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UPPER BOUND PERFORMANCE OF RADIAL BASIS FUNCTION DECISION FEEDBACK EQUALISED BURST-BY-BURST ADAPTIVE MODULATION

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ABSTRACT

The upper-bound performance of radial basis function decision feedback equalised (RBF DFE) burst-by-burst adaptive modulation is presented for tranmissions over dispersive wideband mobile channels. The RBF DFE is capable of estimating the 'short term bit error rate' of the received data burst and this estimate is used as the modem mode switching criterion in order to switch between different modulation schemes. The performance of this scheme and that of the individual fixed modulation schemes is compared, demonstrating a significant mean bit error rate (BER) and bits per second (BPS) performance improvement.

1 BACKGROUND

A novel adaptive modem scheme is presented for transmissions over wideband mobile channels, which employs a Radial Basis Function (RBF) based channel equaliser with decision feedback, in order to mitigate the effects of the dispersive wideband channel. The principles of adaptive quadrature amplitude modulation (AQAM) scheme were presented for example by Torrance [1] et al and Wong [2] et al. Chen, McLaughlin, Mulgrew and Grant [3] proposed a range of so-called RBF network based channel equalisers, which are capable of error-freely detecting the received signalling symbols even in a scenario, where the phasors become linearly non-separable due to the inter-symbol interference inflicted by the channel. In this situation conventional equalisers would be unable to remove the effects of ISI and hence would exhibit a residual BER. Additionally, Chen *et. al.* [4] introduced decision feedback in their RBF-based equaliser, in order to reduce its computational complexity. The RBF decision feedback equaliser (RBF DFE) was then extended to higher-order QAM schemes, which were investigated in [5]. The reader is referred to the above references for background reading.

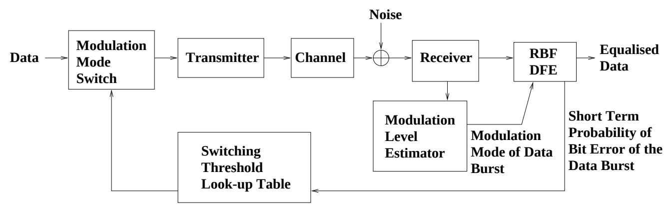


Figure 1. System schematic of the joint adaptive modulation and RBF equaliser scheme

2 SYSTEM DESCRIPTION

The schematic of the joint AQAM and RBF network based equalisation scheme is depicted in Figure 1. The short-term probability of bit error or BER of the transmitted burst is calculated from the output of the RBF network and is used as the modem mode switching criterion. The estimated short-term BER within the received transmission burst is compared to a set of switching BER values and the modulation mode is selected for the next burst's transmission on the basis of assumming reciprocity of the uplink and downlink. The modulation modes utilized in our system are BPSK, 4QAM, 16QAM, 64QAM and no transmission (NO TX). In this contribution we will investigate this scheme with the aim of producing an upper bound performance estimate. The short-term BER and the assumptions stipulated for evaluating the upper bound performance will be described in more detail in the forthcoming Sections.

2.1 Switching Criterion

The RBF equaliser invoking the optimal Bayesian decision function is capable of providing the 'on-line' estimation of the BER in the receiver without the knowledge of the transmitted symbols. This is possible, since the equaliser is capable of estimating the a-posteriori probabilities of each legitimate $\mathcal{M}$QAM symbol, $\varsigma_i(k), i = 1, \ldots, \mathcal{M}$, if we assume perfect channel estimation and that the so-called centers of the RBF network are assigned the values of the channel states [5]. Given the probability of bit error $P_b^i(k)$ for the ith bit of an AQAM symbol, the average probability of bit error for a detected AQAM symbol at signalling instant k is given as $P_b(k) = \frac{\sum_{i=0}^{\text{BPS-1}} P_b^i(k)}{\text{BPS}}$, where BPS is the number of bits per AQAM symbol and the overall probability of bit error of the detector is given by $P_{\text{bit}} = E\{P_b(k)\}$.

For our joint AQAM and RBF DFE scheme, we are unable to employ the true probability of bit error P_{bit} as the modem mode switching criterion, since a prompt modem mode selection is required. Hence we invoked the estimated short term probability of bit error or BER, $P_{\text{bit, short-term}}$, which was estimated by averaging P_{bit} over a single transmission burst according to:

$$P_{\text{bit, short-term}} = \frac{\sum_{n=1}^{\mathcal{F}} P_b(n)}{\mathcal{F}}, \tag{1}$$

where $\mathcal{F}$ is the number of AQAM symbols per frame. Thus, we could estimate the channel quality on a frame-by-frame basis, based on the estimated $P_{\text{bit, short-term}}$ value.

2.2 Upperbound Performance Assumptions

In deriving the upper bound performance of this joint adaptive modulation and RBF based equalisation scheme, the following assumptions were stipulated:

1. Perfect channel impulse response estimation or channel state estimation was used at the receiver. The RBF's centers were assigned the values of the channel states.

2. The channel impulse response is time-invariant for the duration of the transmission burst, but varies from burst to burst, which corresponds to assumming that the channel is slowly varying.

3. We assumed furthermore that the receiver had perfect knowledge of the modulation mode used in its received transmission burst.

4. The RBF DFE used in the system neglected error propagation due to erroneous decision feddback, which in practical terms implied a negligibly low probability of symbol errors, hence feeding the correct symbol to the RBF subset center selection [5] process.

5. The short-term BER estimate $P_{\text{bit, short-term}}$ was available prior to transmission with respect to all the modulation modes used in the system. We also assumed that given the estimated $P_{\text{bit, short-term}}$ for a particular modulation mode, the transmitter was capable of estimating the corresponding short-term BER for the other modulation modes used in the system under the same channel conditions.

Having described the assumptions stipulated, in order to derive the upper bound performance of this joint adaptive modulation and RBF based equalisation scheme, we now describe our simulation model, followed by the associated simulation results.

3 SIMULATION RESULTS

In our experiments, pseudo-random symbols were transmitted in a fixed-length burst for all modulation modes across the frame-invariant wideband channel to fulfill assumptions 2 and 5. The receiver received each data burst potentially having different modulation modes and equalised each burst independently. The estimated short-term BER for each modulation mode was obtained, as described in Section 2.1. The highest-order modulation mode, $\mathcal{M}^*$ that provided a short-term BER $P_{\text{bit, short-term}}^{\mathcal{M}^*}$, which was below the targeted BER $P_{\text{bit, target}}$, i.e., when $\mathcal{M}^* = \max\{\mathcal{M} = 2, 4, 16, 64$, such that $P_{\text{bit, short-term}}^{\mathcal{M}} \leq P_{\text{bit, target}}\}$, was chosen to be the actual modulation mode that was used by the transmitter and its corresponding equalised frame was used for the BER calculation of the system, where the notation $P_{\text{bit, short-term}}^{\mathcal{M}}$ represents the short-term BER of the $\mathcal{M}$-QAM modem mode.

The simulation parameters are listed in Table 1, noting that we analysed the joint AQAM and RBF equaliser scheme over a two-path Rayleigh fading channel. The wideband fading channel was frame-invariant. The RBF DFE used in our simulations had a feedforward order of $m = 2$, feedback order of $n = 1$ and decision delay of $\tau = 1$.

No. of data symbols per burst	144
No. of training symbols per burst	27
Transmission Frequency	1.9GHz
Transmission Rate	2.6MBd
Vehicular Speed	30 mph
Normalised Doppler Frequency	3.3×10^{-5}
Channel weights	$0.707 + 0.707z^{-1}$

Table 1. Simulation parameters

Figure 2 portrays evolution of the short-term BER of the frame-invariant channel versus symbol index, as estimated by the RBF DFE at different channel SNR values. As seen in the figure, for the simulated scenario, ie for a Doppler frequency of 3.3×10^{-5} the short-term BER is slowly varying and it is relatively predictable for a number of consecutive data burst. Thus, assumption 2 of Section 2.2 is valid for our scenario.

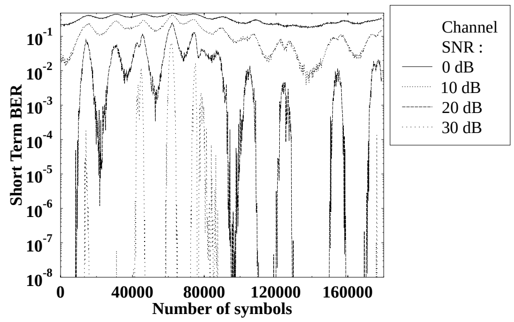


Figure 2. Short-term BER versus symbol index as estimated by the RBF DFE for 16QAM modulation scheme and varying channel SNRs over the two-path Rayleigh fading channel of Table 1. Perfect channel impulse response estimation is assumed and error propagation in decision fedback is ignored.

Let us now analyse the upper bound performance of the joint AQAM and RBF DFE scheme in more detail, using the assumptions listed in Section 2.2. We designed two systems, a higher integrity scheme, having a target BER of 10^{-4}, which can be rendered error-free by error correction coding and hence we referred to this arrangement as a data transmission scheme; the lower integrity scheme was designed for maintaining a BER of 10^{-2}, which is adequate for speech transmission. The target BPS values of these schemes were 3 and 4.5, respectively.

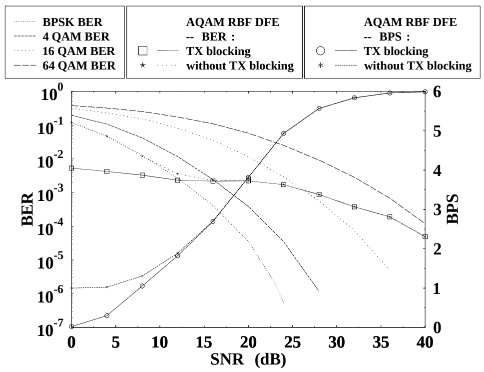
Figure 3(a) and Figure 3(b) portray the simulated upper bound performance of the joint AQAM and RBF DFE scheme for the target BER of 10^{-2} designed for speech transmission and for the target BER of 10^{-4} created for data transmission, respectively. The BER performance of the constituent fixed modulation schemes is also depicted in both figures for comparison. The upperbound performance was evaluated for two different adaptive modulation schemes. In the first scheme, the transmitter always transmitted data without transmission blocking, while in the second scheme there was no data transmission, whenever the estimated short-term BER was higher than the target BER, a scenario, which we referred to as transmission blocking.

We will commence by analysing Figure 3(a), where the joint AQAM and RBF DFE scheme was designed for speech transmission. For the adaptive scheme, which did not incorporate transmission blocking, the performance with adaptive modulation was better or equivalent to that of BPSK in terms of the mean BER and mean BPS for the SNR range between 0dB and 9dB. At the channel SNR of 9dB, even though the mean BER performance was similar for the adaptive scheme and the BPSK scheme, the mean BPS performance for the adaptive scheme improved by a factor of 1.5, resulting in a mean BPS of 1.5. In the SNR range of 9dB to 16dB, the adaptive scheme outperformed the 4QAM scheme in terms of its mean BER performance. At the channel SNR of 16dB, the mean BERs of both schemes were similar, although the mean BPS of the adaptive scheme was 2.7, resulting in a substantial improvement, when compared to 4QAM. The adaptive scheme that utilized transmission blocking achieved a mean BER below 10^{-2}. As the SNR improved, the performance of the adaptive schemes both with and without transmission blocking converged, as the probability of encountering high short-term BERs reduced. The mean BER and mean BPS performance of both adaptive schemes converged to that of 64QAM for very high SNRs, where 64QAM became the dominant modulation mode.

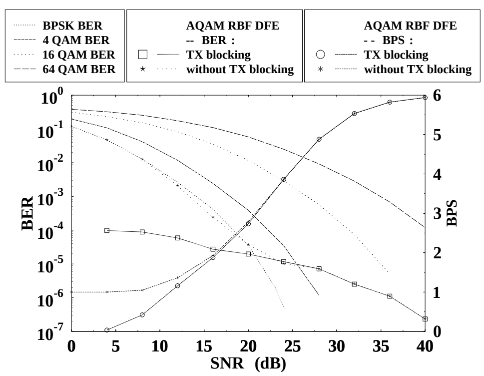
Similar trends were observed for data-quality transmission in Figure 3(b). However, we note that for the SNR range between 8dB to 20dB, the mean BER of the adaptive scheme without transmission blocking was better, than that of BPSK. This phenomenon was also observed in the narrowband adaptive modulation scheme of [1] and in the wideband joint AQAM and DFE scheme of [2], which can be explained as follows. The mean BER of the system is the ratio of the total number of bit errors to the total number of bits transmitted. The mean BER will decrease with decreasing number of bits error or upon increasing the number of total bits transmitted in the data burst. For a fixed number of symbols transmitted, the number of total bits transmitted in a data burst is constant for the BPSK scheme, while for the adaptive scheme, the total number of bits transmitted in a data burst increased when a higher-order modulation mode was used. However, when a higher-order modulation mode was used for transmission, the probability of erroneous bits increased. When the relative bits per symbol increment upon using AQAM was higher, than the relative bit error ratio increment, then the mean BER of the adaptive scheme was improved. Consequently the adaptive mean BER can be lower than that of BPSK. The probability of encountering each modulation mode employed in the adaptive scheme without transmission blocking based on the estimated short-term BER switching mechanism is shown in Figure 4 for speech-quality transmission. As expected, the sum of the probabilities at each particular SNR is equal to one. At low SNRs, the lower order modulation schemes are dominant, producing a robust system, achieving a mean BER close to the targeted BER. At higher SNRs, the higher order modulation schemes become dominant, yielding a higher mean BPS and yet a reduced mean BER.

4 SUMMARY AND CONCLUSIONS

In summary, the proposed RBF / DFE-assisted burst-by-burst adaptive modem outperformed the individual constituent fixed modulation modes in terms of mean BER



(a) Target BER is 10^{-2} (mean BER for speech transmission)



(b) Target BER is 10^{-4} (mean BER for data transmission)

Figure 3. The simulated upper bound BER and BPS, versus average SNR performance of the joint adaptive modulation and RBF DFE showing also the BER performance of the constituent fixed modulation schemes over the two-path Rayleigh-fading channel of Table 1 and using the assumptions of Section 2.2.

and mean BPS performance. Note however for the adaptive scheme without transmission blocking that the target BER performance of the speech- and data-scheme can only be achieved, if the channel SNR is higher than 9dB and 18dB, respectively. The target mean BERs for speech transmission (10^{-2}) and data transmission (10^{-4}) were achieved for all channel SNRs, when we utilized transmission blocking. The target BPS performance of the speech and data schemes (3 and 4.5, respectively) were achieved for the adaptive scheme with and without transmission blocking, when the channel SNR was above about 22dB. Thus, the advantage of using an adaptive scheme with transmission blocking is that the performance of the

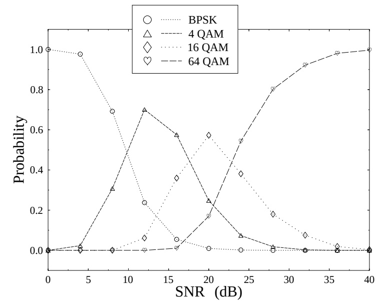


Figure 4. The probability of encountering the various $\mathcal{M}$-QAM modulation modes in the joint AQAM and RBF DFE scheme without transmission blocking during speech-quality transmission (target BER of 10^{-2}) over the two-path Rayleigh fading channel using the simulation parameters listed in Table 1 and the assumptions stated in Section 2.2.

joint AQAM and RBF DFE scheme can be 'tuned' to a certain required mean BER performance. However, the disadvantage is that the utilization of transmission blocking results in transmission latency.

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