ITERATIVE RADIAL BASIS FUNCTION ASSISTED TURBO EQUALISATION OF VARIOUS CODED MODULATION SCHEMES

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ABSTRACT

A Radial Basis Function (RBF) assisted turbo equaliser (TEQ) scheme is investigated, which is based on various coded modulation schemes. Specifically, Trellis Coded Moudulation (TCM), Turbo Trellis Coded Modulation (TTCM), Bit-Interleaved Coded Modulation (BICM) and BICM with iterative decoding (BICM-ID) are studied, when communicating over frequency selective fading channels. At a given complexity, the TTCM RBF-TEQ provides the best Bit Error Ratio (BER) and Frame Error Ratio (FER) performance. The RBF-TEQ structure is shown to provide an SNR performance improvement of about 4dB at a BER of 10^{-4} compared to the conventional non-iterative DFE scheme.

1. INTRODUCTION

One of the most important criteria in the design of digital cellular systems is the efficient exploitation of the available spectrum, in order to accommodate the ever-increasing traffic demands. Since the characteristics of the radio channel are strongly dependent on the frequency band used, the propagation environment and on the velocity of the terminal, the information typically has to be protected by channel coding, in order to keep the number of transmission errors at a level acceptable for the desired quality of service. Coded modulation schemes, which are based on combining the functions of channel coding and modulation, constitute bandwidth efficient arrangements that have been widely recognized as attractive error control techniques suitable for numerous applications [1, 2, 3, 4, 5, 6].

Systems transmitting at high bit rates, such as 150Mb/s for example in Mobile Broadband Systems (MBS), experience a high grade of channel-induced dispersion and suffer from Inter Symbol Interference (ISI) [7]. Hence channel equalisation techniques are necessary for mitigating these effects in the context of single carrier modulation. The application of non-linear Radial Basis Function (RBF) based equalisation was studied in conjunction with channel codecs [8, 9], when using a space-time codec [10] as well as a turbo-equaliser (TEQ) [11]. The BER performance of RBF-based turbo equalisation presented in [11] in the context of Quadrature Amplitude Modulation (QAM) was similar to that of the conventional trellis-based turbo equaliser [12]. The RBF-assisted schemes are however capable of maintaining a lower complexity than their conventional trellis-based counterparts, when communicating over dispersive Gaussian and Rayleigh faded channels.

Motivated by these trends, in this contribution, we aim for investigating the performance of RBF-based turbo equalisation (RBF-TEQ) of various spectrally efficient coded modulation schemes, namely Trellis Coded Modulation (TCM), Turbo Trellis Coded Modulation (TTCM), Bit-Interleaved Coded Modulation (BICM) and BICM with iterative decoding (BICM-ID) [13].

2. SYSTEM OVERVIEW

The schematic of the transceiver invoking different coded modulation schemes, namely TCM, TTCM, BICM, BICM-ID, is shown in Figure 1. The information bits u_n are encoded by the TCM/TTCM/-BICM encoder. The coded bits c_n are interleaved,

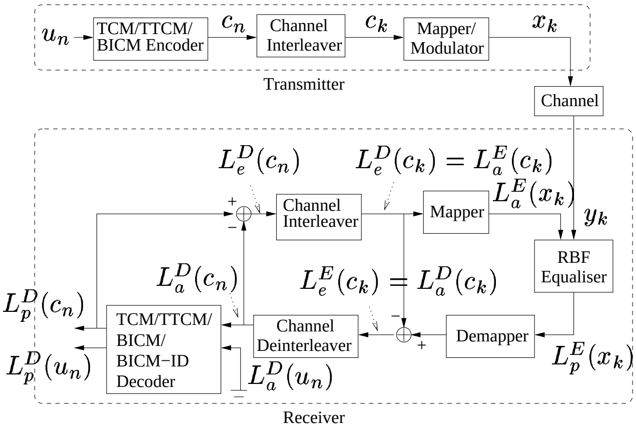

Figure 1: System overview of transceiver with different coded modulation schemes using RBF based turbo equaliser, which performs the equlisation, demodulation and channel decoding iteratively.

mapped to the phasors according to Gray- or Set-Partitioning (SP)-based labelling and modulated before transmission. The proposed receiver employs two Soft-In/Soft-Out (SISO) blocks, namely the RBF equaliser and the coded modulation decoder, as shown in Figure 1. In our simulations, the decision feedback assisted Jacobian RBF equaliser (RBF DFE) of [8] was employed, which reduced the complexity of the equaliser by utilising the Jacobian logarithmic function and decision feedback for RBF-center selection. The decoders were implemented using Log-MAP algorithm for the sake of maintaining a low complexity. In the schematic of the turbo equaliser depicted in Figure 1 we used the notation L for denoting the log likelihood values output by the SISO decoders/equalisers. The superscripts D and E were used for representing the values output by the SISO decoder and equaliser, respectively, while the subscripts a, p and e represent the a priori, a posteriori and extrinsic likelihood values, respectively. Referring to Figure 1, the SISO equaliser processes the channel outputs y_k as well as the a priori information $L_a^E(x_k)$ of the coded symbols. The SISO equaliser also generates the a posteriori values $L_a^E(x_k)$ of the coded symbols, which are then demapped according to Gray- or SP-based labelling to the phasors of the constellation for generating the a posteriori log likelihood values $L_p^E(c_k)$ of the coded bits. The extrinsic log likelihood values of the coded bits are then extracted and deinterleaved before passing them to the SISO decoder. The extrinsic information $L_e^D(c_k)$ of the coded bits obtained from the decoder is then fed back to the equaliser, where it is used as the a priori information $L_a^E(x_k)$ in the next equalisation iteration. The following section will present our simulation results.

3. RESULTS AND DISCUSSION

Scheme	Rate	State	$\tilde{m}$	H^0	H^1	H^2
TCM	2/3	64*	2	103	30	66
TTCM	2/3	8	2	11	02	04

Table 1: Parameters of the 8PSK TCM and TTCM codecs used. '*' indicates Ungerböck's TCM codes [1]. "Punctured" TCM codes are used as the TTCM component codes. An octal format is used for representing the generator polynomials H^i and $\tilde{m}$ denotes the number of coded information bits per modulated symbol.

Scheme	Rate	State	g^1	g^2	g^3
BICM	2/3	64	15	6	15
BICM-ID	2/3	8	4	2	6

Table 2: Parameters of the 8PSK BICM and BICM-ID codecs used. Octal format is used for representing the generator polynomials g^i of Paaske's code, page 331 of [14].

The 8PSK coded modulation schemes studied are Ungerböck's TCM [1], Robertson's TTCM [15], Zehavi's BICM [3] and Li's BICM-ID [5] which were discussed in detail in [13]. The parameters of the various encoders used in our simulations are shown in Table 1 for the TCM and TTCM schemes, and in Table 2 for the BICM and BICM-ID schemes. The TTCM scheme invokes two component TCM codes, as described in Table 1. The number of decoder iterations is 4 and 8 for the TTCM and BICM-ID schemes, respectively. The specific parameters of the TCM, TTCM, BICM and BICM-ID schemes in Tables 1 and 2 were fixed such that all schemes exhibited a similar complexity, where the complexity was deemed propotional to the code's memory and to the number of decoding iterations. A Time Division Multiple Access (TDMA)/Time Division Duplex (TDD) system was considered, providing 16 slots per 4.615 ms

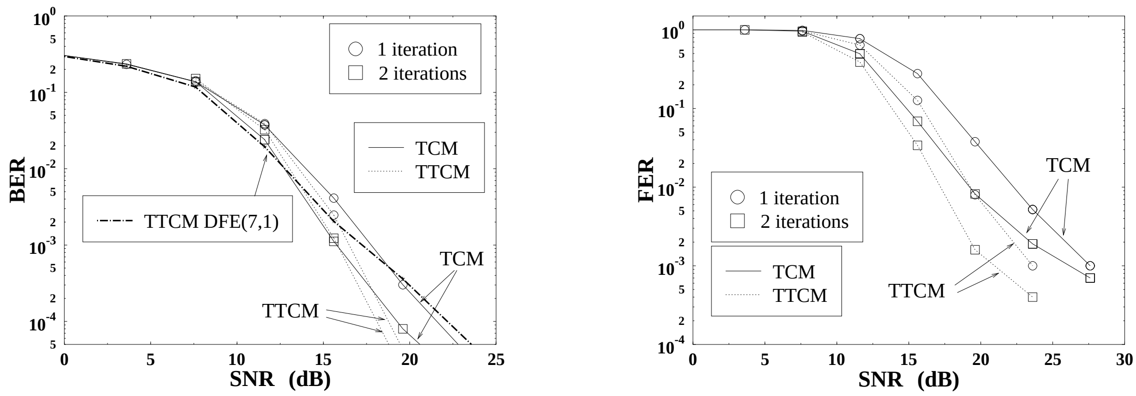

Figure 2: BER (left) and FER (right) performance of the 8PSK RBF-DFE-TEQ TCM and TTCM schemes for transmission over the symbol-spaced dispersive two-path Rayleigh fading channel. The channel interleaver and deinterleaver operate on a four-burst basis. The BER performance of the 8PSK TTCM scheme employing conventional DFE having with a feedforward order of seven and feedback order of one instead of the RBF-DFE-TEQ is also shown for comparison.

TDMA frame, while the transmission burst duration was 288 μs, as specified in the Pan-European FRAMES proposal [16].

Figures 2 and 3 show the Bit Error Ratio (BER) and Frame Error Ratio (FER) performance of various coded modulation schemes, where the RBF DFE used the feedforward order of $m = 2$, feedback order of $n = 1$ and decision delay of $\tau = 1$ for transmission over two-path, symbol-spaced Rayleigh fading channels having a normalised Doppler frequency of 3.25×10^{-5}. In our simulations we assumed that the channel was sufficiently slowly fading for employing a frame-invariant channel impulse response (CIR). Perfect CIR estimation was considered. For our initial study, the channel interleaver length was set to four transmission bursts, where the system had a total latency of less than 20ms. As seen in Figures 2 and 3, the TCM, TTCM, BICM and BICM-ID RBF-DFE-TEQ schemes were capable of achieving a BER of 10^{-4} after the second iteration for a channel SNR of 19dB, 18dB, 19.5dB and 19dB, respectively. The TEQ BER iteration gain for the TCM, TTCM, BICM and BICM-ID schemes are 2.5dB, 1dB, 1.5dB and 1dB, respectively. We observed that at a given complexity, the iterative schemes employing iterative decoding and TEQ provide a better performance compared to a non-iterative scheme, especially for higher SNRs, even though the component codes of the iterative TTCM and BICM-ID schemes are less powerful. The additional gain achieved by outer iterative loop of the TEQ was lower for the iterative decoding schemes, i.e. for TTCM and BICM-ID, than for their non-iterative counterparts, since a substantial iteration gain was already attained by the iterative coded modulation decoder. As for the non-iteratively decoded TCM and BICM schemes, TCM performs better than BICM in the slow Rayleigh fading channel. However, if a longer channel interleaver is employed, the channel fading will be less correlated and BICM will perform better than TCM [3].

The BER performance of the 8PSK TTCM scheme using a low complexity conventional minimum mean square DFE having a feedforward order of 7 and feedback order of 1 was also portrayed in Figure 4 for the sake of performance comparison. At the cost of a higher computational complexity, the RBF-DFE-TEQ TTCM scheme is capable of providing a SNR improvement of 4dB at BER of 10^{-4} compared to the TTCM scheme using a conventional DFE.

Figures 2 and 3 demonstrate that a FER of 10^{-2} is achieved at the channel SNR of 19dB, 17dB, 18.5 and 18dB for the TCM, TTCM, BICM and BICM-ID schemes, respectively. Furthermore, TEQ assisted iteration gains of 3dB, 2dB, 2dB and 2dB were attained after the second iteration, when considering the FER curves of Figures 2 and 3. The TEQ provides a higher iteration gain in terms of the FER performance. Overall, the TTCM scheme provided the best overall performance.

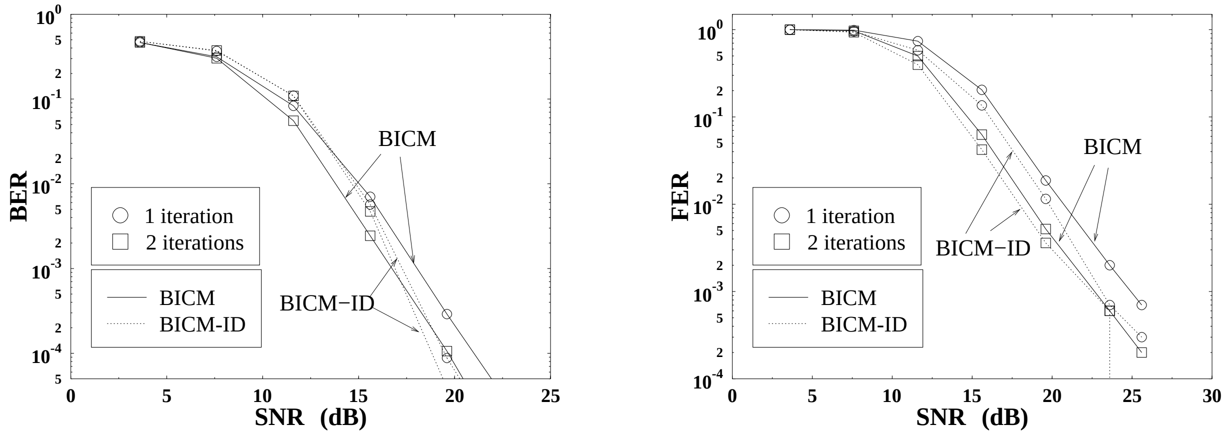

Figure 3: BER (left) and FER (right) performance of the 8PSK RBF-DFE-TEQ BICM and BICM-ID schemes for transmission over the symbol-spaced dispersive two-path Rayleigh fading channel. The channel interleaver and deinterleaver operate on a four-burst basis.

The TEQ structure is capable of exploiting the multipath and temporal diversity and hence its performance improves with the aid of time-diversity provided by the system's channel interleaver as well as with advent of the channel's multipath diversity. This is demonstrated in Figure 4 for the TCM scheme. The notation RBF(m,n,τ) in Figure 4 refers to the RBF equaliser's feedforward order m, feedback order n and decision delay τ employed in our simulations. The performance of the TCM scheme recorded for transmission over non-dispersive Gaussian and Rayleigh faded channels is also shown for reference in Figure 4 as the best possible TCM Gaussian and TCM Rayleigh bounds. For determining the Rayleigh bound, the system utilized a channel interleaver length of four burst depth. The BER performance of the RBF-DFE-TEQ was found to be better in Figure 4 than the Rayleigh bound for the SNR range above 12 dBs. The error propagation induced SNR degradation is less than 2.5dB, as shown in Figure 4, when we compare the performance curves associated with the perfect or correct symbols as well as with potentially erroneous symbols fed back to the RBF equaliser. The associated performance degradation decreases, as the channel SNR improves. Comparing the performance gains due to multipath diversity, the achievable performance of the system communicating over 2-path and 3-path equal-weighted symbol-spaced, Rayleigh faded channels is approximately 8dB and 5dB away from the Rayleigh bound at a BER of 10^{-4} for the first TEQ iteration. At the final TEQ iteration, the performance recorded for the 2-path and 3-path Rayleigh faded channel is improved by approximately 2dB and 5dB, respectively. Hence, the TEQ's iterative gains improve upon increasing the multipath diversity. Figure 4 also demonstrates an approximately 10dB better SNR performance at the BER of 10^{-4}, when the channel interleaver depth is increased from one to four transmission bursts. The TEQ's iteration gain improves from 0.5dB for a single-burst interleaver to about 2dB for a four-burst interleaver. The performance of the proposed RBF TEQ assisted coded modulation scheme can be further improved by capitalising on additional spatial diversity, as it was demonstrated by Tonello in [17] for the 4PSK BICM scheme using the trellis-based TEQ.

4. CONCLUSIONS

We have studied a RBF-DFE-TEQ system in conjunction with various coded modulation schemes. At a given complexity, the iterative TTCM scheme using TEQ provides the best performance, as seen in Figure 2, especially for higher SNRs. TTCM is followed by BICM-ID, TCM and BICM in terms of both the BER and FER preference order. Two TEQ iterations were found to be sufficient for attaining the best possible BER and FER performance. We observed in Figure 2 that the RBF-

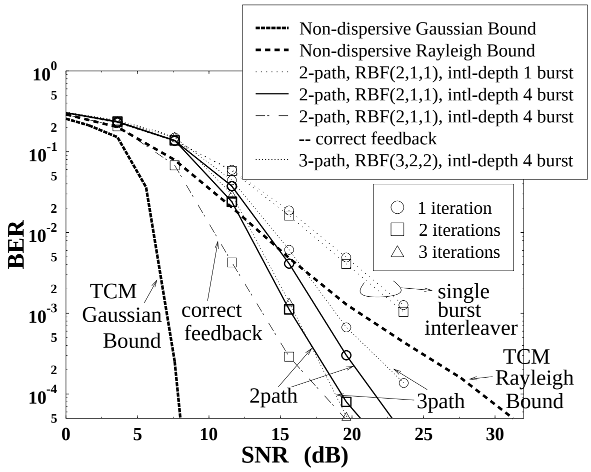

Figure 4: BER performance of the 8PSK TCM scheme for various system parameters.

DFE-TEQ is capable of providing an SNR performance improvement of 4dB at a BER of 10^{-4}, when compared to the low-complexity conventional DFE benchmarker in conjunction with the TCM scheme, although this is achieved at the cost of a higher computational complexity. We also demonstrated that the performance of the RBF-DFE-TEQ assisted coded modulation scheme significantly improves with the advent of channel-coding assisted time diversity and channel induced multipath diversity. The SNR performance improved by more than 10dB, when the channel interleaver length was increased from one to four transmission bursts. The RBF-TEQ-DFE assisted coded modulation scheme using a four-burst channel interleaver provided an SNR performance improvement of about 10dB in comparison to the non-dispersive Rayleigh channel's performance bound. For attaining a performance closer to the non-dispersive Gaussian bound, a higher interleaver length is necessary, which inevitably increases the transmission latency. Alternatively, space diversity has to be provided, which is only possible at a higher complexity.

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