e-NBs that participate in the PTM and MBSFN transmission, respectively.

$$C_{M1\_PTM} = D_{M1} \cdot N_P \cdot N_{eNB\_PTM} \quad (6)$$

$$C_{M1\_MBSFN} = D_{M1} \cdot N_P \cdot N_{eNB\_MBSFN} \quad (7)$$

Furthermore, $D_{M1}$ depends on the number of hops between the nodes connected by M1 interface and the profile of the M1 link in terms of its capacity [10]. Generally, a high link capacity corresponds to a low packet delivery cost over M1 and a small number of hops, corresponds to a low packet delivery cost.

### 5.5 Synchronization cost

The synchronization cost appears only in the case of MBSFN transmission scheme. By the term synchronization, we refer to the timing for radio frame transmission and the detection of packet loss. The packets' robustness is conducted with respect to packet loss and the synchronization process utilizes time stamps, sequence numbers, and byte counters.

The transmissions from multiple cells (e-NBs) in an MBSFN area must be tightly time-synchronized with an accuracy of a few μs to achieve symbol-level alignment within the cyclic prefix. The method of achieving synchronization is selected by the e-NB. The overall user plane architecture for content synchronization is depicted in Fig. 3.

The SYNC protocol layer is defined on transport network layer to support content synchronization. It carries additional information that enables e-NBs to identify the timing for radio frame transmission and detect packet loss. The SYNC protocol operates between e-BM-SC and e-NB. As a result, synchronization ensures that the same content is sent over the air to all UEs [1].

The total telecommunication cost for the transmission of the synchronization packets is derived from the following equation, where $D_{M1}$ is the cost of the delivery of a single packet over the M1 interface and $N_{p\_burst}$ is the mean value of the number of packets transmitted each time in the sequential bursts of the MBSFN session [20].

$$C_{SYNC} = \frac{N_p}{N_{p\_burst}} \cdot D_{M1} \cdot N_{eNB\_MBSFN} \tag{8}$$

### 5.6 Total telecommunication cost

The total telecommunication cost is a metric that takes into account the number of transmitted packets and all the properties of the interfaces and intermediate nodes. It is formed by the combination of PTM, MBSFN costs and the polling costs and therefore is provided by the following sum:

$$C_{TOTAL} = C_{PTM} + C_{MBSFN} + C_{Polling} \tag{9}$$

According to the detailed analysis presented previously in this section, the total cost for the MBSFN transmission is the following:

$$C_{MBSFN} = C_{Uu\_MBSFN} + C_{M1\_MBSFN} + C_{SYNC} \tag{10}$$

The estimation of the PTM cost takes into account the air interface and core network telecommunication cost. The equation below shows the total cost for PTM transmission scheme:

$$C_{PTM} = C_{Uu\_PTM} + C_{M1\_PTM} \tag{11}$$

## 6 File repair and cost estimation

In this section, we analyze three approaches for implementing the file repair procedure. Each approach is used depending on the utilized error recovery scheme:

- Approach A1: Retransmission of the lost file's segments.
- Approach A2: Fixed 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

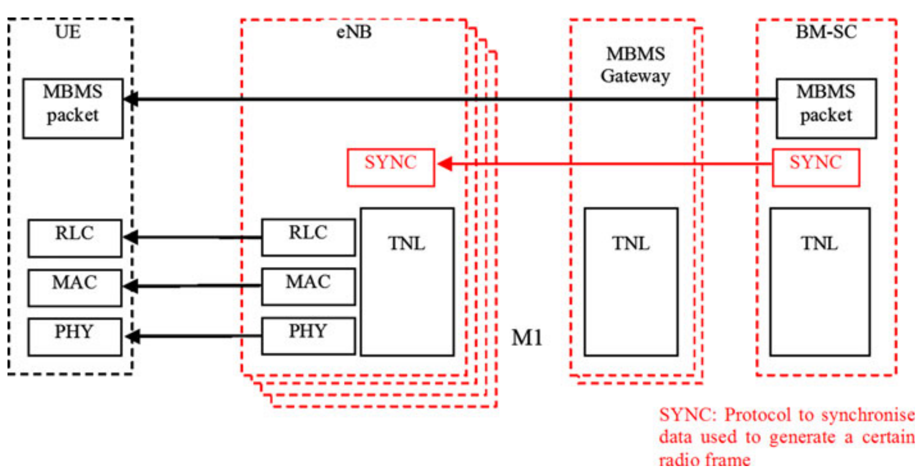


**Fig. 3** Content synchronization in MBSFN

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 [21] (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.

The scheme that we propose introduces exclusive use of FEC for efficient error recovery during MBMS transmission over MBSFN. In 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.

It is worth mentioning that the total telecommunication cost that occurs from the usage of a certain file repair approach depends on the current deployment. So it is necessary to declare how we calculate the telecommunication cost for each file repair scheme. For this purpose, we propose an 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 above, and calculate the normalized telecommunication cost for the certain file repair scheme. This type of normalization over the cost values is used in order to obtain results that are less dependent on the examined network topology. Therefore, we calculate the total cost for each deployment and we then divide the corresponding costs with the maximum cost calculated for the same topology. The value of the normalized cost varies between 0 and 1 and equals to the current cost divided by the corresponding maximum one.

The pseudo-code of the algorithm 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 fixed 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, the two parts of cost (FEC coding and retransmission) are calculated and summed. When the file repair scheme consists only of Raptor coding (third case), we keep track of which receivers have acknowledged and continue to send redundant encoding symbols until all receivers have acknowledged complete file recovery.

```
% 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 (fixed_FEC_overhead)
        break_file_into_source_blocks( )
        identify_missing_file_segments( )
        define_fixed_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
```

Below, we present the pseudo-code of the algorithm that is used for the calculation of the optimal telecommunication cost. It is the main algorithm that was used for the implementation of the MBSFN/PTM Cost Estimation Tool [4]. The main idea is to sequentially compare the intermediate calculated costs until we find the minimum total one. More specifically, the grid subroutine constructs the environment where we carry out our experiments. The evaluate subroutine calculates the total cost for each cell and then returns the cost of the system. The mutate subroutine randomly enables and disables MBSFN cells and returns the changes it recently made. The demutate subroutine can undo those changes later if the evaluation of the grid shows a decrease in the cost of the system topology because of those changes.

**% Telecommunication Cost Optimization Algorithm**

```
grid = create_grid( )
create_rings(grid, number_of_assisting_rings)
cost = evaluate(grid)
best = cost
output("Initial Cost: ", best)
While (not user_break)
        mutations = mutate(grid)
        cost = evaluate(grid)
        if cost < best then
                best = cost
                output("Current cost: ", best)
                export_grid_to_file(grid)
        elseif cost == best then
                best = cost
        else
                demutate(grid, mutations)
        end
end
```

## 7 Performance evaluation

The three error correction approaches presented in Sect. 6 are applied over each one of the configurations presented in Sect. 5.1. For each case, we calculate the total telecommunication cost concerning different factors such as packet loss and number of users in each cell. The system simulation parameters that are taken into account for our simulations are presented in Table 2. 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 [19].

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 and PTM transmission schemes given by (10) and (11) respectively [10]. In brief, the total telecommunication cost for the data delivery during MBSFN operation consists of the transmission cost over air interface [1], the transmission costs over core network [12, 13], the processing cost for synchronization and the cost of polling procedure in each e-Node B (base station). For PTM transmission scheme, the same parameters are involved except for synchronization cost. It is also important to mention that we examine in detail the FEC procedure and we use the conducted cost analysis in order to support our evaluation.

The first part of the experiments concerns the total telecommunication cost for the different approaches presented in Sect. 6. We modify some parameters such as the packet loss, the number of multicast users and the FEC overhead. In the second part, we conduct experiments that combine MBMS service and FEC methods. We calculate the total cost for file recovery, while the number of cells that obtain multicast users increases.

**Table 2** Simulation setting

| Parameter | Units | Value |
|---|---|---|
| Cellular layout | | Hexagonal grid |
| Inter site distance (ISD) | m | 500 |
| Carrier frequency | MHz | 2,000 |
| System bandwidth | MHz | 1.4 |
| Channel model | | 3GPP typical urban |
| BS transmit power | dBm | 46 |
| UE speed | Km/h | 3 |

### 7.1 Telecommunication cost for file recovery

In this paragraph, we calculate the total telecommunication cost for file recovery for the configurations depicted in Fig. 2.

#### *7.1.1 Telecommunication cost versus number of multicast users*

Initially, 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 4 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 set to 5% and the amount of the fixed FEC overhead is also set to 5%.

An important result is that the conventional retransmissions of lost segments (A1) and the application of a fixed FEC overhead (A2) may keep the total cost in acceptable levels only for small number of users. As the number of users increases, approaches A1 and A2 do not perform efficiently 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 varies 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.

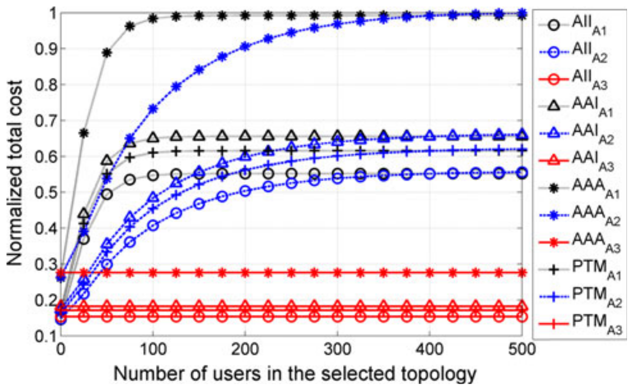


**Fig. 4** Total cost versus number of users

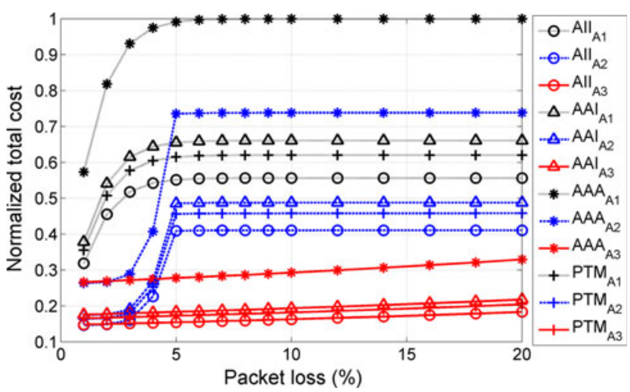


**Fig. 5** Total cost versus packet loss rate

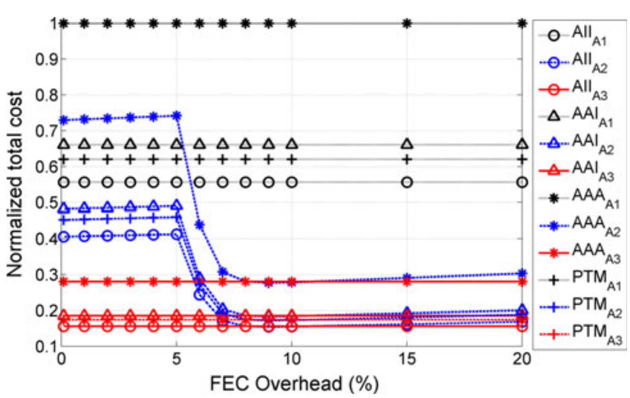


**Fig. 6** Total cost versus FEC overhead

### *7.1.2 Telecommunication cost versus packet loss*

For different packet loss rates, as presented in Fig. 5, the conventional retransmission of lost segments (approach A1) is the most inefficient method compared to the other two methods that utilize FEC, irrespectively of the packet loss percentage. The fixed parameters in this experiment are the number of multicast users (set to 100) and the fixed FEC overhead (set to 5%). It is interesting to note that deployment AII is the most cost-efficient.

Furthermore, in Fig. 5, we observe that approach A2 has almost 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.

### *7.1.3 Telecommunication cost versus FEC overhead*

This paragraph presents the telecommunication cost concerning the amount of fixed FEC overhead. In FEC schemes choosing the appropriate amount of overhead is very important, in order to exploit the benefits of FEC usage. 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 Fig. 6, approach A3 ensures the lowest cost and constitutes a stable solution when network conditions change. Another observation is that, the fixed FEC overhead percentage has a direct impact on the performance of approach A2. While the additional information introduced by FEC remains low enough (up to 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 behaviour among all the proposed deployments, for the examined parameters.

In Table 3, we present an overview of how the value of the total telecommunication cost varies based on the FEC overhead and the packet loss rate. The experiment is conducted for 100 UE users and for all the MBSFN deployments (AAA, AII, AAI) with similar results and therefore we only present the results for AII (with one assisting ring) deployment, which has been proved as the most efficient. It is should be mentioned that the term FEC overhead is only used for comparison reasons since the FEC overhead only affects the performance of approach A2, where this term actually represents the fixed FEC overhead that is selected.

A thorough analysis of the figures in Table 3 reveals that the total cost introduced by the approach A3 increases linearly as the packet loss rate increases, ensuring in this way the system's stability. On the other hand, the increase in the packet loss rate causes an abrupt increment in the

**Table 3** Numerical representation of cost versus packet loss rate and FEC overhead

| FEC overhead | 0% | | | | 10% | | | |
|---|---|---|---|---|---|---|---|---|
| Packet loss rate | 5% | 10% | 15% | 20% | 5% | 10% | 15% | 20% |
| $AII_{A1}$ | 0.5514 | 0.5563 | 0.5563 | 0.5563 | 0.5514 | 0.5563 | 0.5563 | 0.5563 |
| $AII_{A2}$ | 0.5514 | 0.5563 | 0.5563 | 0.5563 | 0.1534 | 0.4176 | 0.4176 | 0.4176 |
| $AII_{A3}$ | 0.1546 | 0.1630 | 0.1745 | 0.1833 | 0.1546 | 0.1630 | 0.1745 | 0.1833 |
| FEC overhead | 20% | | | | 30% | | | |
| Packet loss rate | 5% | 10% | 15% | 20% | 5% | 10% | 15% | 20% |
| $AII_{A1}$ | 0.5514 | 0.5563 | 0.5563 | 0.5563 | 0.5514 | 0.5563 | 0.5563 | 0.5563 |
| $AII_{A2}$ | 0.1671 | 0.1671 | 0.2488 | 0.4315 | 0.1810 | 0.1810 | 0.1810 | 0.1814 |
| $AII_{A3}$ | 0.1546 | 0.1630 | 0.1745 | 0.1833 | 0.1546 | 0.1630 | 0.1745 | 0.1833 |

total cost of A1 and A2. For comparison reasons, in Table 3 we have highlighted with green colour the method that leads to the lowest telecommunication cost depending on the FEC overhead percentage and the packet loss rate. It is clear that method A3 ensures (in the majority of the cases) the lowest telecommunication cost irrespectively of the packet loss and the FEC overhead rate. This fact can relax the network in heavy load conditions.

### 7.2 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 (Fig. 7). The final topology is constructed in 14 steps sequentially by adding cells, neighbouring to the first cell. The experiment takes into account the following variables: 100 multicast users, 5% fixed overhead and 5% packet loss.

As Figs. 8, 9 and 10 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 that contain multicast users increases.

In Fig. 8, 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.

As far as Fig. 9 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 fixed percentage of FEC coding has been consumed and therefore additional retransmission of repair symbols is necessary. Deployment AII shows similar behaviour with AAI for a small number of cells (1–6) but for larger number of cells the cost for AAI increases rapidly. The overall conclusion is that AII constitutes generally a more stable and cost efficient solution.

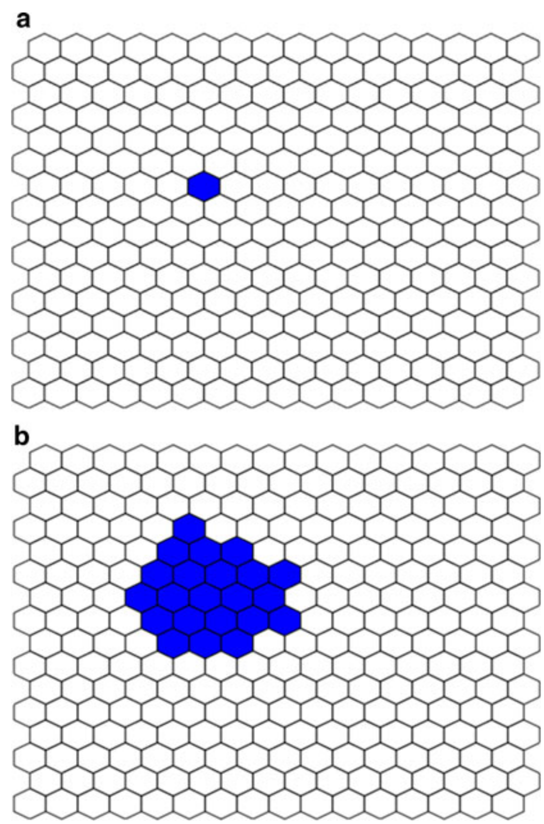


**Fig. 7** First and final snapshot of the created topology

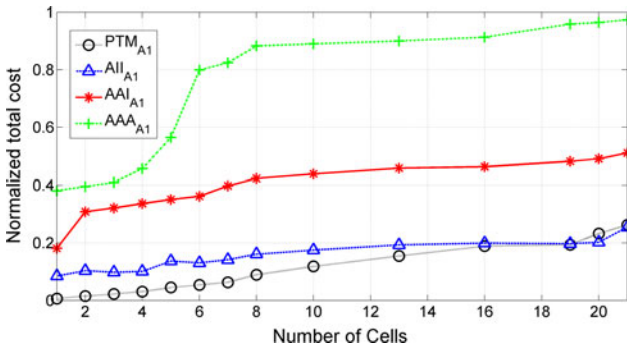


**Fig. 8** Scalable topology: total cost for approach A1 (retransmission)

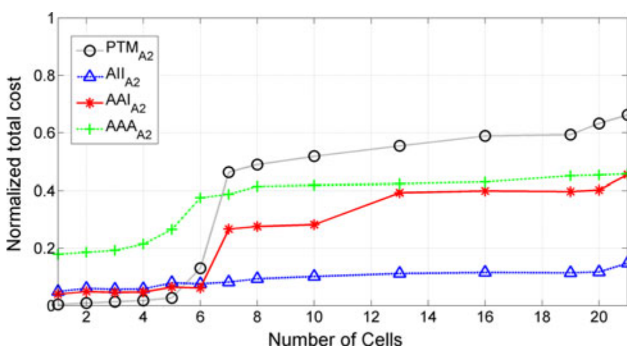


**Fig. 9** Scalable topology: total cost for approach A2 (fixed FEC overhead)

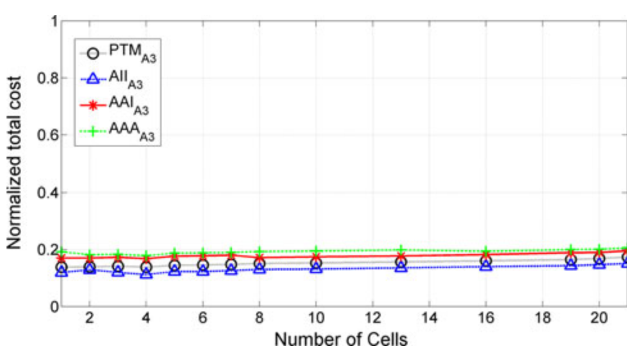


**Fig. 10** Scalable topology: total cost for approach A3 (redundant symbols)

Finally, by observing Fig. 10, we notice that approach A3 constitutes a stable solution 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 the approach that uses fixed FEC overhead (A2) seems to have better results compared to approach A3. So, depending on the network configuration and the file transmission scheme we can choose the optimal file repair scheme.

### 7.3 Telecommunication cost for moving users located in a group of cells

This part of the simulation experiments attempts to estimate how the total telecommunication cost for file repair varies as the multicast user distribution changes. To this direction, initially we consider a set of 22 adjacent cells (primary area) where the multicast users are located (Fig. 11a). Then, we examine the scenario where some of the users that are located at the edge cells of the MBSFN area recede from the primary area. Each step of the above procedure is called "hop". The sequential detachment of users from the primary area is presented in Fig. 11.

(a) Hop 1 (primary area) (b) Hop 2 (c) Hop 3
(d) Hop 4 (e) Hop 5

In the figures that follow, the normalized total telecommunication cost for each hop and each file repair approach is presented. Additionally, all the available deployments (PTM, AII, AAI and AAA) are examined.

The curves in Fig. 12 present the cost for approach A1. According to the results, for the deployments that use MBSFN (AII, AAI, AAA), the cost increases as the group of users moves away from the initial topology. On the other hand, the cost for the deployment that uses PTM remains constant and lower than the other deployments. Therefore, for approach A1, the most efficient deployment is the deployment that uses PTM transmissions.

The next part of the experiment calculates the cost when approach A2 is utilized. The results are depicted in Fig. 13. The FEC overhead is defined to 5%. It is quite interesting to observe that as the users move away from the primary area, the cost increases for all deployments. However, the deployment with one assisting cell (AII) shows the most cost efficient behavior compared to the others deployments.

Finally, Fig. 14 presents the cost when exclusive transmission of redundant symbols is used for file recovery (approach A3). According to the results, for this approach AII deployment results in the lowest cost, while AAA results in the highest cost.

## 8 Conclusions and future work

In this work, we have presented a complete evaluation study of the MBMS service provision through MBSFN and

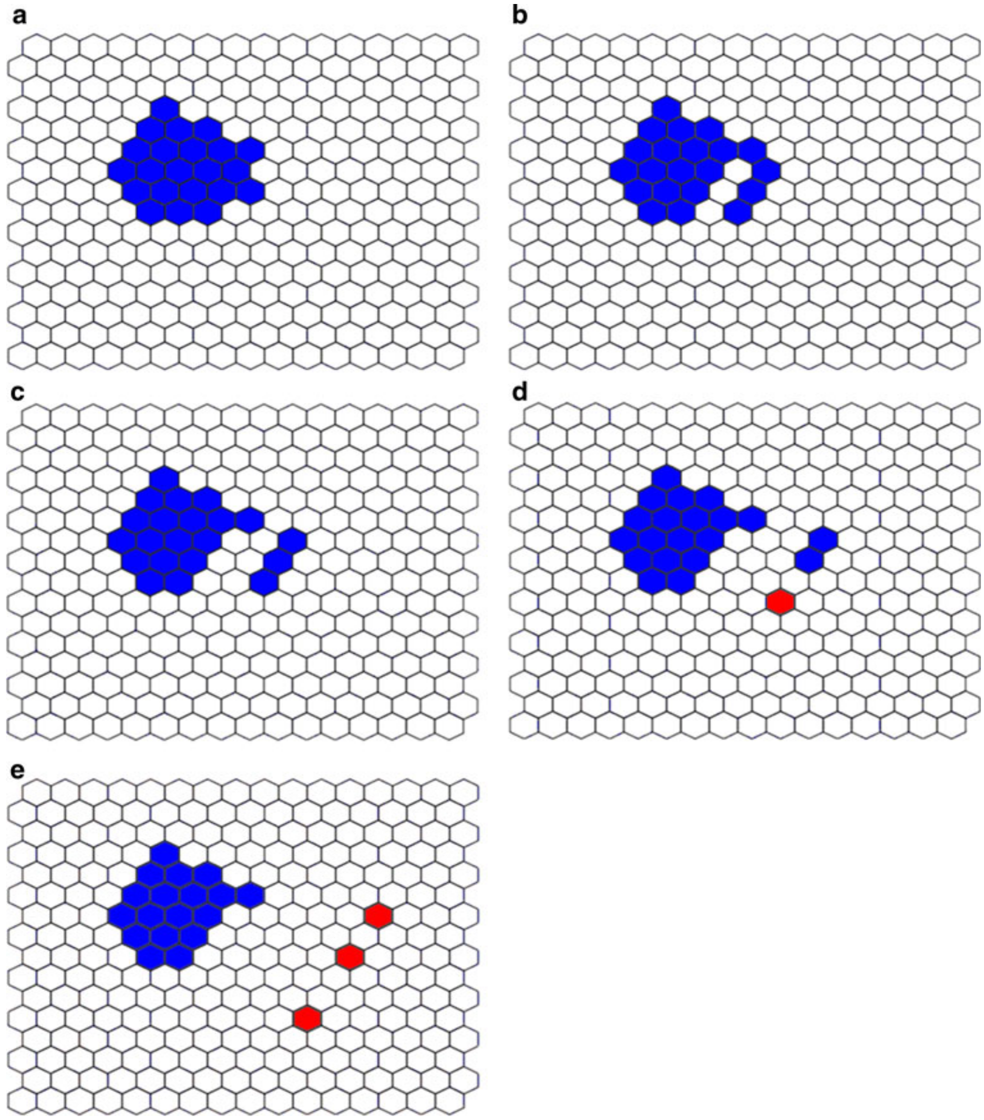


**Fig. 11** Group of cells moving away from the primary area

PTM transmission methods. Our evaluation has been performed using a metric that reflects the telecommunication cost for the MBMS service provision. We have presented an analysis of the telecommunication cost for MBSFN and PTM transmission methods that concerns, the various processes for the MBMS data delivery, the packet transmission costs over the various LTE network interfaces and the cost for control procedures and signalling.

This cost analysis allowed us to perform a 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.

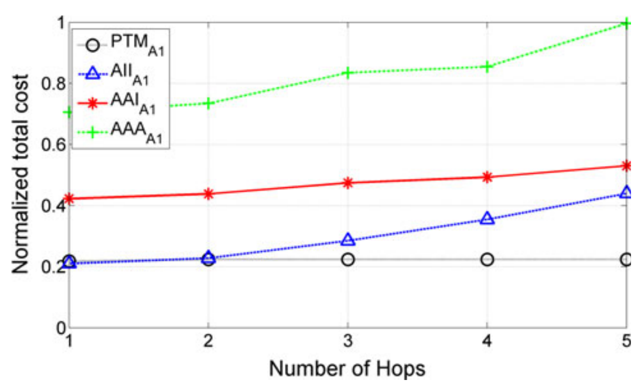


**Fig. 12** Moving users: total cost for approach A1 (retransmission)

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

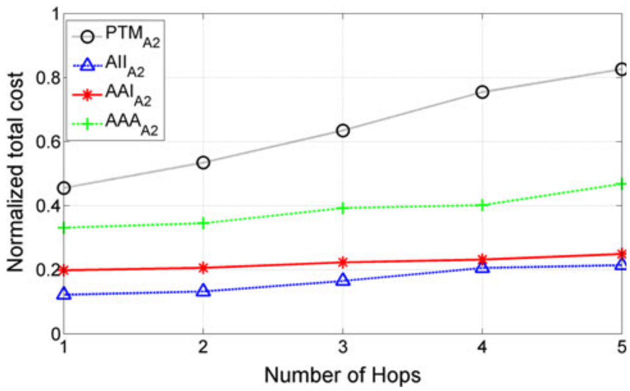


**Fig. 13** Moving users: total cost for approach A2 (fixed FEC overhead)

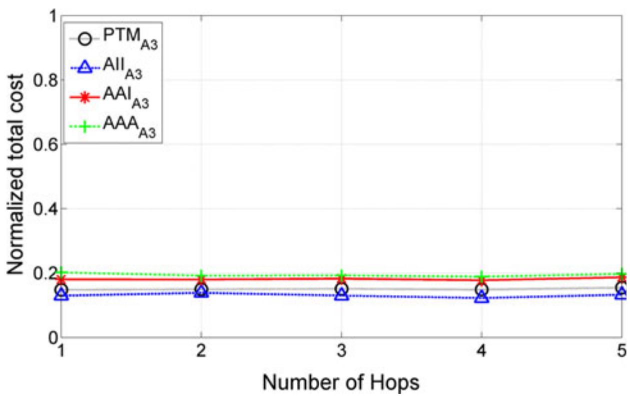


**Fig. 14** Moving users: total cost for approach A3 (redundant symbols)

related to 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. All the simulation results have shown that our selection mechanism is able to provide a cost efficient transmission session through a combination of MBSFN and PTM transmission schemes in comparison with the other examined methods.

This research work is one step towards the specification of a mechanism that makes an optimal MBSFN area selection in LTE systems. This field is expected to become of extreme interest since in the next releases of the LTE systems, the MBSFN area deployment will be dynamically determined contrary to the current 3GPP standard that specifies static MBSFN area configuration. A future step should also be the cost estimation with different kind of network dynamics and a look into the problem in a more optimization theoretic approach by trying to formulate the cost minimization problem.

Furthermore a future step could be the enhancement of the simulation tool in order to support different cell properties (e.g. cell sizes). This will enable the application of the existing analytical model to real mobile network deployments in order to draw more real-life conclusions. Also another proposal for further research based on this work could be the investigation of the proposed file repair approach and the modelling 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.

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