Adopting Forward Error Correction for Multicasting over Cellular Networks

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***Abstract*—FEC is an error control method that can be used to augment or replace other methods for reliable data transmission. Such schemes inevitably add a constant overhead in the transmitted data. However, they are so simple as to meet a prime objective for UMTS multicast services, that is scalability to applications with thousands of receivers. This is the reason that 3GPP recommends the use of FEC for MBMS framework. In this paper, we use a probabilistic model for the multicast user distribution in the network and we define a scheme for multicast data delivery that combines FEC with traditional ARQ. It is important that our analysis is compliant with the 3GPP specifications and considers the latest advances in mobile networks. In this framework we investigate the impact of FEC use, we examine whether it 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.**

Keywords-component; forward error correction; multicast; mobile network; multimedia broadcast/multicast service

I. INTRODUCTION

Mobile networks have focused on the provision of advanced services along with high data rates. Multimedia services like videoconference or distance learning are demanding features which load the network nodes and consume a large portion of the bandwidth provided. Despite the high capacity that UMTS networks provide, the expected demand will certainly overcome the available resources. This is the reason why 3rd Generation Partnership Project (3GPP) started the standardization of Multimedia Broadcast/Multicast Service (MBMS) framework.

There are many ways to provide reliability in multicast transmission. A common method is to use Automatic Repeat re-Quest (ARQ); that is automatic request for retransmission. With ARQ, receivers use a back channel to the sender to send requests for retransmission of lost packets. ARQ works well for point-to-point transmission and has also been an effective reliability tool for point-to-multipoint transmission. However, when the number of receivers increases, ARQ reveals its limitations. One major limitation is the feedback implosion problem which occurs when too many receivers are transmitting back to the sender. Another problem is that for a given packet loss rate, and a set of receivers experiencing losses, the probability that every single data packet needs to be retransmitted quickly approaches unity as the number of receivers gets large. In other words, a high average number of transmissions are needed per packet. In a wireless environment, ARQ has a second major disadvantage, due to the requirement for a bidirectional communication link. On most wired networks the feedback channel comes for free, but on wireless networks the transmission of feedback from the receiver can be expensive, either in terms of power consumption, or due to limitations of the communication infrastructure.

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 multicast protocols however, the use of FEC techniques has very strong motivations. The encoding eliminates the effect of independent losses at different receivers. This makes these schemes able to scale irrespectively of the actual loss pattern at each receiver. Additionally, the dramatic reduction in the packet loss rate largely reduces the need to send feedback to the sender. FEC schemes are therefore so simple as to meet a prime objective for UMTS multicast services, that is scalability to applications with thousands of receivers. This is the reason why 3GPP recommends the use of FEC for MBMS and, more specifically, adopts the use of Raptor FEC code [2].

In this paper, we study the applicability of FEC over the multicast data transmission in UMTS. We define a probabilistic model for the multicast user distribution in the network and we analyze the multicast data delivery cost. In this framework we investigate the impact of FEC use in MBMS. We try to determine the efficient working point in the trade-off between the FEC code overhead and the retransmission cost. We examine whether FEC use 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.

The paper is structured as follows: in Section II, we indicatively present the related work to this scientific domain. In Section III, we briefly describe the UMTS network architecture for MBMS and we provide some basic information about the FEC process in MBMS. Section IV provides a cost analysis of data delivery in UMTS. This analysis is based on a probabilistic model and concerns both the p-t-p and p-t-m transmission for MBMS. Section V describes our simulation scheme, the simulation experiments and their results. Finally, some concluding remarks and possible next steps are stated in Section 0.

II. RELATED WORK

The initial research over FEC for multicast was conducted in the domain of fixed networks. The deployment of IP multicast in the Internet Multicast Backbone made the implementation of error control functions more challenging for multicast than for unicast. As a result, a lot of studies were published. For instance, the authors of [13] propose a layered FEC scheme for video multicast over fixed networks. In this scheme receivers can obtain different levels of protection that are commensurate with their respective channel conditions. This is achieved through the organization of FEC into multiple layers. The effects of bursty losses are amortized by staggering the FEC streams in time, giving rise to a trade-off between delay and quality.

The standardization of MBMS by 3GPP triggered the research over FEC for multicast in the domain of mobile networks. Even though this research area is relatively new, a lot of solutions have been proposed so far. In [7] the performance of Systematic Raptor FEC is evaluated through simulation and the results are presented. The experimental results are analyzed and the amount of additional repair data is estimated for various packet error rates. This study focuses to the determination of the MBMS Systematic FEC features and characteristics in order to deploy an optimum service from an operator's point of view.

The authors of [10] investigate the application of Raptor codes to MBMS in a realistic simulation environment. This work focuses on the download delivery method of MBMS and uses an overall system model that models accurately the physical channel and user mobility in a cellular network. In this realistic simulation environment, optimal system parameters are proposed for both levels under different mobility models, with different bearer parameters, and without and with selective combining.

In [9] the authors focus on the MBMS download delivery method and deal with the trade-off between FEC protection and successive file repair. They present a scheme that combines a p-t-m file repair transmission with a p-t-p file repair mechanism in a way that the UMTS resource usage is optimized. The proposed scheme balances the FEC transmission overhead with the file repair procedures after the MBMS transmission.

The adoption of FEC is examined from another aspect in [13]. A potential bottleneck of the radio network is taken into consideration by the authors of this study. Therefore, they investigate which are the optimal operation points in order to save radio resources and use the available spectrum more efficiently.

Despite the high quality and the scientific vigour of the published studies, none of them presents a complete evaluation study on the use of FEC in mobile multicast. It is our belief and a motivation behind our study that the multicast user distribution is an aspect of major importance in multicast data delivery in UMTS which has not been considered so far. Additionally, all studies are based on the traditional UMTS system and the application of FEC has not presented in a framework that incorporates the evolution of UMTS beyond its 3rd generation.

III. DATA DELIVERY IN MBMS

A. Mobile Network Architecture

3GPP is currently standardizing the MBMS service as a broadcasting service with both broadcast and multicast service mode. During the rest of our analysis we focus on the multicast mode since it is the most generic and covers all the aspects of the broadcast mode. Fig. 1 gives an overview of the UMTS network entities and architecture as defined for MBMS by 3GPP in [1] and [2].

Some basic UMTS network nomenclature used is listed in TABLE I. Since this is not in the purposes of this paper, the functionality of each element is not described. However, for more information on this the reader is referred to the relevant bibliography, e.g. [8].

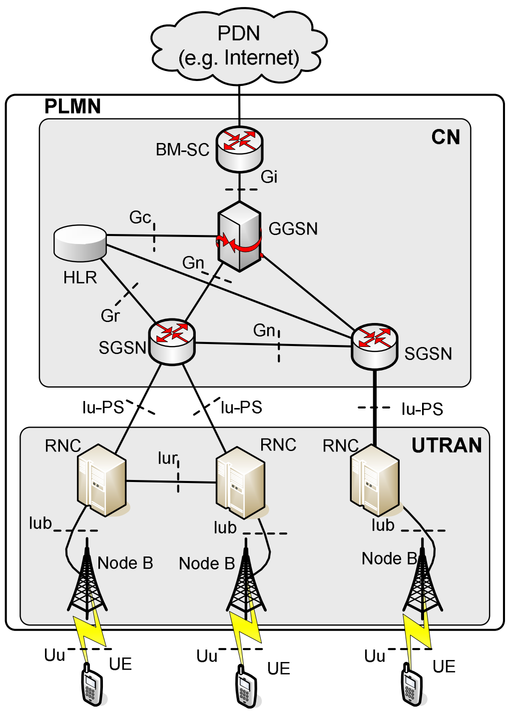

Figure 1. UMTS architecture for MBMS.

An interesting domain in MBMS data delivery is the downlink transport channels used in the UTRAN. Data transmission in the UTRAN is differentiated depending on transport channels. The transport channels define the characteristics of the data transfer according to the service requirements. Although there are several types of transport channels specified, our analysis focuses on the most important that are related to the multicast date delivery. These are the High-Speed Downlink Shared Channel (HS-DSCH) and the Forward Access Channel (FACH). The HS-DSCH is a downlink transport channel shared by several UEs. It has been introduced for High-Speed Downlink Packet Access (HSDPA) operation which is an evolution of 3G UMTS. FACH also exists only in the downlink direction. It is a common channel and, consequently, a single FACH can carry information for more than one UE in a cell. It is obvious that HS-DSCH belongs to the class of the p-t-p transport channels, whereas FACH, due to its multicast nature, belongs to the class of p-t-m transport channels.

The coexistence of transport channels of different nature (both p-t-p and p-tm) in the same service and the capability of switching between these different types are some of the most important features of MBMS. Their importance is based on that these features allow high flexibility and a very efficient use of the scarce radio resources while the service constraints are preserved [3], [6], and [8].

TABLE I. BASIC UMTS NETWORK NOMENCLATURE.

Acronym	Expanded Meaning
BM-SC	Broadcast Multicast – Service Center
CN	Core Network
GGSN	Gateway GPRS Support Node
PDN	Packet Data Network
PLMN	Public Land Mobile Network
RA	Routing Area
RNC	Radio Network Controller
SGSN	Serving GPRS Support Node
UE	User Equipment
URA	UTRAN Registration Area
UTRAN	UMTS Terrestrial Radio Access Network

B. Raptor Codes for MBMS FEC

3GPP standardized Raptor codes as the application layer FEC codes for MBMS aiming to improve service reliability, [2]. Both the streaming delivery and the download delivery methods in MBMS mandate that the UE supports Raptor codes [4]. During streaming delivery, application layer Raptor codes are applied on UDP flows, either individually or on bundles of streams. On the other hand during download delivery method FLUTE protocol provides reliability using Raptor FEC. Fig. 2 illustrates how the Raptor FEC encoding is incorporated in the MBMS protocol stack for both streaming and download delivery service.

Apart from the provision of improved system reliability, Raptor codes also offer a large degree of freedom in parameter choice. Raptor codes are fountain codes, meaning that as many encoding symbols as desired can be generated by the encoder on–the–fly from the source symbols of a source block of data. The decoder is able to recover the source block 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 exactly the number of source symbols for recovery.

The Raptor code specified for MBMS is a systematic fountain code producing n encoding symbols E from $k < n$ source symbols C. This code can be viewed as the concatenation of several codes. The most–inner code is a non–systematic (Luby–Transform) LT code with L input symbols F, which provides the fountain property of the Raptor codes. This non–systematic Raptor code is not constructed by encoding the source symbols with the LT code, but by encoding the intermediate symbols generated by some outer high–rate block code. This means that 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 [9], whereas details on specific parameters are listed in [2].

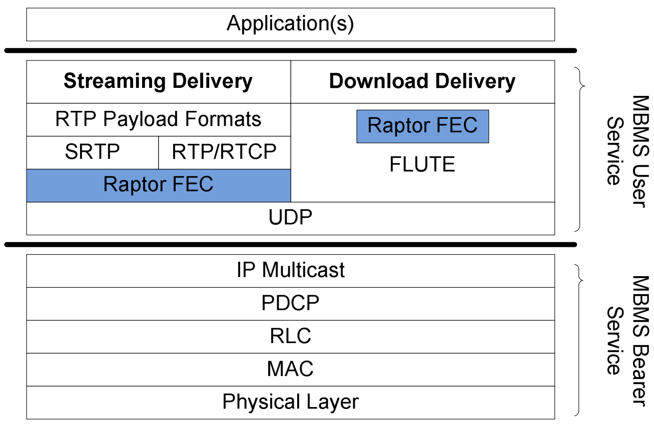

Figure 2. MBMS protocol stack.

The simulation results presented in [9] 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:

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

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.

IV. Cost Analysis of Data Delivery

A. Multicast Users Distribution

For the purposes of the cost analysis, we consider a typical UMTS network consisting of a single GGSN as that depicted in Fig. 1. For simplicity reasons, during our analysis we consider that the functionality of the BM-SC is incorporated in the GGSN. The cost analysis is based on a probabilistic method that models the multicast user distribution in the network. This method calculates the number of multicast users in the network, the number of SGSNs that serve multicast users, the number of RNCs that serve multicast users, and the number of Node Bs that serve multicast members.

During the cost analysis of data delivery we use several parameters. The terms that are used during this analysis as well as their description are listed in TABLE II.

TABLE II. Cost Analysis Terms.

Term	Description
D_{gs}	Tx cost for delivery from GGSN to SGSN
D_{sr}	Tx cost for delivery from SGSN to RNC
D_{rb}	Tx cost for delivery from RNC to Node B
D_{FACH}	Radio Tx cost for delivery over FACH
$D_{HS\text{-}DSCH}$	Radio Tx cost for delivery over HS-DSCH
P_g	Processing cost for unicast delivery in GGSN
P_{gM}	Processing cost for multicast delivery in GGSN
P_s	Processing cost for unicast delivery in SGSN
P_{sM}	Processing cost for multicast delivery in SGSN
P_r	Processing cost for unicast delivery in RNC
P_{rM}	Processing cost for multicast delivery in RNC
P_b	Processing cost of delivery Node B
n_{UE}	Number of multicast users in the PLMN
n_{SGSN}	Number of SGSNs serving multicast users
n_{RA}	Number of RAs having multicast users
n_{RNC}	Number of RNCs serving multicast users
n_{NODEB}	Number of Node Bs serving multicast users
N_{RA}	Total number of RAs in the PLMN
N_{ra}	Number of RAs served by the same SGSN
N_{rnc}	Number of RNCs belonging to the same RA
N_{ura}	Number of URAs managed by the same RNC
N_{nodeb}	Number of Node Bs belonging to the same URA

It should be noted that all the listed parameters that represent cost correspond to the cost for a single packet delivery.

The probabilistic method considers the classification of the network RAs into L_{RA} categories. If we consider that for $1 \le i \le L_{RA}$, there are $N_{(RA)i}$ RAs of class i, then the total number of RAs within the UMTS network is:

$$N_{RA} = \sum_{i=1}^{L_{RA}} N_{(RA)i}$$

Let that the distribution of the multicast users among the classes of RAs follows a Poisson distribution with $\lambda = \theta_{(RA)i}$ where $1 \le i \le L_{RA}$. Then the probability that k multicast users reside in the RAs of class i is:

$$p(k, \theta_{(RA)i}) = \frac{e^{-\theta_{(RA)i}} \cdot (\theta_{(RA)i})^k}{k!}$$

Therefore, the probability that at least one multicast user is served by the RAs of class i is:

$$p = 1 - p(0, \theta_{(RA)i}) = 1 - e^{-\theta_{(RA)i}}$$

Since every class i consists of $N_{(RA)i}$ RAs then, if $\theta_{(RA)i}$ denotes the number of multicast users for the $N_{(RA)i}$ RAs of class i, then the total number of the RAs that have multicast users is:

$$n_{RA} = \sum_{i=1}^{L_{RA}} N_{(RA)i} \left(1 - e^{-\theta_{(RA)i}}\right) \quad (2)$$

If θ_i denotes the number of multicast users in the RAs of class i, the total number of multicast users in the network is represented from the following equation:

$$n_{UE} = \sum_{i=1}^{L_{RA}} N_{(RA)i} \cdot \theta_i \quad (3)$$

If N_{RA} is the total number of RAs in the PLMN and if each SGSN serves a number of N_{ra} RAs, then the probability that an SGSN does not control any RA serving multicast users is:

$$p_{SGSN} = \begin{cases} \dfrac{\binom{N_{RA} - N_{ra}}{n_{RA}}}{\binom{N_{RA}}{n_{RA}}} & \text{if } n_{RA} \le N_{RA} - N_{ra}, \\ 0 & \text{otherwise.} \end{cases} \quad (4)$$

Since the total number of SGSNs that serve multicast users is $n_{SGSN} = N_{SGSN}(1 - p_{SGSN})$ it can be calculated based on Equation (4).

Assuming that all RNCs within an RA of class i have the same multicast population distribution density as in the RA case, then the multicast user population for an RNC within the service area of a class i RA is $\theta_{(RNC)i} = \theta_{(RA)i} / N_{rnc}$ and the total number of RNCs of class i is $N_{(RNC)i} = N_{(RA)i} \cdot N_{rnc}$, where N_{rnc} is the number of RNCs belonging to the same RA.

Without loss of generality, we consider that the number of RA categories is equal to the number of RNC categories ($L_{RNC} = L_{RA}$) and then the total number of RNCs serving multicast users is:

$$n_{RNC} = \sum_{i=1}^{L_{RNC}} N_{(RNC)i} \cdot \left(1 - e^{-\theta_{(RNC)i}}\right) \quad (5)$$

A similar analysis leads to the below representation of the total number of Node Bs serving multicast users:

$$n_{NODEB} = \sum_{i=1}^{L_{NODEB}} N_{(NODEB)i} \cdot \left(1 - e^{-\theta_{(NODEB)i}}\right) \quad (6)$$

In Equation (6) the multicast user population for a Node B within a cell of a class i RA is $\theta_{(NODEB)i} = \theta_{(RNC)i} / (N_{ura} \cdot N_{nodeb})$ and the total number of Node Bs of class i is $N_{(NODEB)i} = N_{(RNC)i} \cdot N_{ura} \cdot N_{nodeb}$, where N_{ura} is the number of URAs administered by the same RNC and N_{nodeb} is the number of cells belonging to the same URA.

B. Cost Aspects

The cost evaluation has been performed in terms of telecommunication costs. It should be noted that although other studies like [11] consider the cost of multicast group management as part of the total telecommunication cost, this study does not follow the same approach. The reasoning is that this study focuses only on the actual data transmission along with its cost. On the other hand, the multicast group management cost should not be added since it precedes the data delivery. Therefore, the cost of paging is not taken into account in our analysis.

1) Unicast Telecommunication Cost

In unicast data delivery, each packet is forwarded separately from the BM-SC and the intermediate GGSN, SGSN and RNC (Fig. 1). Finally, it is transmitted to the mobile terminal through the selected UTRAN transport channel. Naturally, p-t-p data delivery through HS-DSCH is used for the unicast transmission and thus the cost of a single packet transmission to n_{UE} receivers is given by the number of receivers times the cost of a single packet delivery over the data delivery path. Therefore the total cost for unicast data delivery to multiple receivers is given by the following equation:

$$U = n_{UE} \cdot (P_g + D_{gs} + P_s + D_{sr} + P_r + D_{rb} + P_b + D_{HS-DSCH}) \quad (7)$$

2) Multicast Telecommunication Cost

In multicast data delivery, the SGSNs and RNCs forward a single copy of each packet to the RNCs or Node Bs, respectively, that are serving multicast users. As soon as the packets are received at the Node Bs serving multicast users, they are transmitted to the appropriate UEs via common or shared transport channels. The total cost for the multicast data delivery is derived from Equation (8) below:

$$M = P_{gM} + n_{SGSN} \cdot (D_{gs} + P_{sM}) + n_{RNC} \cdot (D_{sr} + P_{rM}) + C_{UTRAN} \quad (8)$$

C_{UTRAN} represents the cost of data delivery over the UTRAN. Both FACH and HS-DSCH can be used as UTRAN transport channel and therefore the C_{UTRAN} calculation varies depending on the channel used. The following equation gives this cost:

$$C_{UTRAN} = \begin{cases} n_{NODEB} \cdot (D_{FACH} + D_{rb} + P_b) & \text{if channel is FACH,} \\ n_{UE} \cdot (D_{HS-DSCH} + D_{rb} + P_b) & \text{if channel is HS–DSCH.} \end{cases} \quad (9)$$

$D_{HS\text{-}DSCH}$ and D_{FACH} represent the cost over the Uu interface. In more detail, D_{FACH} represents the cost of using a FACH to serve all the multicast users residing in a specific cell whereas $D_{HS\text{-}DSCH}$ represents the cost of using a single HS-DSCH to transmit the data to a single multicast user of the network.

Regarding the cost over the Iub interface, if FACH is used as transport channel each multicast packet is sent once over the Iub interface and then it is transmitted to the multicast receivers by the corresponding Node B. The use of HS-DSCH for the transmission of the multicast packets means that a separate timeslot must be used to transport the multicast data to each multicast receiver per Node B.

V. Experimental Evaluation

A. Simulation Scheme

As it is specified by 3GPP in [2], both techniques of FEC with Raptor codes and ARQ may be employed by the BM-SC in order to provide a reliable data download delivery. Moreover, 3GPP specification [2] recommends that the retransmission should be performed over a selective unicast context, since the setup of a new multicast bearer for packet retransmission is rather costly.

The scheme that we designed and implemented combines both of the fundamental repair processes and therefore combines the following contexts:

1) MBMS multicast bearers and application level FEC.
2) unicast bearers for selective retransmission for lost data.

Our scheme incorporates all the properties of a typical Raptor code defined for data delivery over MBMS as they are described by 3GPP in [3]. It is worth to mention that since n encoding symbols are produced from $k < n$ source symbols, then the overhead added due to the Raptor encoding, i.e. the number of repair symbols divided by the number of source symbols, equals to the fraction $(n - k) / k$. Given that the packet size is fixed, the FEC overhead that is needed for the transmission of a file of given size is also equal to the same fraction and, thus, the overhead of additional packets that are needed for the download delivery of a given file is $(n - k) / k$.

During the decoding procedure in each UE, there is a decoding failure probability represented by Equation (1). When a packet loss rate $p_{loss} > 0$ is applied over the 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, the failure probability $p_f(m,k)$ increases. If the recovery of the k source symbols through decoding procedure fails in a UE, then ARQ is invoked by the UE for the retransmission of the lost packets from the BM-SC over a unicast context.

B. Simulation Environment

For the definition of our simulation environment we assumed a typical PLMN topology with $N_{SGSN} = 10$, $N_{ra} = 10$, $N_{rnc} = 10$, $N_{ura} = 5$ and $N_{nodeb} = 5$. Moreover, we assumed that we have two classes of RAs: RAs of class $i = 1$ have multicast user population of $\theta_1 = 1/\delta$ and RAs of class $i = 2$ have multicast user population $\theta_2 = \delta$. If α denotes the proportion of the class $i = 1$ and $(1 - \alpha)$ be the proportion of the class $i = 2$. Thus, the number of RAs of class $i = 1$ is $N_{(RA)1} = \alpha \cdot N_{RA}$ and the number of RAs of class $i = 2$ is $N_{(RA)2} = (1 - \alpha) \cdot N_{RA}$. Similarly, each RA of class $i \in \{1,2\}$ is divided into N_{rnc} RNCs of the same class i, and each RNC of class $i \in \{1,2\}$ is subdivided into $N_{ura} \cdot N_{nodeb}$ Node Bs of the same class.

The estimated value of the packet transmission cost (D_{xx}) in any segment of the network depends on two parameters:

1) the number of hops between the edge nodes of this network segment, and
2) the capacity of the link of the network segment.

The typical values of above parameters that are used for the purpose of our experimental evaluation are presented in TABLE III.

TABLE III. CALCULATION OF THE TRANSMISSION COST.

Link	Link Capacity Factor (k)	Number of Hops (l)	Tx Cost (D)
GGSN−SGSN	$k_{gs} = 0.5$	$l_{gs} = 6$	$D_{gs} = 12$
SGSN−RNC	$k_{sr} = 0.5$	$l_{sr} = 3$	$D_{sr} = 6$
RNC−Node B	$k_{rb} = 0.2$	$l_{rb} = 1$	$D_{rb} = 5$

It is obvious from the Equations (7) and (8) that the costs of the schemes depend on several other parameters. The work presented in [5] has been used as input for the determination of the parameters values which are listed in TABLE IV.

TABLE IV. VALUES OF THE SIMULATION PARAMETERS.

D_{rb}	P_g	P_s	P_r	P_{gM}	P_{sM}	P_{rM}	P_b	D_{FACH}	$D_{HS\text{-}DSCH}$
5	1	1	1	2	2	2	1	16	12

C. Cost vs. Multicast User Density

Fig. 3 depicts the cost in function of α when p_{loss} is 5% and δ equals to 500 for various amounts of recovery symbols. Before proceeding to the analysis of Fig. 3 it should be clarified what parameter α qualitatively represents. The value of α denotes the proportion of the RAs belonging in the class $i = 1$ and therefore the properties of the RAs belonging in either class $i = 1$ or $i = 2$ prevail as the value of α approaches zero or one respectively. The properties of each class of RAs are determined by the value of δ. If $\delta \gg 1$, the RAs of class $i = 1$ have a small multicast user population and the RAs of class $i = 2$ have a large multicast user population. Consequently, the parameter α qualitatively represents the multicast user density in the sense that as the value of α increases the number of RAs with small multicast user population increases and vice versa.

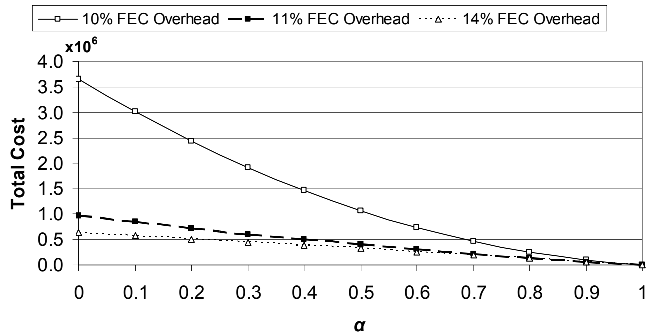

Figure 3. Total cost against α when $p_{loss} = 5\%$ and $\delta = 500$.

We observe that the total cost decreases as α increases. This occurs because as α increases, the number of RAs with no multicast users increases and hence the multicast user population resides in a restricted number of RAs. For small FEC overheads, the cost decreases exponentially with α whereas for large FEC overheads the cost decreases linearly.

For a given value of α, the total cost decreases as the FEC overhead increases but down to a lower bound. When the FEC overhead exceeds the value that corresponds to this bound, the total cost starts to increase. This is reasonable, since the addition of new recovery symbols increases linearly the total cost whereas it has minor contribution to the source symbol recovery. The FEC overhead that achieves the optimal cost depends on the given parameters. For the scenario depicted in Fig. 3 the optimal FEC overhead is around 13.5%. Similar behaviour is observed when different packet loss rates are applied.

D. Cost vs. Multicast User Population

The other aspect that was examined during our simulation experiments was the total cost versus the multicast user population. The magnitude of the multicast user population in the defined classes of RAs is determined by the value of δ. As δ increases the probability that there are no multicast members in a RA of class $i = 1$ increases whereas the multicast user population in the RAs of class $i = 2$ increases. In the figures below, the total cost is plotted against δ for 5% packet loss rates and two different values of α.

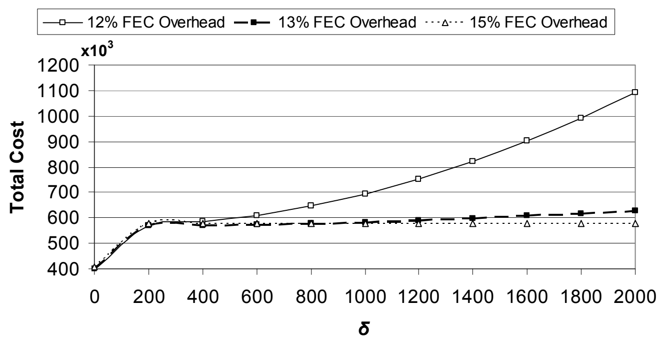

Figure 4. Total cost against δ when $p_{loss} = 5\%$ and $\alpha = 0.1$.

When $\alpha = 0.1$ the total cost constantly increases as the value of δ increases. This is reasonable since the value of α is low and therefore there is a large number of RAs with a lot of multicast users residing in them. As δ increases, the number of the multicast users in those RAs increases and so does the total cost. There is also an optimal FEC overhead that creates a minimal total cost for a given δ. For the scenario depicted in Fig. 4 this optimal FEC overhead is 14%. For a given packet loss rate this optimal FEC overhead increases as the value of δ increases. A qualitative explanation of this is that as the multicast user population increases the number of the receivers that cannot recover a transmitted packet increases and so does the cost due to packet retransmissions.

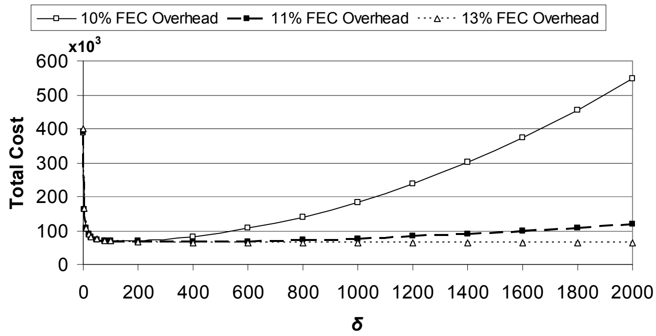

Figure 5. Total cost against δ when $p_{loss} = 5\%$ and $\alpha = 0.9$.

When $\alpha = 0.9$ there exist a lot of RAs with a few or no residing receivers. For small values of δ the cost is too high independently of whether FEC is used or not. This is because the multicast transmission cost does not depend on the number of the actual receivers, but it depends on the number of the cells where they reside. As δ increases, the multicast population increases and the total cost does the same. It should be noted that the optimal FEC overhead increases as δ increases.

E. Optimal Overhead vs. Packet Loss Rate

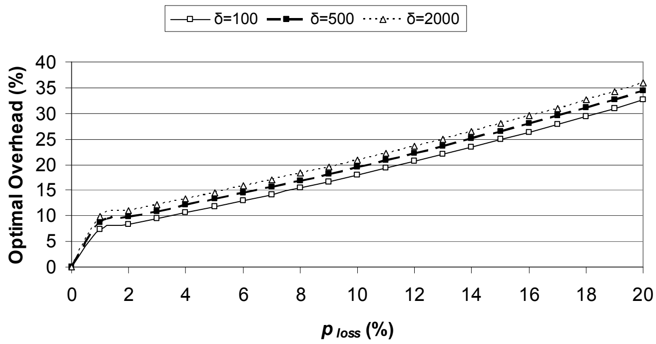

Figure 6. Optimal overhead against packet loss rate when $\alpha = 0.1$.

The last but not least part of our experiment was the evaluation of the optimal overhead against the applied packet loss rate. In Fig 6 we observe that the optimal overhead of recovery symbols increases as the packet loss probability increases. For $p_{loss} > 1\%$ the increase is linear with gradient around 1.3. For small values of p_{loss} the optimal overhead rapidly increases as the packet loss rate increases. This is caused owing to the poor effectiveness of Raptor codes for small number of recovery symbols.

VI. Conclusions and Future Work

We have presented a study on the FEC application over UMTS mobile networks. The Raptor codes standardized by 3GPP for FEC in mobile multicast have been evaluated. Raptor codes inevitably add a constant overhead in the transmitted data and are computationally expensive as all the FEC schemes do. Nevertheless, they are resistant to the feedback implosion and are also essential when the use of the feedback uplink channel is costly. In our study, the use of FEC is evaluated in terms of telecommunication cost under various user distributions.

Our simulation scheme is based on a probabilistic method that models the multicast user distribution in a UMTS network. We have presented a cost analysis that considered the properties of an evolved UMTS network that uses HSDPA technology for a high speed data delivery to mobile terminals, as they are determined by the 3GPP specifications. The results of our simulation experiments were presented and analyzed. In more detail, the behaviour of the standardized FEC scheme was evaluated against parameters like the multicast user density and the multicast user population. The optimal dimensioning of FEC codes, i.e. the efficient working point in the trade-off of the FEC code overhead against the retransmission cost was estimated depending on the network conditions. Last but not least, all the above results were qualitatively assessed and explanations for the model behaviour were given.

The step that follows this work may be the investigation of the Raptor codes from power control perspective. The work presented in this paper could be the base for a scheme that combines FEC code selection with efficient power allocation. Another idea is the modelling and the implementation of a mechanism that makes efficient Raptor code selection for UMTS networks. This mechanism could monitor the network conditions and use them as input in order to select the appropriate amount of redundant symbols for FEC encoding.

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