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A model to evaluate MBSFN and AL-FEC techniques in a multicast video streaming service

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***Abstract*—In a multicast video streaming service over a cellular network, the same content is sent to a mass audience using a common channel. However, users belonging to the same multicast channel perceive different characteristics of the radio channel. Moreover, in wireless environments, the radio interface introduces an important level of interference and noise, resulting in a high rate of transmission errors. Therefore, a protection of the information is needed at each receiver using Forward Error Correction (FEC) schemes, which allow the recovery of the lost packets sending redundancy together with the payload. FEC solutions can be used in combination with other techniques to overcome the existing limitations of the mobile network, in particular, the use of a single-frequency network to prevent the effect of destructive signal interference. This paper analyzes the performance of a video streaming service comparing different FEC schemes, Raptor and RaptorQ codes, where some system parameters can be tuned in a single-frecuency network.**

I. INTRODUCTION

The distribution of video in wireless environments has become a challenge, since it presents inherent limitations that impact on the streaming services. The limited bandwidth or the existing noisy channel are some of these limitations, which affects, definitely, on the quality of the service, increasing the perception by users of typical problems, such as, high latency or the picture often freezes during the playback time.

These problems are even more relevant in live streaming services. Applications must guarantee strict delays and bandwidth requirements in communications over noisy channels, i.e. with a high packet loss rate. Nowadays, there are several mechanisms to prevent the loss of packets, but not all of them are suitable to use with multicast streaming services in real time. Automatic Repeat reQuest (ARQ) and Hybrid Automatic Repeat reQuest (HARQ) are well known error correction techniques based on retransmissions and the use of feedback from the users. However, due to the constraints of the multicast streaming services in a cellular network, the use of these techniques cannot be applied because of there is not a multicast feedback channel.

Pure Forward Error Correction (FEC) techniques are an alternative method to ensure reliable transmissions over unreliable channels without resorting to retransmissions. The idea behind these well-known techniques is to send redundancy together with the payload, allowing each user to overcome the loss of packets based on the whole information received. The main difference between FEC schemes and techniques based on retransmissions is its capacity to recover lost packets avoiding the use of a feedback channel. This solution is very adequate in scenarios with limited resources, where the content is sent to a mass audience using only one multicast stream.

To improve the scalability of multicast transmissions over mobile networks, 3rd Generation Partnership Project (3GPP) has defined Evolved Multimedia Broadcast and Multicast Service (eMBMS) [1]. This solution utilizes a common channel to send the same data to multiple receivers, thereby improving the efficiency of the use of network resources. The solution standardized by 3GPP to ensure reliable transmissions over eMBMS is to use of Raptor codes as the Application Layer - Forward Error Correction (AL-FEC) scheme. Nevertheless, emerging solutions provide better performance and lower failure probabilities in the decoding process, such as the evolution of the Raptor code itself, RaptorQ, or RS+LDPC-Staircase. In addition, Multicast/Broadcast over Single Frequency Network (MBSFN) has been proposed to improve the performance of multicast transmissions. This improvement is achieved with the cooperation of all base stations belonging to the same MBSFN area to transmit the same signal with very precise time/frequency synchronization.

Several works analyze the use of these techniques for eMBMS. In [2] a single-cell scenario is simulated to research how the FEC overhead can vary according to the cell range and the number of satisfied users. Other works [3] analyze, in a specified deployment of 19-cell MBSFN area, the impact of the joint utilization of Raptor code at application level and the Modulation and Coding Scheme (MCS) used at physical layer. Moreover, several works compares Raptor and RaptorQ. In [5], both FEC techniques are evaluated in terms of startup delay, rebuffering percentage and Peak Signal-to-Noise Ratio (PSNR). In [6], both techniques are compared in terms of the complexity and performance.

In a previous work, we have analyzed a multicast streaming service, by means of multiple simulation scenarios whose parameters are shown in Table I. Note that we have considered different MCS [4] covering the whole range for Long Term Evolution (LTE). Furthermore, we have used a variable size of the MBSFN area in order to study how it affects the improvement of the correct reception of the video segments in combination with other techniques.

This paper investigates the consequences of using RaptorQ codes in the deployment of a multicast video streaming service compared to its predecessor, Raptor code, and discusses how it affects its use in several issues: the configuration of MBSFN areas and the definition of the Physical Layer - Forward Error Correction (PHY-FEC) parameters.The objective of this work is to analyze different AL-FEC techniques and other parameters which maximize the service data rate and the coverage of the multicast transmissions, and consequently, reducing the number of the unicast retransmissions.

The rest of the paper is organized as follows. In Section II, an overview about FEC techniques is provided, focused in Raptor and RaptorQ schemes. The system model used in the simulations is detailed in Section III. The performance evaluation results are presented in Section IV. Finally, in Section V, the conclusions are explained.

II. FEC TECHNIQUES OVER EMBMS

This section reviews the use of FEC techniques over eMBMS and provides an overview of the standardized Raptor codes and their most recent evolution, RaptorQ codes. Both two schemes share several important similarities. Firstly, Raptor and RaptorQ are fountain codes, i.e., as many encoded symbols as needed can be generated on-the-fly by the encoder from the k symbols of the source block. The decoder is able to recover the block if it receives a number of symbols slightly higher than k. In this context, the code rate is normally used to represent the amount of redundancy r introduced, and it is defined as the ratio between the k original symbols and the $k+r$ encoded symbols. Moreover, 3rd Generation Partnership Project (3GPP) has defined the use of systematic Raptor codes, which means the original unmodified content is sent together with the redundant information generated by the encoder. RaptorQ codes can be used in a systematic form too.

Both Raptor and RaptorQ work splitting the transmitted object into several source blocks. Dynamic Adaptive Streaming over HTTP (DASH) [7] works in the same way, the content has been previously encoded with different bitrates and fragmented into video segments. In this work, we analyze live streaming services, this is the reason for the duration of the segments, in the order of a few seconds. Therefore, it does not make sense to carry out another fragmentation in addition to DASH, due to source blocks has to be large enough for guarantee a good performance in the decoding process. Thus, each source block, i.e, each video segment, is independently encoded, where r repair symbols are generated and added to the k source symbols. Then, the protected video segments are transmitted over eMBMS as objects of the File Delivery over Unidirectional Transport (FLUTE) protocol. Finally, each user, with a different channel quality, decodes the video according to the amount of redundancy introduced at the transmitter and the symbols received. Only when the user is not able to decode the video segment correctly, an Hypertext Transfer Protocol (HTTP) unicast retransmission is used.

A. Raptor Codes

Raptor codes support up to 65,536 source blocks with a maximum of 8,192 source symbols per block. The first step in the encoding process is to pre-code the source symbols to generate L intermediate symbols. Following, a Luby transform (LT) code is applied to these symbols to obtain the encoded symbols, where repair symbols are calculated as the XOR of a subset of the intermediate symbols. It is important to emphasize that the pre-coding step is used to satisfy the systematic property. LT is a fountain code but it does not work like a systematic code.

On the other hand, the coverage of the video service can be defined as the ratio between the video segments successfully decoded and the total number of video segments received. The decoding failure probability depends on the sum of source and repair symbols received, n, and it can be modeled by [8]

$$P(f_{RC}|n) = \begin{cases} 1 & \text{if } n < k \\ 0.85 \times 0.567^{n-k} & \text{if } n \geq k \end{cases} \tag{1}$$

B. RaptorQ Codes

RaptorQ codes support a higher number of source blocks than its predecessor, Raptor codes. Specifically, 16,777,216 source blocks with a maximum of 56,403 source symbols per block. The RaptorQ encoding process is very similar to the standardized Raptor code. However, there are some important differences that highlight the performance improvement achieved using this code. Whereas Raptor codes operate over Galois field (GF)(2), RaptorQ does over GF(256). For this reason, RaptorQ can recovery a source block with a lower number of repair symbols. Moreover, the first step in the encoding process is slightly different from Raptor codes. Padding symbols are added to the source block to let a faster encoding and decoding process. Following, an enhanced pre-coding step is carried out over the source block and the added padding symbols (extended source block). Finally, a more complex LT encoder is used to obtain the repair symbols.

In RaptorQ the decoding failure probability can be calculated as [9]

$$P(f_{RC}|n) = \begin{cases} 1 & \text{if } n < k \\ 0.01 \times 0.01^{n-k} & \text{if } n \geq k \end{cases} \tag{2}$$

As shown in (2), the performance achieved using RaptorQ codes is significantly higher than using Raptor codes. However, the decoding complexity is greater than in Raptor codes, i.e, RaptorQ requires higher decoding times [10]. For this reason, the computational resources available on the device must be taken into account to prevent the degradation of the quality of service perceived by the user.

III. SYSTEM MODEL

This section describes the system model used to analyze the impact of using different FEC techniques and variable size MBSFN areas for the deployment of a multicast video streaming service. This model combine simulations to characterise the packet error rate for different users and a mathematical model to obtain the impact of the packet error rate on the AL-FEC.

Fig. 1 depicts the complete video streaming simulator architecture, where is shown how a content provider delivers

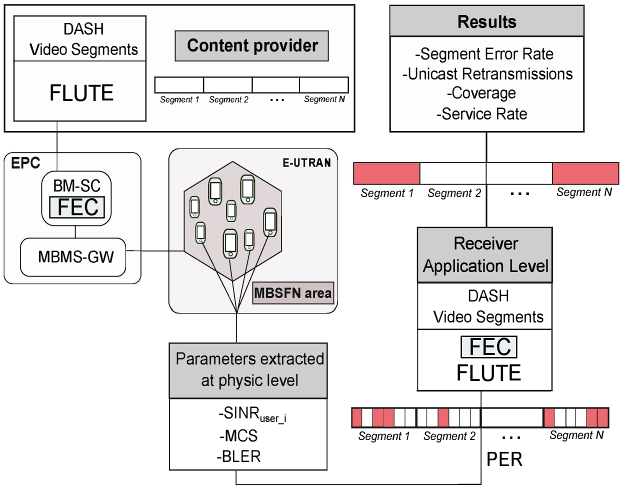

Fig. 1: Video streaming simulator architecture

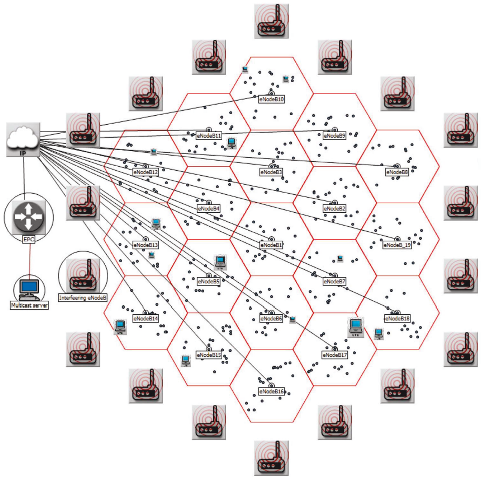

Fig. 2: Simulation scenario for 19-cell MBSFN area

video segments via Broadcast Multicast Service Centre (BM-SC) entity. This is an important element of the eMBMS architecture, since it is responsible to define the parameters used in the AL-FEC scheme. Then, the protected video segments are forwarded, through Multimedia Broadcast Multicast Services Gateway (MBMS-GW), to each Evolved Node B (eNodeB, eNB) belonging to the Multimedia Broadcast and Multicast Service (MBMS) area. Finally, video segments are delivered from eNodeBs to the multicast users using the MBSFN technique.

According to this model, a multicast service has been simulated using only one reserved subframe for MBMS to all the users placed in the region. Around the MBSFN area, we consider one tier of interference eNodeBs. The most important parameters used in the multiples scenarios simulated are shown in the Table I, and the simulation scenario for the 19-cell MBSFN area is depicted in Fig. 2.

Moreover, Fig. 1 shows each video segment is encoded independently using AL-FEC. Using the results obtained in the simulation model we have analyzed the impact of different FEC techniques on a multicast video streaming service over LTE. For this purpose, we have developed a mathematical model, where it is considered that a video segment is correctly decoded if the failure probability in the decoding process is equal or less than 1%. The probability of failure for the decoder $P(f_{RC})$ has been calculated for each user as

$$P(f_{RC}) = \sum_{n=0}^{k+r} P(f_{RC}|n) \times P(N=n) \tag{3}$$

where $P(f_{RC}|n)$ is the failure probability of the decoder in case of receiving n encoding symbols, given as (1) for the standardized Raptor codes and given as (2) for RaptorQ codes. On the other hand, $P(N = n)$ is the probability of correctly receiving n symbols, which is modeled using a binomial distribution, given as

$$P(N=n) = \binom{k+r}{n} \times (1-PER)^n \times (PER)^{(k+r-n)} \tag{4}$$

where the Packet Error Rate (PER) is the probability of a symbol failure. Since $P(f_{RC})$ is the probability of failure when decoding an AL-FEC encoded DASH segment, it can be also considered as the probability of retransmitting this segment using a unicast HTTP transmission. By calculating $P(f_{RC})$ for each segment and each user with different values of k source symbols and r repair symbols, it is possible to obtain the values of coverage for different AL-FEC code rates.

TABLE I: System Parameters

Parameter	Value
MBSFN area size	1 / 7 / 19 eNodeBs
Interference model	1 tier
eNodeBs geographical overlay	Hexagonal
Intersite Distance (ISD)	500 m / 1732 m
Transmission power	45 dBm
Subframes reserved for MBMS	1
Cyclic prefix	Extended ($16.7\mu s$)
Bandwidth	10 MHz
Downlink base frequency	2110 MHz
Pathloss model	3GPP Urban Macrocell
Multipath channel model	ITU Pedestrian B
eNodeBs transmission antennas	1
Total number of UEs	399
UEs distribution	Uniform distribution
Modulation and Coding Schemes	4 / 5 / 6 / 7 / 8 / 10 / 15 / 20 / 25 / 28
Length of Raptor Codes segments	1 sec / 2 sec / 10 sec / 20 seg

IV. PERFORMANCE EVALUATION

The model described above has been used to evaluate MBSFN and AL-FEC techniques in a multicast video streaming service. The performance evaluation has been carried out considering the combination of all the parameters described before, such as: different MCS covering the whole range for LTE, a variable size of the MBSFN area, different Intersite

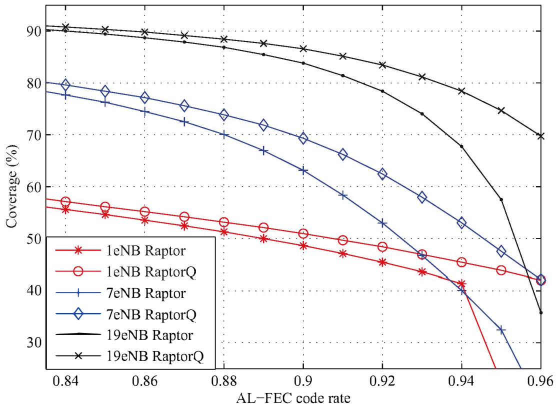

Fig. 3: Coverage vs. AL-FEC code rate for different MBSFN areas and MCS 25

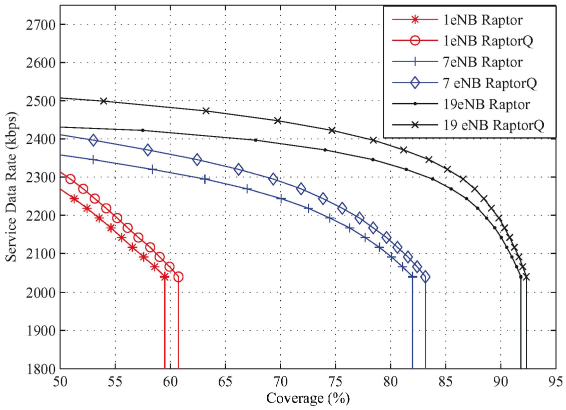

Fig. 5: Service data rate vs. Coverage for different MBSFN areas and MCS 25

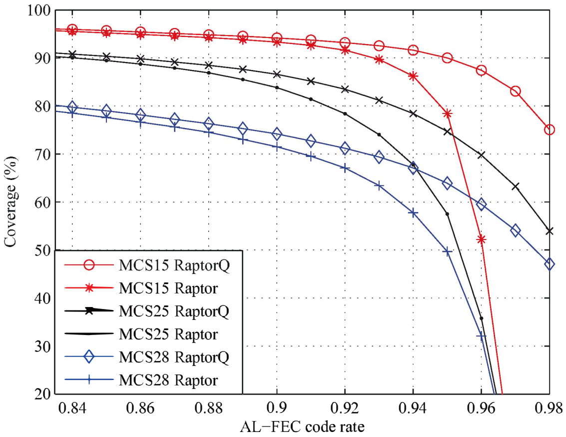

Fig. 4: Coverage vs. AL-FEC code rate for different MCSs in a 19-cell MBSFN area

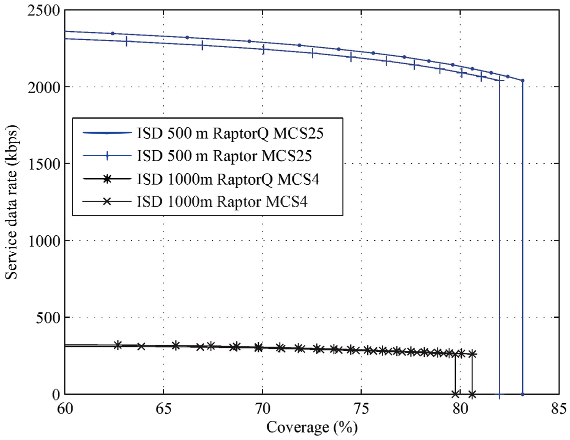

Fig. 6: Service data rate vs. Coverage for different ISDs

Distance (ISD) in the eNodeBs deployment, different length of the video segment duration and different code rates for the AL-FEC schemes considered (Raptor and RaptorQ).

A. Analysis of Coverage vs AL-FEC code rate

Different MCS values have been used for this analysis. Fig. 3 shows the results obtained using MCS 25, comparing the utilization of Raptor and RaptorQ codes for different size of the MBSFN area. This figure illustrates the benefit of using an MBSFN area with a higher number of cells. Furthermore, the improvement in the performance using RaptorQ intead of Raptor codes can be observed. Moreover, we can notice that the difference between Raptor and RaptorQ codes is higher when we are using coding rates close to one, due to the fact that RaptorQ is more efficient than its predecessor, Raptor codes, as we described in Section 2.

Fig. 4 shows the coverage of users depending on the AL-FEC code rate in a scenario of 19-cell MBSFN area. On the one hand, we can appreciate that RaptorQ is more efficient using higher code rates. On the other hand, the Fig. 4 shows that the use of RaptorQ codes allows us to increase the coverage, since more robust MCSs can be chosen [4].

B. Analysis of Service Data Rate vs Coverage

The use of AL-FEC increases the robustness and reliability of the service. However, the repair symbols that have been introduced affect the maximum service data rate versus coverage.

This analysis focuses on the comparison between Raptor and RaptorQ codes in terms of the service data rate that can be achieved using different size MBSFN area deployments and MCSs. Fig. 5 shows the results obtained using a MCS value of 25. The use of a MCS value of 28 reduces significantly the coverage, which means that a larger number of users needs to recover the lost video segments requesting them via unicast retransmissions, which reduces the benefit of using the MBMS

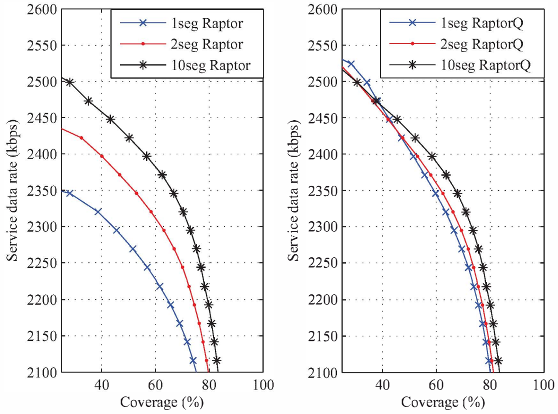

Fig. 7: Service data rate vs. Coverage for different AL-FEC segment length

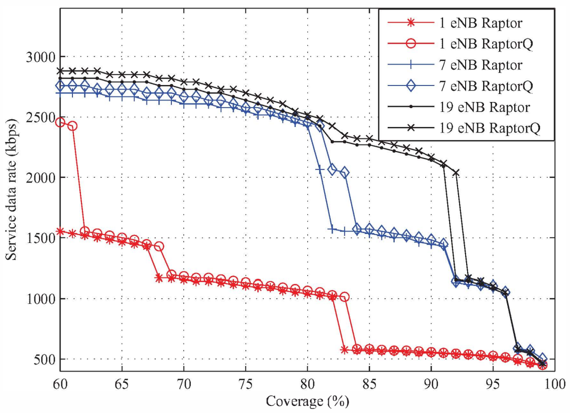

Fig. 8: Maximum data rate vs. Coverage for the AL-FEC/PHY-FEC trade-off

service. Fig. 5 shows the relevance of size of the MBSFN area in order to maximize the coverage and the service data rate. The number of cells included in the MBSFN area is particularly relevant when the highest MCSs are used, because these MCSs are less robust and consequently require better channel conditions in the users.

C. Analysis of ISD in the LTE deployment

This analysis consists in studying the impact of deploying base stations at different distances. For this purpose, we have focused on two extreme cases using an ISD of 500 m and 1,732 m. Fig. 6 shows that using a MCS of value 25, an ISD of 500 m and a 7-cell MBSFN area deployment, the mobile operator is able to provide a service data rate of 2 Mbps, covering 80% of the users. However, if the ISD is 1,732 m, a similar coverage can only be achieved using a MCS value of 4, achieving a service data rate of 300 kbps.

The main result obtained from this analysis is the great improvement of the channel conditions using lower ISD deployments. This is an important parameter to consider for a mobile operator that wants to provide a video streaming service in a suburban area. The operator must take into account this limitation.

D. Analysis of the length of AL-FEC segments

The inherent characteristics of streaming applications, which have strict delays and bandwidth requirements, are even more relevant in the case of live streaming. As a result of this intolerance, the use of video segments with short duration is recommended. In theory, in the case of Raptor codes, the protection of larger blocks (i.e, longer protection periods) increases the performance of the decoding process [11]. However, the use of larger blocks also implies a longer zap time, where this delay is the time elapsed since a user changes a channel until the new channel is played. Fig. 7 shows the service data rate based on the coverage for different segment length, comparing Raptor and RaptorQ codes. For this analysis, we have selected a MCS value of 25 and a 7-cell MBSFN area deployment. Using Raptor codes, we can note that it is possible to obtain higher service data rate increasing the duration of the video segments. However, using RaptorQ codes, due to the higher performance of the code, the difference is not significant.

In conclusion, for Raptor codes it is reasonable to select an appropiate value for the duration of the video segments in order to decrease the zap time in contrast to increase the service data rate. On the other hand, using RaptorQ codes, increasing this duration does not impact in a significant way on the service data rate, so it is not necessary to evaluate this issue for RaptorQ codes and the duration of the video segment has to be selected as small as possible.

E. AL-FEC vs. PHY-FEC trade-off to maximize the Service Data Rate

Finally, we analyze the maximum service data rate achievable in LTE (for the case of only one subframe allocated for multicast transmissions) combining AL-FEC and PHY-FEC techniques and using different size of MBSFN area. This mean that, for this analysis, we have covered all the possible values that can be assigned to the MCS and the code rate (AL-FEC), to obtain the maximum service data rate that is achievable for a specific coverage. Notice that this analysis is slightly different from the study previously done. In that case we evaluated the impact of using AL-FEC on the service data rate and coverage for a fixed MCS, whereas in this case, we are evaluating, for a specific coverage, the maximum service data rate, considering all the possible values of MCS and code rate.

From this analysis, as it can be observed in Fig. 8, we can conclude that the use of RaptorQ codes does not contribute especially to increase the service data rate. However, the utilization of RaptorQ codes may be beneficial to increase some specific points of coverage (e.g, about 80% to 85%), where the use of a lower MCS (i.e, a lower service data rate) is not needed to achieve this level of coverage, due to the higher performance of the code.

Moreover, Fig. 8 shows that achieving higher coverage implies to offer a lower service data rate to the multicast users. Only using a 19-cell MBSFN area deployment, it is possible to achieve both high coverage and service data rate. For a coverage below 80%, there is not a substantial difference between using 7-cell or 19-cell MBSFN area deployment, but the use of MBSFN technique is critical since we can note that the results obtained using only 1-cell MBSFN area are qualitatively and quantitatively worse.

V. CONCLUSION

The deployment of a multicast video streaming service is not a trivial issue. The operator has to evaluate multiple factors in order to provide a good quality of service. Some of these factors have been analyzed here, such as, the ISD between eNodeBs, the number of cells per MBSFN area, the MCS used for the multicast transmission, or the code rate selected for the AL-FEC scheme. We have introduced a new variable in this analysis: the comparison between Raptor and RaptorQ in a service of these characteristics. The effects of using RaptorQ codes, among other techniques, in the service data rate or the coverage achieved have been studied.

Throughout this paper, we have seen that RaptorQ improves the performance for a lower number of repair symbols introduced, however the difference between Raptor and RaptorQ is not so big when using lower code rate. In terms of service data rate, the benefit of using RaptorQ is not very noticiable, unless we use video segments of very short duration. Finally, we have shown the maximum service data rate based on the coverage, comparing Raptor and RaptorQ. Consequently, the use of MBSFN together with Raptor and RaptorQ codes has been evaluated.

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