COMPARATIVE STUDY OF JOINT-DETECTION AND INTERFERENCE CANCELLATION BASED BURST-BY-BURST ADAPTIVE CDMA SCHEMES

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Abstract - The system performances of two different Adaptive Quadrature Amplitude Modulated Code Division Multiple Access multiuser detectors are evaluated. The adaptive multiuser detectors proposed are the Minimum Mean Square Error Block Decision Feedback Equalizer (MMSE-BDFE) and the Successive Interference Cancellation (SIC) receiver. Our investigations show that for a COST 207 7-path Bad Urban Rayleigh fading channel, the MMSE-BDFE outperforms the SIC receiver in throughput performance terms for a target BER of 1%. However, this increased performance is achieved at the cost of a higher complexity.

1. ADAPTIVE QUADRATURE AMPLITUDE MODULATION

Burst-by-burst Adaptive Quadrature Amplitude Modulation (AQAM) is a technique employed in order to increase the throughput of a transmission system by exploiting the time-variant channel quality of mobile channels [1, 2, 3]. AQAM invokes the most appropriate modulation mode from a set of possible modes, based on the instantaneous channel quality estimated, for example, during the previous received burst. This is in contrast to traditional transmission schemes, where only one modulation scheme is used throughout the duration of communications. In AQAM, a low-order modulation mode that transmits a low number of bits per QAM symbol, but exhibits a better Bit Error Rate (BER) performance is chosen, when the channel quality is low. Conversely, when the channel quality is high, a high-order modulation mode is employed in order to transmit as many bits per symbol as possible, thus increasing the average throughput of the system. AQAM in Wideband Time Division Duplex (TDD)/Time Division Multiple Access (TDMA) systems has been proposed in [1] and [2]. Adaptive Code Division Multiple Access (CDMA) systems utilizing AQAM have also been proposed in the literature [3].

2. MULTIUSER DETECTION

Multiuser detectors [4] constitute a class of CDMA receivers that attempt to overcome the multiple access interference (MAI) limitations of conventional single-user oriented matched filters and RAKE receivers. These multiuser detectors utilize the knowledge about the spreading sequences and channel impulse responses (CIR) of all the CDMA users, in order to remove the MAI inflicted on the users. Two of the most common multiuser detectors are joint detection (JD) [5] and interference cancellation (IC) receivers [6].

2.1. Joint detection

Joint detection techniques [5] have been derived from traditional equalization techniques [1] used for removing inter-symbol interference (ISI) from single-user signals, as known for example in the context of zero-forcing (ZF) and minimum mean square error (MMSE) based equalization techniques. In CDMA a cross-correlation (CCL) matrix is constructed from the spreading sequences and CIRs of all the users. For ZF detection algorithms, the inverse of the CCL matrix is obtained and multiplied with the output of the matched filter bank. The matched filter bank consists of a bank of filters matched to the combined CIR of each user which is constituted by the convolution of the spreading sequence of the given user with the CIR of the user concerned. In the context of MMSE schemes, the CCL matrix is biased with the inverse of the covariance matrix of the information symbols being detected. The inverse of this biased CCL matrix is then calculated and the rest of the algorithm is similar to that of ZF schemes.

We have investigated four basic algorithms [5], namely ZF Block Linear Equalization (**ZF-BLE**), MMSE Block Linear Equalization (**MMSE-BLE**), ZF Block Decision Feedback Equalization (**ZF-BDFE**) and MMSE Block Decision Feedback Equalization (**MMSE-BDFE**). The associated decision-feedback assisted equalizer schemes differ from the so-called linear equalizer arrangement in the sense that the feedback assisted schemes incorporate feedback loops which allow symbols that have already been detected to be fed back into the system. These fedback symbols assist in removing the MAI present in the forthcoming symbols that are yet to be detected. In our investigations, we have concluded that the **MMSE-BDFE** provides the best performance, while the detection complexity is similar for all the above-mentioned four schemes. Therefore, in our further investigations, we have used the **MMSE-BDFE**.

2.2. Interference cancellation

In contrast to joint-detection receivers, interference cancellation receivers attempt to remove the MAI by reconstructing the original transmitted signals of one or more users and cancelling the interference imposed by these reconstructed signals on the composite received signal [6]. The resultant signal is then processed using the same procedure, in order to obtain the data estimates for the remaining users, and cancel their interference effect in the received multiuser signal, until all the user signals are detected. Generally, the composite received multiuser signal is processed through a first stage that consists of either a bank of matched filters or RAKE receivers. After this stage, initial estimates of the information symbols are obtained and used for reconstruction and cancellation in the subsequent stages. Interference cancellation techniques are often divided into two categories, namely successive interference cancellation (**SIC**) and parallel interference cancellation (**PIC**) [7].

In **SIC** [6] receivers the users are ranked according to received signal quality. Then, the signal of the highest signal-quality user is reconstructed first using the initial data estimates, CIR and spreading sequence of that user. This reconstructed signal is subtracted from the composite received signal. The remaining signal is then processed through the matched filter bank or RAKE receiver of the next strongest signal, in order to obtain the data estimates for this user. Employing these data estimates, as well as the CIR and spreading sequence of the user, the transmitted signal is reconstructed and subtracted again from the composite multiuser signal that has already had the strongest user's signal cancelled from it. This is repeated, until the data estimates of all the users have been obtained.

3. BURST-BY-BURST ADAPTIVE SYSTEM

In our investigations, the performance of the **MMSE-BDFE** is compared to that of the **SIC** receiver in our burst-by-burst adaptive CDMA system. The **MMSE-BDFE** has a significantly higher complexity, than the **SIC** receiver. However, the iterative nature of the **SIC** receiver imposes a substantial delay on the system. Two different AQAM systems were simulated, a twin-mode AQAM scheme that switched between Binary Phase Shift Keying (BPSK) and 4-QAM; and a triple-mode AQAM system that switched between BPSK, 4-QAM and 16-QAM. Each transmitter chose the modulation mode according to the estimated signal to interference plus noise ratio (SINR) at the output of each receiver. The output SINR of the **MMSE-BDFE** was estimated by using the output SINR equation derived by Klein in Reference [5]. For the **SIC** receiver, the approach used by Patel and Holtzmann [6] was modified for a wideband channel. Assuming perfect channel estimation, the output SINR estimate, γ_o, was then used to switch modulation modes for the triple-mode AQAM scheme, according to the regime of Table 1. For the twin-mode AQAM, only one threshold, t_1, was used to switch between BPSK and 4-QAM.

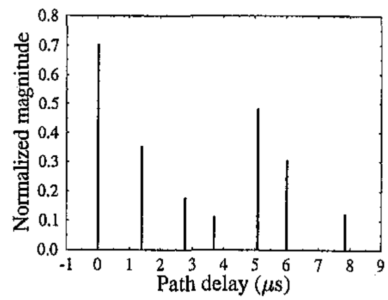
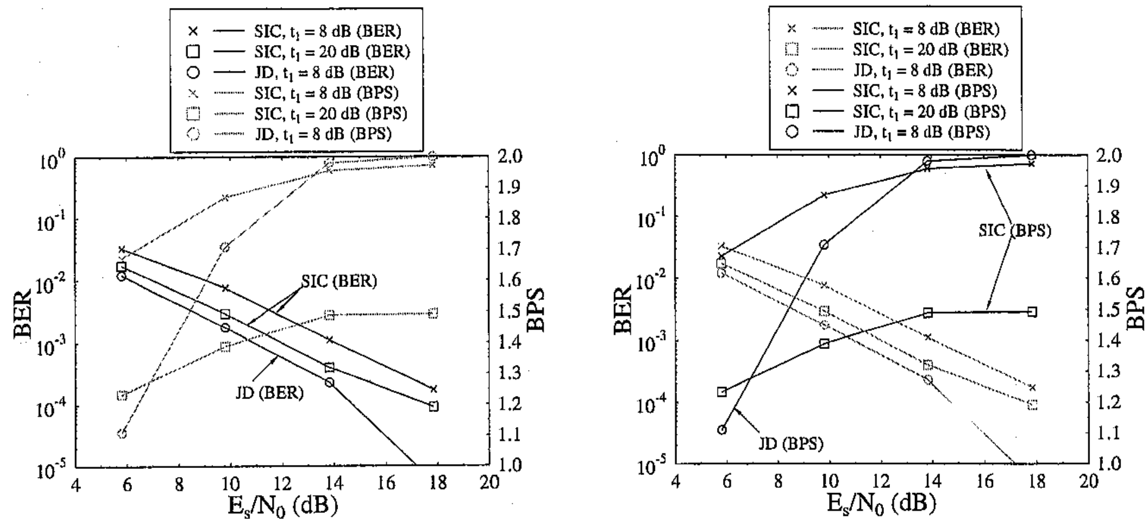


Figure 1: Bad Urban 7-path COST 207 channel used in the simulations [8].

SINR estimate condition	Modulation mode
$\gamma_o < t_1$	BPSK
$t_1 \leq \gamma_o < t_2$	4-QAM
$\gamma_o \geq t_2$	16-QAM

Table 1: Mode switching regime

After the data symbols were modulated according to the chosen modulation mode, the data signal was spread using a $Q = 16$-chip pseudo-random sequence. The signal of each user was transmitted through an independent seven-path channel, shown in Figure 1, which was based on the COST 207 Bad Urban Area channel model [8]. The channel conditions obeyed a Doppler frequency of 80 Hz with a signal Baud rate of 2.167 MBaud. The target BER was set to 1%.



(a) BER comparisons are in bold, BPS comparisons are in grey.

(b) BPS comparisons are in bold, BER comparisons are in grey.

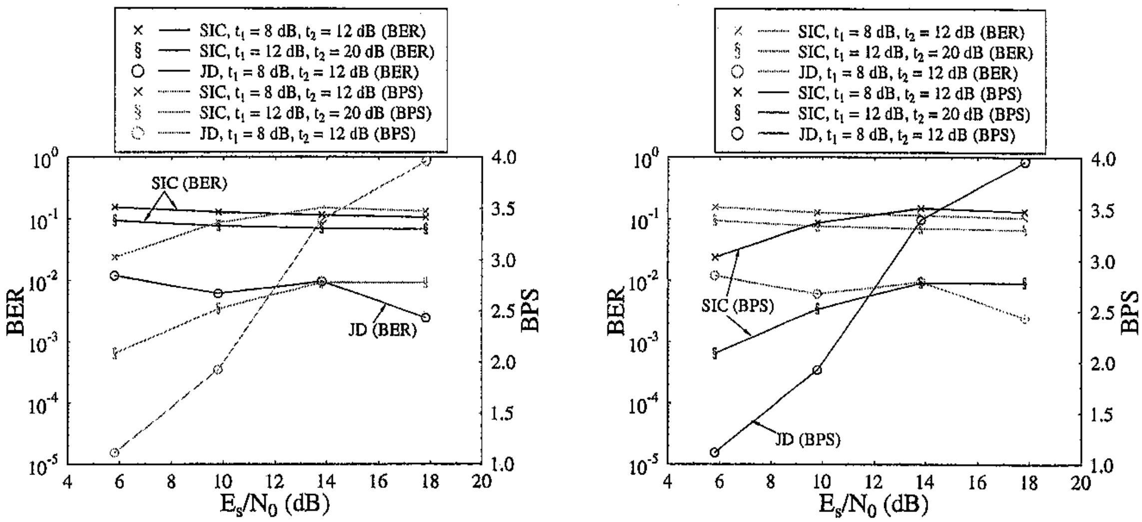
Figure 2: Comparison of the **MMSE-BDFE** and the **SIC** receiver for twin-mode (BPSK, 4-QAM) AQAM transmission and $K = 2$ users.

4. SYSTEM PERFORMANCE

The simulation results for the twin-mode AQAM scheme are depicted in Figure 2. The left y-axis of the graph represents the BER performance scale, while the y-axis on the right represents the throughput scale in bits-per-symbol (BPS). The results are plotted against E_s/N_0, where E_s represents the energy per QAM symbol, as opposed to the energy per bit, E_b. The value of E_s/N_0 can be converted to the corresponding E_b/N_0 value by dividing E_s/N_0 with the number of bits in the QAM symbol. For clarity, Figure 2(a) highlights the BER performance comparison, while the BPS performances are emphasized in Figure 2(b). For the twin-mode AQAM system simulated, the minimum throughput is 1 BPS when BPSK is used, and the maximum is 2 BPS when 4-QAM is employed. In the triple-mode AQAM system, the minimum and maximum throughput values are 1 and 4 BPS, respectively.

Here, the performances obtained with the **SIC** using two different thresholds of $t_1 = 8$ dB and 20 dB are compared to those of the AQAM/JD-CDMA system, where the switching threshold was fixed to $t_1 = 8$ dB. From the figure, we can observe that for the **SIC**, at the lower threshold of $t_1 = 8$ dB, the BER was significantly higher than the BER offered by the JD-CDMA system. At low E_s/N_0 values, the **SIC** throughput was higher than that of the JD system, whilst it was slightly lower at high E_s/N_0 values. When the threshold was increased to $t_1 = 20$ dB, a BER improvement close to the BER of the JD system was observed, but this was accompanied by a drop in throughput that was slightly below the throughput offered by joint detection.

Figure 3 shows the comparison between the JD and SIC systems for the triple-mode AQAM scheme. The BER performances are highlighted in Figure 3(a) and the BPS performances are emphasized in Figure 3(b). When the same switching thresholds - namely $t_1 = 8$ and $t_2 = 12$ dB - are used for both systems, the **MMSE-BDFE** clearly outperforms the **SIC** in BER performance terms. The **MMSE-BDFE** is capable of maintaining a 1% BER, compared to the more than 10% BER attained by the **SIC** receiver. Furthermore, as the E_s/N_0 increased, the throughput performance of the JD system increased correspondingly, until it approached the 4 BPS offered by 16-QAM, without suffering a BER degradation in excess of 1%. Increasing the switching thresholds to $t_1 = 12$ dB and $t_2 = 20$ dB for the **SIC** system did not lead to substantial improvements in the BER, but resulted in a significant drop in average BPS throughput terms. In the case of the **SIC** receiver, the inclusion of 16-QAM as an additional modulation mode increased the probability of feedback error propagation due to the lower distance of the 16-QAM constellation points. This, in turn, led to the degradation in BER performance.



(a) BER comparisons are in bold, BPS comparisons are in grey.

(b) BPS comparisons are in bold, BER comparisons are in grey.

Figure 3: Comparison of the **MMSE-BDFE** and the **SIC** receiver for triple-mode (BPSK, 4-QAM, 16-QAM) AQAM transmission and $K = 2$ users.

The AQAM comparison between the JD and SIC systems was further extended to systems supporting $K = 8$ users. Figures 4 and 5 show the simulation results for our twin-mode and triple-mode AQAM schemes respectively. By increasing the number of users from $K = 2$ to 8, the MAI was increased. The BER curve for the SIC receiver showed an error floor and the target BER of 1% was not achieved. The throughput was also significantly lower, than that achieved by the equivalent JD system. The increase in MAI reduced the reliability of the initial data estimates used for interference cancellation, thus resulting in error propagation. Increasing the switching thresholds for the SIC/AQAM systems would not have improved the performance, because this would have lowered the throughput even further.

5. CONCLUSION

From the simulation results portrayed, we infer that the BER and BPS performance curves follow the same trend for both multiuser detection schemes. At low values of E_s/N_0, the BPSK mode was chosen with a higher probability, as demonstrated in the modem mode Probability Distribution Function (PDF) of Figure 6, thus reducing the throughput. However, as E_s/N_0 was increased, the channel quality improved, thus allowing the 4-QAM and 16-QAM modes to be activated more often, which resulted in an increased

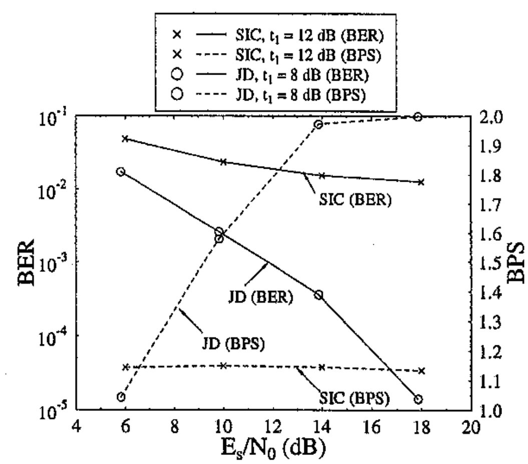


Figure 4: Comparison of the **MMSE-BDFE** and the **SIC** receiver for twin-mode (BPSK, 4-QAM) AQAM transmission. Both systems supported $K = 8$ users.

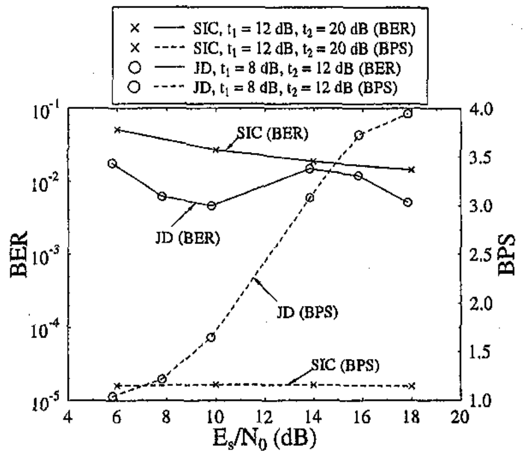


Figure 5: Comparison of the **MMSE-BDFE** and the **SIC** receiver for triple-mode (BPSK, 4-QAM, 16-QAM) AQAM transmission. Both systems supported $K = 8$ users.

average BPS performance. In comparing the two multiuser receivers, at low E_s/N_0 values the **SIC** receiver had a lower performance than the **MMSE-BDFE**. For the twin-mode AQAM system, when the target BER of 1% was achieved by both systems, the throughput offered by the **MMSE-BDFE** in bits-per-symbol terms was higher than that of the **SIC** receiver. In the triple-mode AQAM system, the **MMSE-BDFE** consistently outperformed the **SIC** receiver in both BER and BPS throughput performance terms. However, the increased performance of the **MMSE-BDFE** was achieved at the expense of a higher complexity compared to the **SIC** receiver.

6. CURRENT WORK

Current investigations are concentrated on characterising the effect of imperfect SINR and CIR estimation on the performance of AQAM-CDMA systems. Further work is concentrated on comparing the two different multiuser receivers for adaptive CDMA systems that vary the bit rate by controlling the spreading factor, while keeping the chip rate constant.

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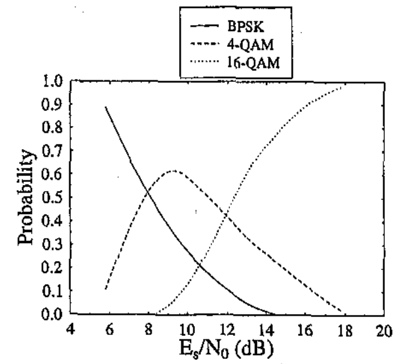

Figure 6: The probability of each modulation mode being chosen for transmission in a triple-mode (BPSK, 4-QAM, 16-QAM), two-user AQAM/JD-CDMA system.

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