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Performance of a Two Level Unequal Error Protection Scheme for MP3 Transmission over LTE

Prateema Ragpot
University of Mauritius
Réduit
Mauritius

Tulsi Pawan Fowdur
University of Mauritius
Réduit
Mauritius

Sunjiv K. M. Soyjaudah
University of Mauritius
Réduit
Mauritius

ABSTRACT
Long-Term Evolution (LTE) is a wireless broadband communication technology which is highly used for the transmission of data and voice over the internet. However, due to noise and other channel deteriorations, the transfer of data and voice over LTE is very challenging. With the phenomenal increase of data and voice traffic, the management of Quality of Service (QoS) is a challenging problem. This paper presents an enhanced audio transmission scheme with two levels of Unequal Error Protection (UEP) for audio over LTE. The unequal importance of the bits generated by an MP3 codec as well as the varying importance of the bitstreams generated by a Turbo encoder is exploited and different level of protection are offered to them during LTE transmission. This is achieved by positioning the different bits in such a way so that the least important ones are given less protection than the more important bits. With 16-Quadrature Amplitude Modulation (QAM), the proposed two level UEP scheme provides an average gain of 22.36 dB in Segmented Signal to Noise Ratio (SSNR) over a conventional Equal Error Protection (EEP) one at a Turbo code rate of 1/2.

General Terms
QoS, LTE

Keywords
MP3, Audio Transmission, Prioritisation, UEP

1. INTRODUCTION
The volume of calls and data transmission has increased considerably during the last decade. This has fueled the emergence of new next-generation networks such as LTE. LTE was proposed as an international standard in 2004 and worldwide deployment started in 2010. The maximum speed of LTE is being pushed by operators across the world and its coverage is expanding to the point that in several countries 4G networks are now as ubiquitous as the 3G networks that preceded them [1].In parallel, the technological evolution of hand held devices has boosted the demand for new multimedia services such as live audio and video streaming. This expansion in multimedia traffic and the increase in the number of LTE subscription has placed a consequential burden over wireless broadband networks. Audio transmission in a wireless environment is indeed very challenging. A certain level of Quality of Service (QoS) must be sustained for the development and usage of broadband applications. Guaranteeing a high QoS for the distribution of compressed audio data over LTE using conventional methods is very demanding as compressed audio data is extremely vulnerable to error propagation. A string of bits can be unusable due to a single transmission error. Retransmission has a limited use due to stringent delay constraints for services such as live audio streaming. Therefore, a number of UEP schemes have been developed. An overview of these techniques is given next.

A new UEP scheme was proposed for Orthogonal Frequency Division Multiplexing (OFDM) transmission systems for multimedia applications in [2]. The encoded data having highest value were assigned to carriers that have less chance of fade error to be transmitted. The results showed a greater tolerance for error in transmission with UEP. The performance of image transmission with UEP based on irregular Low-Density Parity-Check (LDPC) codes was investigated in [3]. The different information bits of the image bytes were mapped to different positions of the LDPC codes which were in turn mapped on a power efficient QAM constellation. The parity check bits were mapped into a spectrally efficient 16-QAM constellation. Simulation results showed that the UEP scheme was effective. UEP can be achieved by assigning different level of protection through hierarchical 16-QAM. High priority data were mapped on the most significant bits of the 16-QAM constellation point and the low priority one were mapped onto the less significant bits. This was presented in [4]. Simulation results showed that the EEP schemes were outperformed by the new proposed UEP scheme. In [5], it was demonstrated that prioritized QAM constellation mapping has a positive impact on the error performance of Turbo Codes by using the UEP characteristics of the QAM constellation where the systematic information bits are given a higher protection. A robust transmission of H.264/AVC coded video using hierarchical QAM (HQAM) was presented in [6]. The non-uniformly distributed importance of frames as well as the sensitivity of the coded bitstream against transmission error were taken into consideration. UEP was based on HQAM constellation and various bit dividing schemes so that the critical data of the video content was protected. The system was tested under Additive White Gaussian Noise (AWGN). The results demonstrated a better quality of the reconstructed video data was obtained compared to a system offering equal protection. A multilevel UEP system using multiplexed HQAM was proposed in [7]. Numerical results showed that the performance was significantly enhanced by the proposed methods. In [8], UEP for audio over ADSL was investigated. An MP1 codec generates subbands of different importance. This was exploited to offer different level of protection to them during Asymmetric digital subscriber line (ADSL) transmission. The proposed scheme outperformed a conventional one. [9] demonstrated that using UEP with Forward Error Correction (FEC) for the transmission of audio over ADSL surpasses an EEP scheme.

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An enhanced scheme for MP3 compressed audio files transmission over LTE is proposed in this paper. The hypothesis behind is to divide the compressed audio bit stream into different levels according to their importance and to prioritize their transmission by giving more protection to the most important levels. For the first level of UEP, the difference in importance of the control information bits and scalefactor and subband sample bits is exploited. For successful MP3 decoding, the control information bits are more relevant than the scalefactor and subband sample bits. For the second level of UEP, the Turbo encoded bits have been divided into systematic bits and parity bits, where the systematic bits are considered more important that the parity bitstream

The paper is organized as follows. Section 2 gives a detailed explanation of the complete system model. Section 3 gives a thorough analysis of the simulation results and the paper is concluded in Section 4.

2. SYSTEM MODEL

The two level UEP system was implemented as per the block diagram given in Figure 1. On the transmitter side, an audio file is sent to the MP3 encoder. The file is processed by the different signal processing blocks such as Fast Fourier Transform (FFT), 32 channel polyphase analysis filterbank, psychoacoustic analysis, modified discrete cosine transform (MDCT) adaptive segmentation, bit allocation, code side info and multiplexer [10]. The control information bits (CI) together with the scalefactor and subband sample bits (SB) form an MP3 frame. The MP3 bitstream is then sent to the Turbo Encoding, Bit Separation, Bit Reordering and Prioritised Constellation mapping block where they are encoded, separated according to their importance, reordered and mapped on the constellation being used in the AWGN channel.

On the receiver side, the received bits are demapped, reordered, merged and Turbo decoded before being sent to the MP3 decoder. In the MP3 decoder, the bits go through a series of signal processing blocks such as Synchronization and Error Check, Huffman Decoding, Scalefactor decoding, Requantisation, Reordering, Alias Reduction, Inverse MDCT (IMDCT), frequency inversion and Synthesis Polyphase Filterbank so that the audio file can be reconstructed [10].

2.1 First Level UEP Bit Separation

The control information bits (CI) are considered more important than the scalefactor and subband sample bits (SB). Using this information, the bits in the MP3 frame are separated into two bitstreams. The CI bits form the CI bitstream, which are prioritized over the SB bits which form the SB bitstream.

2.2 Turbo Encoding

The two bitstreams are then sent to the Turbo encoder separately. For each bitstream, the Turbo encoder generates systematic bits, d_0 and parity bits d_1 and d_2 and rearranges them such that the d_0 bits are placed in the beginning followed by bit-by-bit interlacing of the two parity streams, d_1 and d_2, in order to form a single output buffer [11]. The Turbo encoder outputs six different types of bits, namely control information systematic bits (CId_0), control information parity 1 bits (CId_1), control information parity 2 bits (CId_2), scalefactor and subband sample systematic bits (SBd_0), scalefactor and subband sample parity 1 bits (SBd_1) and lastly, scalefactor and subband sample parity 2 bits (SBd_2) as illustrated in Figure 2.

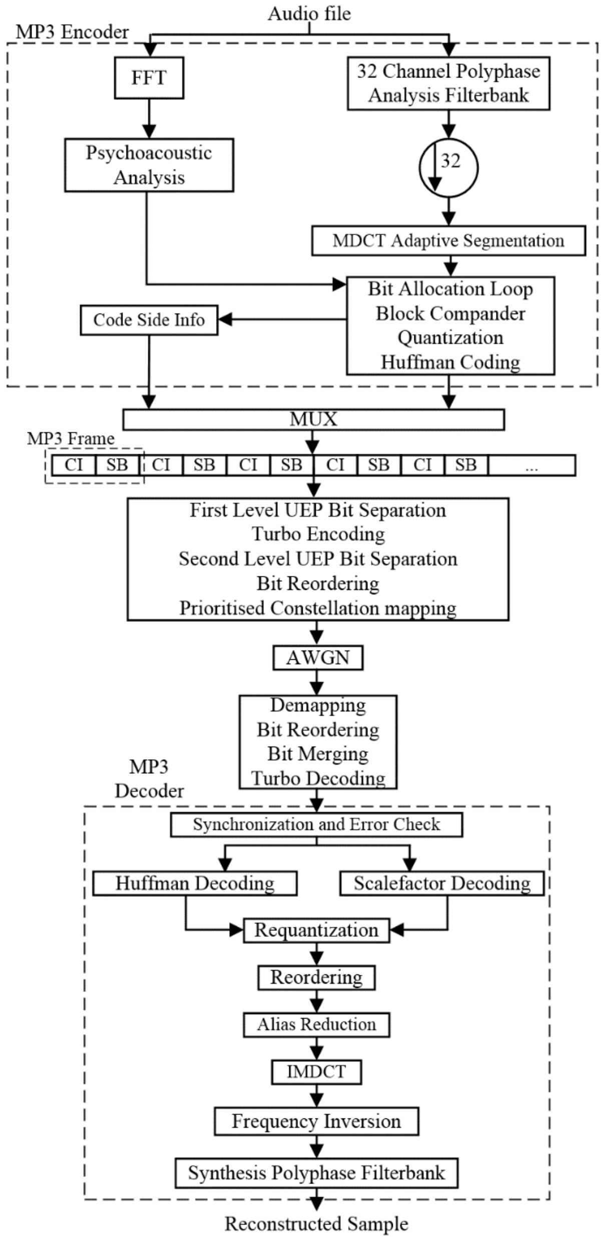

Figure 1: The proposed system

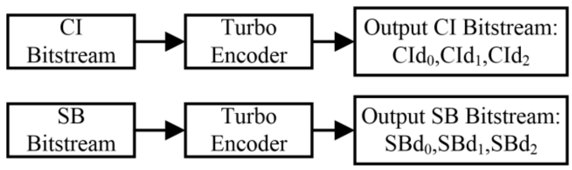

Figure 2: Turbo Encoding Input and Output

The output CI bitstream is the High Priority (HP) bitstream and the output SB bitstream is the Low Priority (LP) one.

2.3 Second Level UEP Bit Separation

The systematic bits are more important than the parity bits so the low priority bitstream, that is, the output SB bitstream is

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separated accordingly and the bits are placed in two buffers – Low Priority Systematic (LP-Sys) Buffer and Low Priority Parity(LP-Par) Buffer. The SBd_0 bits are stored in the LP-Sys Buffer and the SBd_1 and SBd_2 are moved to the LP-Par Buffer. The bit separation is done as per Figure 3.

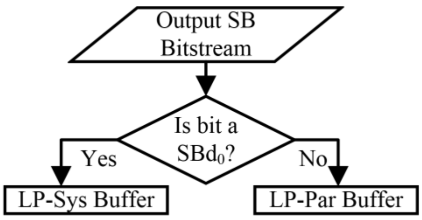

Figure 3: Bit Separating Algorithm

The HP bitstream together with the bits in the LP-Sys Buffer form the Most Important (MI) bitstream and the LP-Par Buffer bits are the Least Important (LI) bitstream. Table 1 summarises the bits found in each bistream.

Table 1: Bitstream summary

UEP Level	Description	Bitstream	
First	Considering difference between CI and SB bits only	**HP**	**LP**
		CId_0, CId_1 and CId_2	SBd_0, SBd_1 and SBd_2
Second	Considering difference between CI and SB, as well as difference between systematic SB and parity SB bits	**MI**	**LI**
		CId_0, CId_1, CId_2 and SBd_0,	SBd_1 and SBd_2

2.4 Bit Reordering and Prioritized Constellation Mapping

To achieve prioritized constellation mapping, the more important bits are placed at the most strongly protected points on the QAM constellation [12].

A 16-QAM constellation is formed by 16 symbols and each symbol consists of 4 bits. The first and third bits of a symbol are more protected than the bits found in the second and fourth position. This can be explained by using Figure 4.

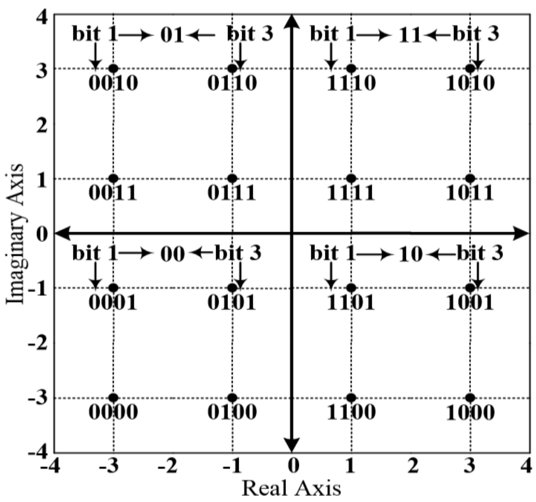

Figure 4: 16-QAM constellation with major quadrants

The bits in positions one and three determine the major quadrants. For instance, in the upper left quadrant of the constellation, the first and third bits are 0 and 1 respectively. Thus, the first and third bits of the 16-QAM constellation are correctly de-mapped if the de-mapper correctly distinguishes between the four quadrants [12]. For the first level of UEP, the bits are reordered so that the bits in the HP bitstream are always at positions one and while the low priority bits are placed at positions two and four of the four bits that form one symbol. For the two level UEP scheme, the bits in the MI bitstream are allocated to positions one and three and the LI bits are placed at positions two and four. The bit placement is summarized in Figures 5 and 6 and Table 2.

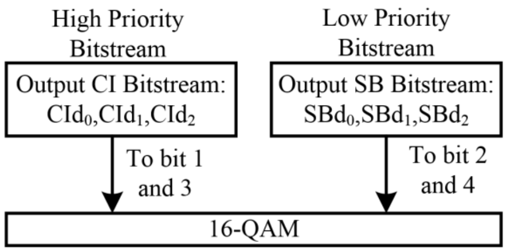

Figure 5: Bit placement for first level UEP in 16-QAM constellation

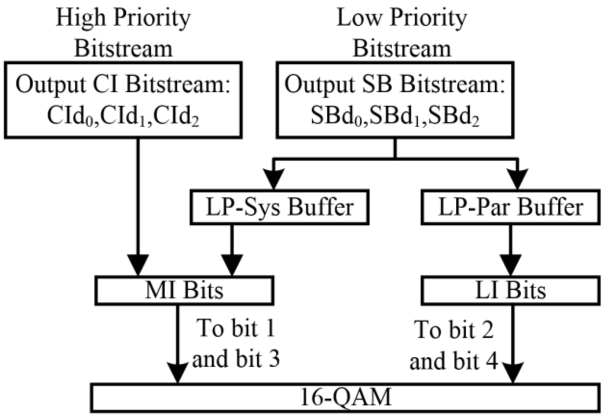

Figure 5: Bit placement for second level UEP in 16-QAM constellation

Table 2. Bit placement for 16-QAM constellation

UEP Level	Bit 1	Bit 2	Bit 3	Bit 4
1	HP bits	LP bits	HP bits	LP bits
2	MI bits	LI bits	MI bits	LI bits

With 16-QAM, a non-uniform modulation has been used by modifying the modulation parameter, α which is given as follows:

$$\alpha = \frac{d_1}{d_2} \qquad (1)$$

where, d_1 is the minimum distance between quadrants and d_2 is the minimum distance between the points.

In the 64-QAM constellation used in this system, the first two bits are more protected than the bits in the third to sixth

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positions. Figure 6 gives the placement of the 6-bits symbol on the 64-QAM constellation.

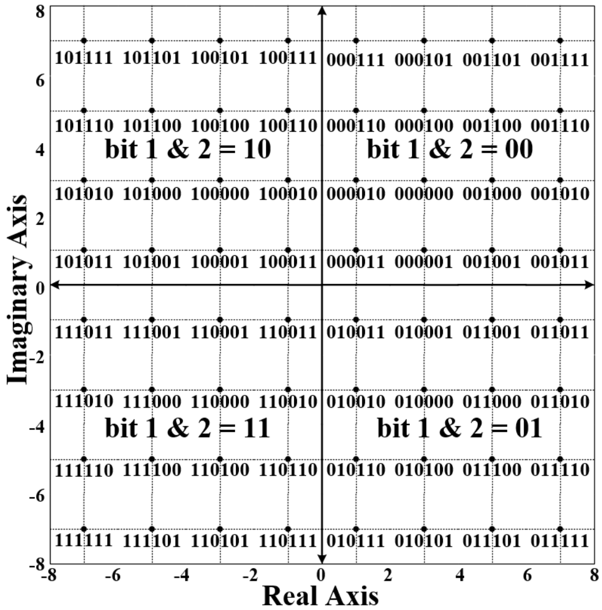

Figure 6: 64-QAM constellation quadrants

In this 64-QAM constellation point, the four major quadrants are distinguished by the bits in positions one and two. For example, in the upper left major quadrant of the 64-QAM constellation, the first and second bits are 1 and 0 respectively. Thus, the first and second bits of the 64-QAM constellation are correctly de-mapped if the de-mapper correctly distinguishes between the four quadrants. In each major quadrant, there are four minor quadrants which are distinguished using the bits in position three and four of the constellation points. As a result, it can be said that bits 1 and 2 are most protected, bits 3 and 4 have medium protection while bits 5 and 6 are least protected. Thus, for the first level of UEP, the HP bits are positioned at bit 1 and 2 of the six bits that are mapped onto one symbol of the 64-QAM constellation. The low priority bits are placed at bit positions 3 to 6 of the 6-bits symbol. For the two level UEP scheme, the MI bits are allocated to positions one and two and the LI bits are positioned at bit positions 3 to 6 on the 64-QAM constellation as shown in Figure 7.

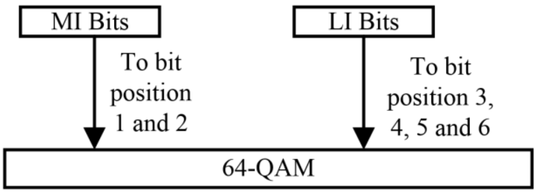

Figure 7: Bit placement for second level UEP in 64-QAM constellation

To further enhance this scheme, the LI bitstream is divided into the scalefactor and subband sample parity 1 (SBd_1) bits that are placed in the third and fourth positions of the 6-bit symbol and the scalefactor and subband sample parity 2 (SBd_2) bits that are placed in the last two bits positions. The bit separation and reordering is done as per Figure 8 and the 64-QAM bit placement is summarized in Table 3.

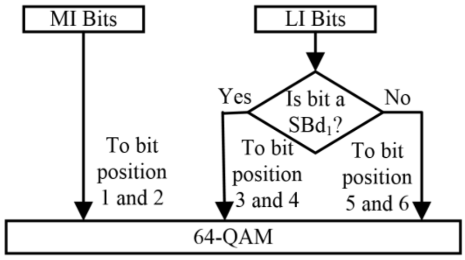

Figure 8: Bit separation and reordering with SBd_1 assigned to bit positions 3 and 4 of 64-QAM constellation

Table 3. Bit placement for 64-QAM constellation

UEP Level	Bit Position					
	1	2	3	4	5	6
1	HP Bits		LP Bits			
2	MI Bits		LI Bits			
2 with medium protection to parity 1 bits	MI Bits		LI Bits SBd_1		LI Bits SBd_2	

2.5 Turbo Decoding

The received symbols are sent to a soft-output QAM demapper to produce soft bits. These soft bits are rearranged and demultiplexed. The parity soft bits are deinterlaced. The systematic and parity soft bits are sub-block deinterleaved and sent to the Turbo decoder [12]. The bits from the decoder are then fed to the MP3 decoder for further processing.

3. SIMULATION RESULTS AND ANALYSIS

In all schemes, two audio files have been used with AWGN as channel model. The parameters of the audio files is in Table 4.

Table 4. Audio file 1 and file 2 parameters

Parameters	File 1	File 2
Rate /kHz	44.1	44.1
Size /kbits	95	107
Maximum SSNR /dB	153.38	168.19

For all schemes, two different rates – ½ and 1/3 and two different interleaver block sizes – 3072 and 6144 have been used for the Turbo code. For the 16-QAM the simulation with rate = ½, α was set to 0.6 and for rate = 1/3, α was set to 0.3. Since the performance of audio transmission is being evaluated, SSNR is used as a measure. The average SSNR gain is calculated for the different E_b/N_0 range used.

3.1 Results with 16-QAM

The performances of the following schemes are compared:

Scheme 1 – Conventional MP3 transmission over LTE Turbo coded 16-QAM system with interleaver block size 3072.

Scheme 2 - MP3 transmission over LTE Turbo coded prioritized 16-QAM constellation with one level UEP only with interleaver block size 3072.

Scheme 3 - MP3 transmission over LTE Turbo coded prioritized 16-QAM constellation with two level UEP with interleaver block size 3072.

Scheme 4 – Conventional MP3 transmission over LTE Turbo coded 16-QAM system with interleaver block size 6144.

Scheme 5 - MP3 transmission over LTE Turbo coded prioritized 16-QAM constellation with one level UEP only with interleaver block size 6144.

Scheme 6 - MP3 transmission over LTE Turbo coded prioritized 16-QAM constellation with two level UEP with interleaver block size 6144.

3.1.1 Results with first audio file

The graph of SSNR against E_b/N_0 at a rate of ½ for the range of 2.5 dB ≤ E_b/N_0 ≤ 3.625 dB is given in Figure 9. A gain of 7.29 dB on average is obtained by Scheme 2 over Scheme 1. Scheme 3 surpasses Scheme 1 by a mean of 28.57 dB in SSNR. The two level UEP scheme, Scheme 3 increases the gain obtained by Scheme 2 by an average of 21.28 dB. Scheme 5 yields 5.68 dB on average over Scheme 4. Scheme 4 is outperformed by Scheme 6 by 30.82 dB on average. The gain in SSNR between Scheme 5 and Scheme 6 is 25.14 dB on average. The average SSNR of Scheme 3 is exceeded by that of Scheme 6 by 9.04 dB.

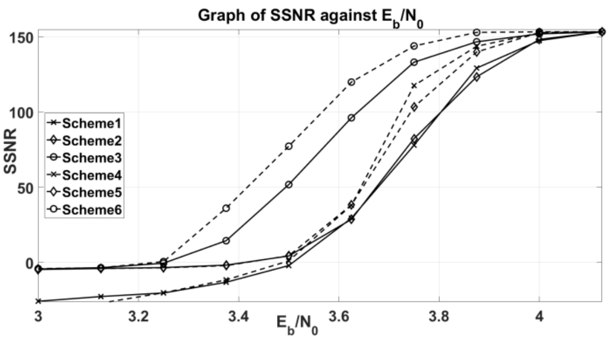

Figure 9: Graph of SSNR against E_b/N_0 at rate ½.

The graph of SSNR against E_b/N_0 over an E_b/N_0 range of 2.5 dB to 3.625 dB at rate 1/3 is shown in Figure 10. Scheme 2 surpasses Scheme 1 by a mean of 8.58 dB in SSNR and Scheme 3 adds 18.64 dB to this increase in SSNR. Scheme 3 exceeds Scheme 1 by 27.22 dB on average. Scheme 4 is surpassed by Scheme 5 by 7.66 dB and by Scheme 6 with 28.81 dB on average. Scheme 6 increases the gain of Scheme 5 by an average of 21.15 dB. Scheme 6 boost the performance of Scheme 3 by 6.51 dB on average.

3.1.2 Results with second audio file

The graph of SSNR against E_b/N_0 at a rate of ½ for the range of 2.875 dB ≤ E_b/N_0 ≤ 4.25 dB is given in Figure 11. Scheme 1 is outperformed by Scheme 2 by a gain of 4.81 dB in SSNR. The two level UEP scheme, Scheme 3 adds 17.55 dB on average to this rise in SSNR. The gain in SSNR between Scheme 1 and Scheme 3 is 22.36 dB on average. Scheme 4 is surpassed by Scheme 5 by a mean of 4.57 dB in SSNR. A gain of 25.42 dB on average is obtained by Scheme 6 over Scheme 4 and Scheme 6 yields a gain of 20.54 dB on average over Scheme 5. Scheme 6 yields 10.44 dB over Scheme 3.

The graph of SSNR against E_b/N_0 over an E_b/N_0 range of 2.375 dB to 3.625 dB at rate 1/3 is shown in Figure 12. Scheme 1 is surpassed by Scheme 2 by 11.36 dB and by Scheme 3 with 30.16 dB on average. Scheme 3 boost the performance of Scheme 2 by 18.79 dB on average. Scheme 5 surpasses Scheme 4 by 6.58 dB on average in SSNR and Scheme 6 adds 20.03 dB to this increase in SSNR. A gain of 26.60 dB on average is obtained by Scheme 6 over Scheme 4. Scheme 3 is outperformed by Scheme 6 by 4.85 dB on average.

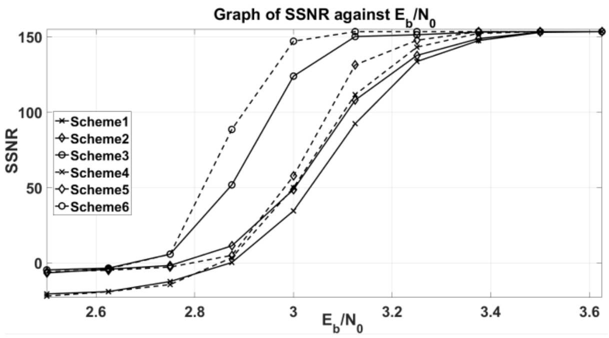

Figure 10: Graph of SSNR against E_b/N_0 at rate 1/3.

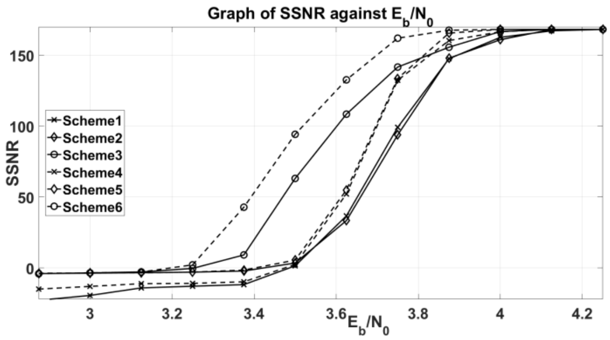

Figure 11: Graph of SSNR against E_b/N_0 at rate ½.

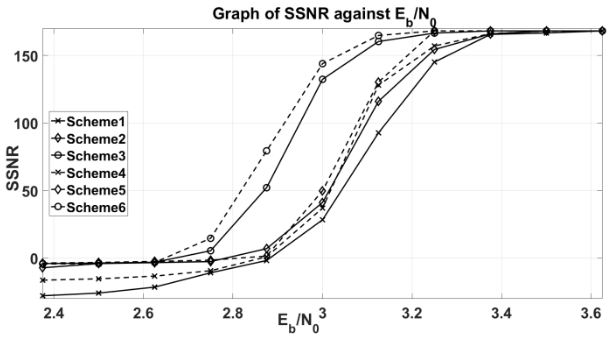

Figure 12: Graph of SSNR against E_b/N_0 at rate 1/3.

3.2 Results with 64-QAM

The performances of the following schemes are compared:

Scheme 1 – Conventional MP3 transmission over LTE Turbo coded 64-QAM system with interleaver block size 3072.

Scheme 2 - MP3 transmission over LTE Turbo coded prioritized 64-QAM constellation with one level UEP only with interleaver block size 3072.

Scheme 3 - MP3 transmission over LTE Turbo coded prioritized 64-QAM constellation with two level UEP with interleaver block size 3072.

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Scheme 4 - MP3 transmission over LTE Turbo coded prioritized 64-QAM constellation with two level UEP and parity 1 prioritization with interleaver block size 3072.

Scheme 5 Conventional MP3 transmission over LTE Turbo coded 64-QAM system with interleaver block size 6144.

Scheme 6 - MP3 transmission over LTE Turbo coded prioritized 64-QAM constellation with one level UEP only with interleaver block size 6144.

Scheme 7 - MP3 transmission over LTE Turbo coded prioritized 64-QAM constellation with two level UEP with interleaver block size 6144.

Scheme 8 - MP3 transmission over LTE Turbo coded prioritized 64-QAM constellation with two level UEP and parity 1 prioritization with interleaver block size 6144.

3.2.1 Results with first audio file

The graph of SSNR against at rate ½ for the range of 7 dB ≤ E_b/N_0 ≤ 10 dB is shown in Figure 13. Scheme 2 surpasses Scheme 1 by a mean of 0.17 dB in SSNR and Scheme 3 adds 86.36 dB to this increase in SSNR, thus 86.53 dB on average is obtained by Scheme 3 over Scheme 1. The gain between Scheme 4 and Scheme 1 is 88.38 dB on average. The performance of Scheme 2 is exceeded by that of Scheme 4 by 88.20 dB on average. Scheme 4 increases the gain of Scheme 3 by 1.84 dB in SSNR. Scheme 5 is surpassed by Scheme 6 by 3.07 dB, by Scheme 7 with 88.91 dB and by Scheme 8 with 89.37 dB on average. An average gain of 85.84 is noted between Scheme 6 and Scheme 7. Scheme 8 outperforms Scheme 6 by 86.30 dB and Scheme 8 surpasses Scheme 7 by 0.46 dB. Scheme 8 boost the performance of Scheme 4 by 0.16 dB on average.

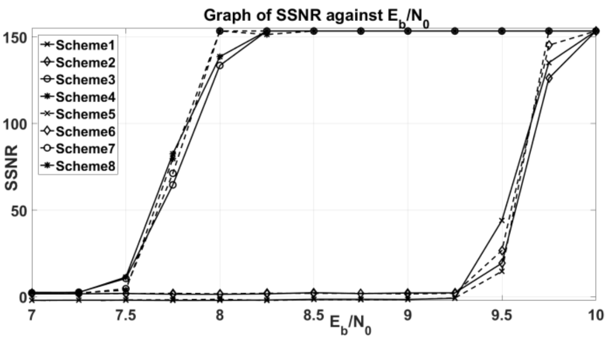

Figure 13: Graph of SSNR against E_b/N_0 at rate ½.

The graph of SSNR against E_b/N_0 at a rate of 1/3 for the range of 4 dB ≤ E_b/N_0 ≤ 10 dB is given in Figure 14. The performance of Scheme 1 is enhanced by Scheme 2 by 3.29 dB, by Scheme 3 with 54.12 dB and by Scheme 4 with an increase of 83.44 dB dB on average in SSNR. Scheme 3 increases the raise in SSNR of Scheme 2 by 50.83 dB and Scheme 4 increases this raise by a mean of 80.14 dB. The gain in SSNR between Scheme 3 and Scheme 4 is 29.32 dB on average. Scheme 5 is exceeded by Scheme 6 by 3.73 dB on average. Scheme 7 raises the average SSNR of Scheme 5 by 54.27 dB and Scheme 8 increases the same average by 83.96 dB. An average gain of 50.53 is noted between Scheme 6 and Scheme 7. Scheme 8 outperforms Scheme 6 by 80.22 dB and Scheme 8 surpasses Scheme 7 by 29.70 dB. Scheme 4 is surpassed by Scheme 8 with a gain of 1.37 dB on average.

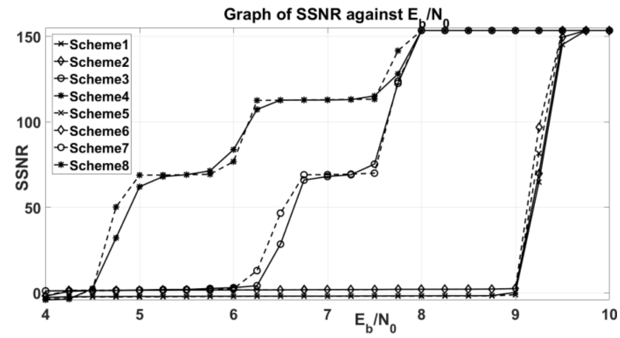

Figure 14: Graph of SSNR against E_b/N_0 at rate 1/3.

3.2.2 Results with second audio file

The graph of SSNR against E_b/N_0 at a rate of 1/3 for the range of 4 dB ≤ E_b/N_0 ≤ 10 dB. Scheme 1 is surpassed by Scheme 2 by 26.65 dB, by Scheme 3 with 53.25 dB and by Scheme 4 with 54.51 dB on average. An average gain of 26.60 is noted between Scheme 2 and Scheme 3. Scheme 4 outperforms Scheme 2 by 27.86 dB and Scheme 4 surpasses Scheme 3 by 1.25 dB. Scheme 5 is exceeded by Scheme 6 by 25.48 dB on average. Scheme 7 raises the average SSNR of Scheme 5 by 53.61 dB and Scheme 8 increases the same average by 53.96 dB. An average gain of 28.14 is noted between Scheme 6 and Scheme 7. Scheme 8 outperforms Scheme 6 by 28.06 dB and Scheme 8 surpasses Scheme 7 by 0.775 dB. Scheme 4 is surpassed by Scheme 8 with a gain of 1.11 dB on average.

The graph of SSNR against at rate 1/3 for the range of 4 dB ≤ E_b/N_0 ≤ 9.75 dB is shown in Figure 16. The performance of Scheme 1 is enhanced by Scheme 2 by 31.65 dB, by Scheme 3 with 66.71 dB and by Scheme 4 with an increase of 104.91 dB dB on average in SSNR. Scheme 3 increases the raise in SSNR of Scheme 2 by 35.06 dB and Scheme 4 increases this raise by a mean of 73.26 dB. The gain in SSNR between Scheme 3 and Scheme 4 is 38.21 dB on average. Scheme 5 is exceeded by Scheme 6 by 32.74 dB on average. Scheme 7 raises the average SSNR of Scheme 5 by 68.01 dB and Scheme 8 increases the same average by 105.75 dB. An average gain of 35.26 is noted between Scheme 6 and Scheme 7. Scheme 8 outperforms Scheme 6 by 73.01 dB and Scheme 8 surpasses Scheme 7 by 37.75 dB. Scheme 8 boost the performance of Scheme 4 by 0.97 dB on average.

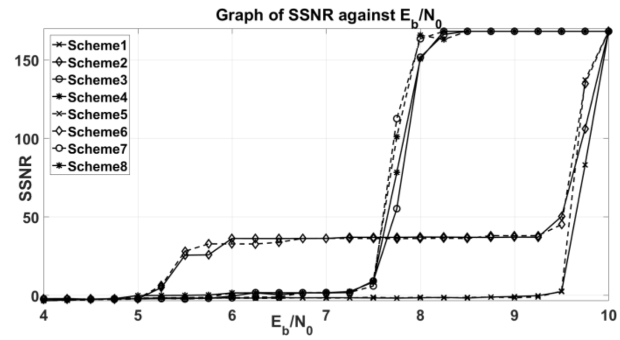

Figure 15: Graph of SSNR against E_b/N_0 at rate ½.

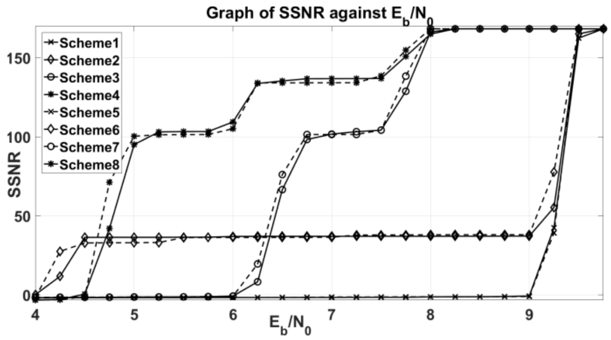

Figure 16: Graph of SSNR against E_b/N_0 at rate 1/3.

For 16-QAM, the gain of Schemes 2 and 5 over Schemes 1 and 6 respectively is due to the prioritization of the control information bits. Giving more protection to the high priority bitstream and the systematic bits of the low priority bitstream further enhances the system as can be seen by the increase in SSNR for Schemes 3 and 6.

For 64-QAM, prioritizing the control information bits enhances the system performance as confirmed by the results of Schemes 2 and 6. Results of Schemes 3 and 7 prove that by giving more protection to the control information bits as well as the systematic bits of the Turbo encoded scalefactor and subband bits better system performance can be achieved. Providing high protection to the high priority bitstream and the systematic bits of the low priority bitstream and giving medium protection to the parity 1 bits of the low priority bitstream increases the gain of the overall system as can be seen by Schemes 4 and 8.

With both 16-QAM and 64-QAM, the system exhibits better performance for the larger interleaver block size.

4. CONCLUSION

This paper proposed an efficient two level UEP scheme for audio transmission with LTE Turbo coded QAM using prioritized constellation mapping. The proposed schemes give significant gains of several dBs over a conventional one. The gains obtained are due to the single and two level UEP schemes used. The gain achieved is accompanied by the increase in complexity at the transmitter and receiver as a bit separating algorithm and bit reordering mechanism has been incorporated in the system. However, the gains obtained counterbalances the additional complexity and the proposed scheme appears to be very favorable for audio transmission over LTE. With the sensational increase in internet traffic, the two level UEP scheme could give an accessible solution to boost the QoS in bandwidth constrained applications. Implementing and testing the proposed scheme in an actual physical environment to achieve realistic results could be an interesting future work.

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