

Transmission Rate Enhancement Schemes for Digital Radio Mondiale Systems

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Abstract

In this paper, transmission rate enhancement schemes for DRM (Digital Radio Mondiale), which is a worldwide standard for digital AM and FM broadcasting in the AM and FM bands below 170 MHz, are presented and compared. The data rate of the legacy DRM system is supported up-to 186kbps with 16QAM and MLC (Multi-level Coding) at 100 kHz bandwidth. However, this rate is not sufficient to achieve new high quality services such as loss-less audio broadcasting and mobile TV. In order to increase transmission rates of the DRM system, two different types of FEC (Forward Error Correction) codes are used with 64QAM in the proposed schemes. One is the MLC (Multi-level Coding) derived straightforwardly from the legacy DRM system while the other is the TC (Turbo Code) designed for an enhanced DRM. The proposed schemes can achieve transmission rates higher than 300kbps. Also, compared with MLC, TC has 1.6 dB – 5 dB SNR gain with code rate 1/2 in different channel environments for Band-II.

Keywords: *Digital Radio Mondiale, DRM, DRM+, Digital Radio Broadcasting*

1. Introduction

The DRM (Digital Radio Mondiale) system, which is a worldwide standard for digital AM and FM broadcasting in the AM and FM frequency bands below 170 MHz, has some advantages such as robustness in fading channels, better audio quality, power-saving at the transmitting side, and data services in comparison to analog AM and FM broadcasting [1]. Also, DRM provides a coherent migration path for both AM and FM to digital. The data rate of DRM system is supported up-to 186 kbps with 16QAM and MLC (Multi-level Coding) at 100 kHz bandwidth [1]. However, this rate is not enough to achieve new high quality services such as a loss-less audio broadcasting and a mobile TV. In order to achieve higher data rate without bandwidth expansion, high-order modulation such as 64QAM has to be used. But in the time-varying multipath fading channels, especially in Band-II band, the performance of the DRM system modulated with 64QAM is deteriorated seriously due to ICI (Inter-Carrier Interference) caused by the time-varying channels. In order to increase the data rate of the DRM system and obtain a good link margin in the fading channels, a powerful FEC (Forward Error Correction) code is required.

In this paper, in order to increase transmission rates of the DRM system, we propose new transmission modes, which are composed of two different types of FEC codes, both MLC and TC (Turbo Code), in combination with 64QAM. And we present the BER (Bit Error Ratio) performances of two data rate enhancement schemes in an AWGN (Additive White Gaussian Noise) and fading channels with different mobile speed. The paper is organized as follows: Section 2 introduces the legacy DRM system. In Section 3, we propose two data rate enhancement schemes based on MLC and TC, respectively. Section 4 shows the simulation results and section 5 concludes the paper.

2. Legacy DRM System Description

The DRM system, which is based on OFDM (Orthogonal Frequency Division Multiplexing), provides various robustness modes for robust reception of signal in different propagation-related transmission conditions. The robustness mode A, B, C, and D are operated on frequencies below 30 MHz whereas the robustness mode E, also called DRM+, is operated on frequencies from 30 to 170 MHz.

The simplified block diagram is shown in Figure 1. In this Figure, the DRM system consists of 3 different channels, the MSC (Main Service Channel), SDC (Service Description Channel), and FAC (Fast Access Channel). The MSC contains the data for services. The SDC gives information on how to decode the MSC and the FAC provides information on the channel and service parameters to allow for fast decoding. These channels are converted into the OFDM signal after being multiplexed into a transmission frame in the OFDM cell mapper. In the robustness mode E the maximum transmission rate for the MSC is 186 kbps when the nominal bandwidth is 100 kHz and the overall code rate of MLC is equal to 5/8 in an EEP (Equal Error Protection) mode.

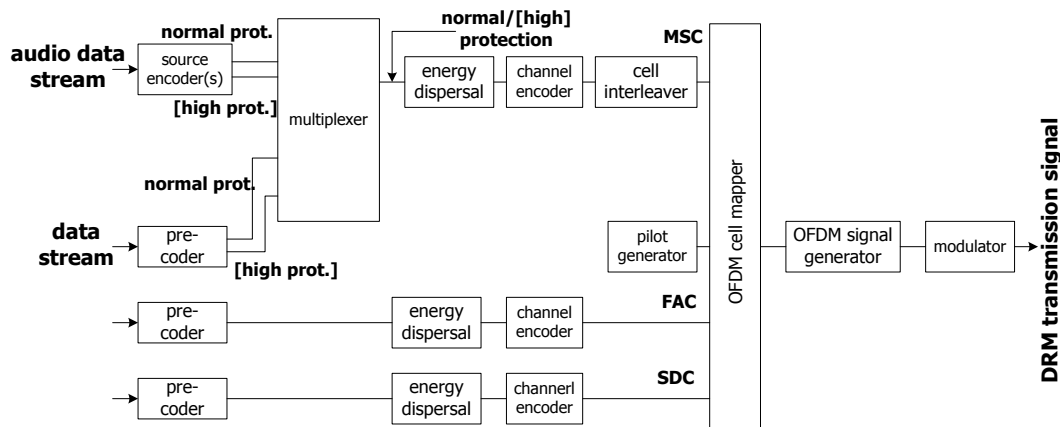


Figure 1. Simplified DRM System Block Diagram

3. Enhanced Modes for DRM

The basic idea for data rate enhancement is to use high-order modulation in combination with a powerful FEC to reduce the bit error probability. In this section, new transmission modes composed of two different types of channel coding techniques in combination with higher order modulation, 64QAM, are proposed for the data rate enhancement of the DRM system. In this paper, both MLC and TC are considered one of the FEC options for enhanced modes of DRM systems in order to overcome the performance degradation due to multipath-fading channels and support the high-speed transmission mode in the frequency bands below 170 MHz.

3.1. 64QAM and MLC Mode

This enhancement scheme use the existent modulation and coding method for compatibility with the legacy DRM system and need only small changes in the FAC. The principle of MLC, adopted in the DRM system, is the joint optimization of coding and modulation to achieve the best performance via applying different code rates to each bit position in the QAM mapping. The different levels of protection is achieved with different

component codes which are implemented with the punctured convolutional codes, derived from the same mother code of code rate 1/4 and constraint length 7 [1]. Figure 2 shows the block diagram of the MLC encoder and iterative decoder for 64QAM SM (Standard Modulation).

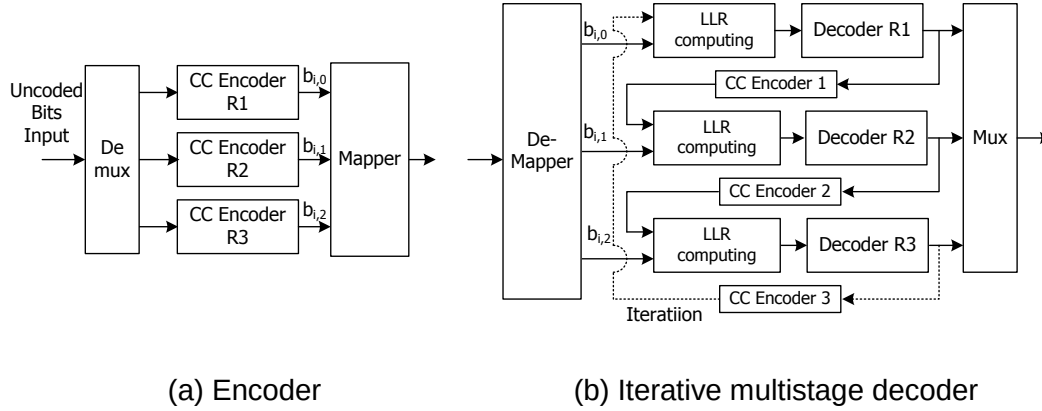


Figure 2. MLC Encoder and Decoder Block Diagram (e.g. 64QAM SM)

The optimal decoder of MLC in the receiver is the ML (Maximum-Likelihood) decoder. But a multistage decoding algorithm is widely used for decoding MLC due to high computational complexity of the ML decoder [2]. Furthermore, the multistage decoder can be operated in an iterative manner to improve the performances as shown in Figure 2(b). In this paper, the multistage decoder is based on the hard-decision Viterbi algorithm whose input is the soft-input, known as LLR (Log-Likelihood Ratio). Assuming equal probability for all complex symbols in an AWGN channel, the LLR can be expressed as

$$L(b) = \ln \left(\frac{\sum_{s \in S_0} e^{-\frac{1}{\sigma_n^2} \|r-s\|^2}}{\sum_{s \in S_1} e^{-\frac{1}{\sigma_n^2} \|r-s\|^2}} \right) \quad (1)$$

where r , s , b , and σ_n^2 represent received signal, ideal symbol point, transmitted bit, and the noise variance of the baseband signal, respectively. Also, S_0 and S_1 denote the set of ideal symbols with bit 0 and the set of ideal symbols with bit 1 at the given bit position b , respectively. In order to reduce the decoding complexity, the approximated LLR computed by taking only the nearest constellation point is proposed in [3]. When the approximated LLR is applied to the soft-input of the multistage decoder, since the decoding result of the previous stage is used as prior information to build a set of ideal symbols in the current stage, the LLR can be written as

$$L_M(b) = -\frac{1}{\sigma_n^2} \left(\min_{s \in S_{0|i}} \|r-s\|^2 - \min_{s \in S_{1|i}} \|r-s\|^2 \right) \quad (2)$$

where $S_{0|i}$ and $S_{1|i}$ denote the set of ideal symbols with bit 0 and the set of ideal symbols with bit 1 at the given bit position b when the decision bit was i at the previous stage. In the next stage, the cardinality of the set $S_{0|i}$ and $S_{1|i}$ becomes in half.

3.2. 64QAM and TC Mode

In this paper, PCCC (Parallel Concatenated Convolutional Code), which consists of two identical constituent RSC (Recursive Systematic Convolutional Code) encoders of code rate 1/2 and a random block-interleaver, is considered as the TC [4-8]. Figure 3 illustrates the block diagram of a TC encoder and decoder. To produce the mother TC with code rate 1/3 as shown in Figure 3(a), the transfer function of RSC with constraint length 4 is given by $G(D)=[1, g_2(D)/g_1(D)]$ where the forward generator polynomial and the backward generator polynomial are defined as $g_1(D) = 1+D+D^3$ and $g_2(D) = 1+D^2+D^3$, respectively [9]. As seen from Figure 3(a), a puncturing circuit generates various code rates from the mother code of code rate 1/3. In the enhanced DRM system, puncturing patterns for code rate 1/2, 2/3, and 3/4 are set to 65₈, 52₈, and 525244₈ in octal, respectively.

Figure 3(b) illustrates the structure of PCCC iterative decoder, *i.e.* Turbo decoder [5-7]. The two constituent decoders for RSC use the same trellis structure and decoding algorithm in the figure. In this paper, to reduce the complexity of a TC decoder, Max-Log-MAP algorithm is applied [1, 7]. For the TC decoder, the approximated LLR is calculated as follows

$$L_T(b) = -\frac{1}{\sigma_n^2} \left(\min_{s \in S_0} \|r - s\|^2 - \min_{s \in S_1} \|r - s\|^2 \right) \quad (3)$$

In the above equation (3), an identical set of complex symbols is applied to all possible bit positions differently from equation (2). In order to improve BER performances, convolutional encoders in MLC can be replaced by TC encoders but its decoding complexity increases exponentially in proportion as the number of bits per a complex symbol.

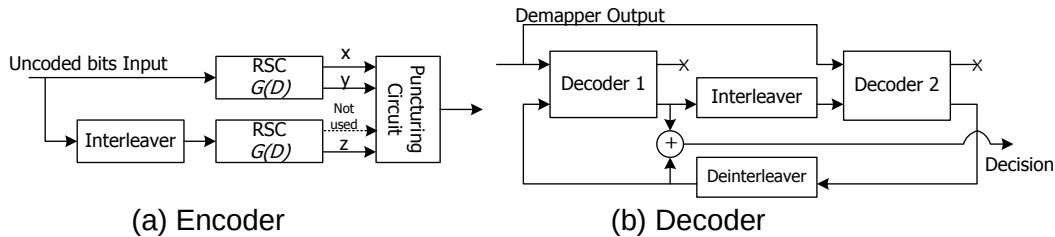


Figure 3. Turbo Encoder and Decoder Block Diagram

3.3. Transmission Rates

Table 1 presents the transmission rates of the MSC according to modulation and coding schemes of the legacy DRM in the robustness mode E and the enhanced DRM proposed in this paper. As shown in Table 1, MLC mode with 64QAM can support up to a maximum data rate of 351 kbps while TC mode can support up to a maximum data rate of 335 kbps. The enhanced DRM modes provide almost two times the data rate of legacy DRM. In this case, a DRM channel of 100 kHz bandwidth below 170 MHz has sufficient capacity to carry high quality audio of 192 kbps AAC (Advanced Audio Coding) or one mobile TV channel. Especially, since the DRM system requires low transmitter powers to cover the same service area, it is more cost-effective to distribute mobile TV over DRM than via either DAB (Digital Audio Broadcasting) or DVB-H (Digital Video Broadcasting - Handheld) at UHF band.

Table 1. Transmission Rates According to Modulation and Coding Schemes

EEP Overall Code Rate, R	Legacy DRM(Mode E)		Enhanced DRM	
	4QAM	16QAM	64QAM+MLC	64QAM+TTC
	Data Rate (kbps)	Data Rate (kbps)	Data Rate (kbps)	Data Rate (kbps)
1/2	74.5	149.1	223.6	223.6
5/8	-	186.4	-	-
27/45	-	-	268.2	-
2/3	-	-	-	298.4
17/24	-	-	316.7	-
3/4	-	-	-	335.68
106/135	-	-	351.0	-

4. Simulation Results

In this section, we evaluate the BER performance of the proposed two schemes in different channel environments. Simulation parameters are presented in Table 2. In the simulation, a carrier frequency of 100 MHz with a system bandwidth of 100 kHz and a sampling frequency of 128 kHz are assumed. Urban model and Rural model are considered as time-variant multipath fading channels and their RMS (Root Mean Square) delay spreads are 0.86 μ s and 0.42 μ s, respectively [10]. In addition, flat-fading model is used to analysis the effect of a high-speed mobile of 300 Km/h. Perfect channel estimation and frequency/time-synchronization are assumed in the simulations.

Figure 4 shows the BER performances of the robustness mode E of a legacy DRM system under an AWGN channel and time-varying channels. From the Figure 4(a), we see that the DRM system requires 1.3 dB SNR for 4QAM and MLC 1/3, and 8.0 dB SNR for 16QAM and MLC 1/2, respectively, to archive a BER= 10^{-4} in an AWGN channel, described in Annex of [1]. Maximum required SNR of the DRM system is approximately 10dB to archive the data rate of 186 kbps (i.e. 16QAM and MLC 15) and BER= 10^{-4} .

Table 2. Simulation Parameters

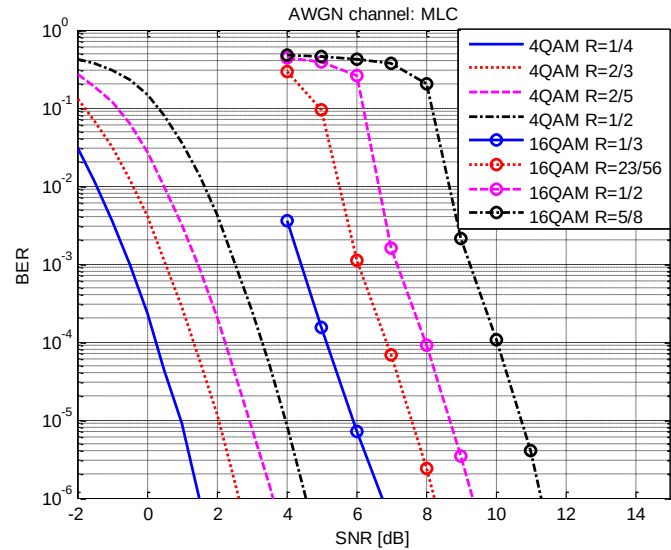
Parameters	Values
Carrier Frequency, F_c	100 MHz
Occupied Bandwidth	100 kHz
Sampling Frequency, F_s	128 kHz
Robustness Mode	Mode E
MSC Cell Interleaving Depth	600 ms
Code Rate	MLC: 1/2, 27/45, 17/24, 106/135 TC: 1/2, 2/3, 3/4
Multipath Channel Models	Urban (60 Km/h), Rural (150 Km/h), Flat-fading (300 Km/h)

Figure 4(a) shows the BER performances of the robustness mode E of a legacy DRM system under time-variant channels when MLC code rate is equal to 1/2. Due to the sufficient guard interval for protection against the delay spread of the multipath channel, no ISI (Intersymbol Interference), which is caused by the large delay spread on the OFDM-based DRM system, is occurred in the simulation environment. If there are no ICI caused by a time-varying channel, the DRM system archives good BER performances when the wireless channel is a frequency-selective and fast-fading channel in the frequency-domain. However, since Urban model is near to non-frequency-selective channel and slow-fading channel, the DRM system has no gain acquired from the combination of FEC and MSC cell-interleaver over this channel environment. For this reason, BER performances in the flat-fading channel with the speed of 300 Km/h are better than that in Urban channel with 60 Km/h. For both 4QAM and 16QAM, the flat-fading channel has approximately 3 dB SNR as against Urban channel.

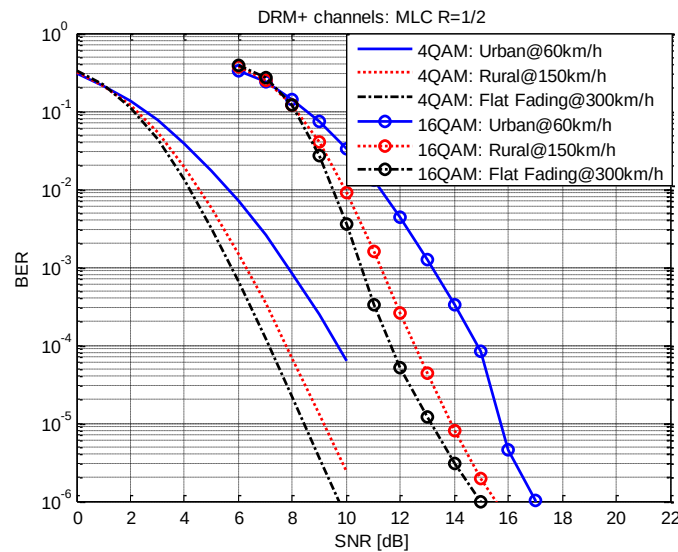
Figure 5(a) shows the BER performances of the proposed schemes in an AWGN channel. From Figure 5(a), it can be seen that the TC mode of code rate 1/2 yields a BER performance of the MSC approximately 3.7 dB better than the MLC mode of code rate 1/2 to achieve a $BER=10^{-6}$. Compared with MLC 17/24 and 106/135, TC 3/4 has approximately 0.8 dB and 2.3 dB gain, respectively. In order to increase the data rate from 149 kbps to 223 kbps, MLC 1/2 and TC 1/2 with 64QAM additionally require 5 dB and 1.3 dB SNR to achieve a $BER=10^{-4}$, respectively, comparing to MLC 1/2 with 16QAM of the legacy DRM system shown in Figure 4(a).

Figure 5(b) illustrates the BER performances of the proposed schemes in multipath fading channels when the coding rate of both MLC and TC is fixed to 1/2, one can see that TC has approximately 1.6 dB, 2 dB, 5 dB SNR gain compared to MLC, respectively. It should be noted that the BER performance in the flat-fading channel with 300 Km/h is the best due to the time diversity obtained by the cell interleaving of 600 ms depth but the performance of

MLC in this channel shows the irreducible error floor at high SNR. As shown from Figure 5(b), the delay spread of a multipath fading channel has a big impact on the BER performances, rather than ICI caused by the fast time-varying channel. In the DRM system transmitted with TC mode, the effects of ICI are compensated by a significant performance improvement provided by TC and cell interleaving. From simulation results, one can see that TC provides a good link budget although the high-order modulation, 64QAM is employed in the system.

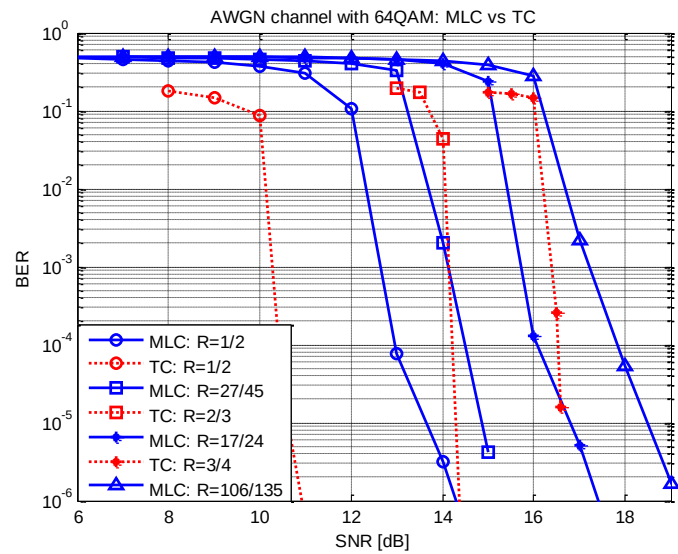


(a) AWGN channel

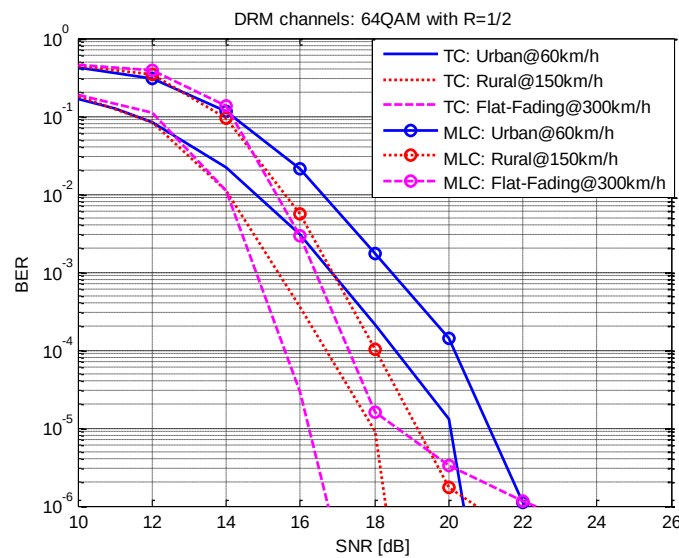


(b) Time-variant multipath channels

Figure 4. BER Performances of the Legacy DRM System (Mode E)



(a) AWGN channel



(b) Time-variant multipath channels

Figure 5. BER Performances of the Proposed Enhancement Schemes

5. Conclusion

In this paper, transmission rate enhancement schemes for the DRM system have been presented and compared. We have proposed new transmission modes consisting of two different types of FEC codes, both MLC and TC (Turbo Code), in combination with 64QAM. In order to increase the data rate of the DRM system from 149 kbps to 223 kbps in an AWGN channel, MLC 1/2 and TC 1/2 with 64QAM additionally require 5 dB and 1.3 dB SNR to achieve a $BER=10^{-4}$, respectively, comparing to MLC 1/2 with 16QAM of the legacy

DRM system. Also, the TC mode of code rate 1/2 yields a BER performance approximately 3.7 dB better than the MLC mode of code rate 1/2 for a BER= 10^{-6} . Furthermore, TC has approximately 1.6 dB, 2 dB, 5 dB SNR gain in multipath fading channels compared to MLC, respectively. The proposed schemes can provide transmission rates higher than 300kbps. Especially, TC provides a good link budget although 64QAM is employed in the system.

Acknowledgements

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