JOINT DETECTION BASED WIDEBAND BURST-BY-BURST ADAPTIVE DEMODULATION UNDER CO-CHANNEL INTERFERENCE

C.H. Wong, E.L. Kuan, L. Hanzo

Dept. of Electr. and Comp. Sc., Univ. of Southampton, SO17 1BJ, UK.
Tel: +44-703-593 125, Fax: +44-703-593 045
Email: lh@ecs.soton.ac.uk
http://www-mobile.ecs.soton.ac.uk

Abstract - **In this contribution the performance of adaptive modulation - applied in conjunction with a Decision Feedback Equalizer (DFE) - is characterized in a co-channel interference impaired environment over a slowly varying wideband multi-path Rayleigh fading channel. Specifically, Joint Detection (JD) techniques in conjunction with convolutional coding are invoked, in order to mitigate the effects of co-channel interference in a Time Division Multiple Access (TDMA) environment. Finally, the throughput of the adaptive system is compared to that of a range of fixed modulation systems in an interference-limited environment.**

1. INTRODUCTION

Adaptive Quadrature Amplitude Modulation (AQAM) is based on a modulation mode switching regime, in which the modulation modes are selected according to the prevalent channel conditions. When the channel envelope exhibits a deep fade, lower order modulation modes are selected, in order to improve the mean Bit Error Rate (BER) performance and similarly, higher-order modulation schemes are chosen, when the channel quality is favourable in order to increase the average throughput. Recent AQAM related developments over narrowband channels have been accomplished by amongst others, Webb *et al* [1], Sampei *et al* [2], Goldsmith *et al* [3] and Torrance *et al* [4].

In a wideband environment, the presence of intersymbol interference (ISI) is combated not only by the employment of AQAM, but also by equalization. Hence we utilized the signal to noise plus residual ISI ratio at the output of the equalizer - termed as the pseudo-SNR - in order to switch the modulation modes in a predominantly noise-limited environment [5]. Then we compared the throughput of fixed modulation and the AQAM schemes for a certain target BER [5]. However, in a practical system the presence of co-channel interference will degrade the BER performance. In this contribution we will only focus on the BER degradation due to a single dominant co-channel interferer inflicted upon both fixed modulation and AQAM schemes.

In view of the detrimental effects of co-channel interference, we will invoke Joint Detection (JD) techniques, which are frequently analysed in a Code Division Multiple Access (CDMA) environment [7]. In these JD techniques for CDMA, the effects of ISI, Multiple Access Interference (MAI) and noise is jointly minimised. However, we can exploit JD also in a TDMA environment by considering the co-channel interference as a multiple access-like interference and assuming that in a TDMA system, a single chip spreading sequence is utilized. This assumes estimating the CIR of both the wanted and the interfering user. At the Base Station (BS), the uplink CIRs are known, while in the downlink, passive reception of the channel sounding sequence is necessary in order to mitigate the co-channel interference. Since the single user performance was analysed in conjunction with a DFE [5], a natural choice was to opt for invoking the Minimum Square Error Block Decision Feedback Equalizer (JD-MMSE-BDFE) [7] joint detector. However, error propagation in the JD-MMSE-BDFE due to co-channel interference can potentially inflict a severe performance degradation. Consequently, convolutional coding is invoked for mitigating these effects with the added feature of sequence feedback - which will be highlighted in the next section - in order to reduce the effects of error propagation.

2. SYSTEM OVERVIEW

The channel impulse response, h_i, used in our investigations is derived from the COST 207 [6] channel model for a typical urban area (TU), which is shown in Figure 1. Each path in this discretised channel impulse response is faded independently, according to a Rayleigh distribution, where the multi-path components are non-uniformly spaced on a grid of symbol-

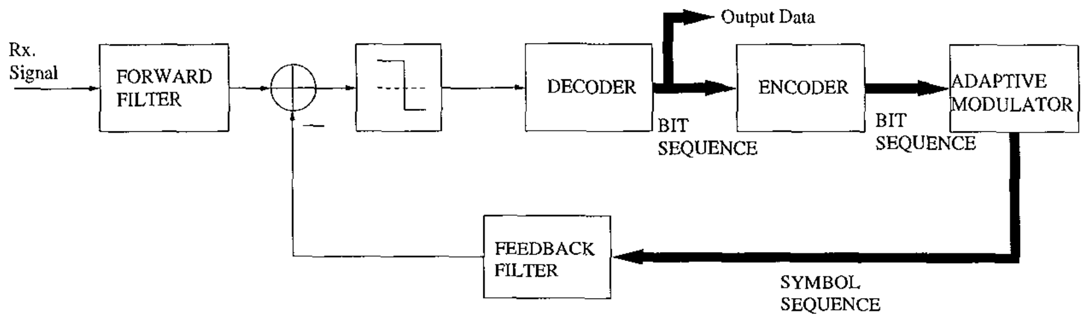

Figure 2: Schematic of the joint convolutional decoding assisted JD-MMSE-BDFE receiver structure depicting the sequence feedback mechanism for the reference user, as described in Section 2.

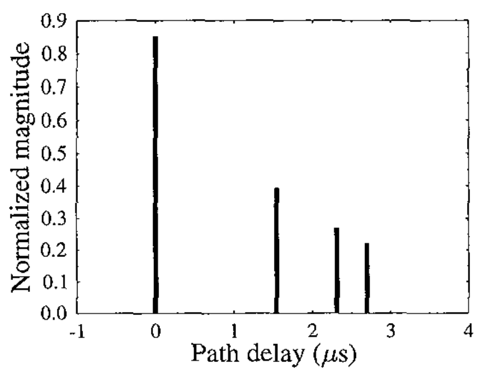

Figure 1: The impulse response of a COST 207 Typical Urban (TU) channel.

spaced legitimate potential positions. The Rayleigh fading statistics obeyed a normalised Doppler frequency of 3.3615×10^{-5}. Variations due to path-loss and shadowing are assumed to be eliminated by power control. The channel model of the synchronous co-channel interferer and the desired user is identical, but it is assumed that there is independent Rayleigh fading for each individual channel. Furthermore, the modulation mode of the interferer is BPSK and the channel impulse response of the interferer is perfectly estimated. This assumes estimating the CIR of both the wanted and the interfering user. At the Base Station (BS), the uplink CIRs are known, while in the downlink, passive reception of the channel sounding sequence is necessary in order to mitigate the co-channel interference.

The basic principle of the joint AQAM and equalization scheme is to utilize the Channel Impulse Response (CIR) and the DFE coefficients in order to calculate the pseudo-SNR, γ_{dfe}, which is then used to select an appropriate modulation mode, based on a set of optimized switching threshold levels, f_n. The switching methodology, using the pseudo-SNR can be summarized as follows:

$$\text{Modulation Mode} = \begin{cases} NOTX & \text{if } \gamma_{dfe} < f_1 \\ BPSK & \text{if } f_1 \leq \gamma_{dfe} < f_2 \\ 4QAM & \text{if } f_2 \leq \gamma_{dfe} < f_3 \\ 16QAM & \text{if } f_3 \leq \gamma_{dfe}, \end{cases} \quad (1)$$

where $f_n, n = 1...3$ are the pseudo-SNR switching thresholds levels and the NOTX mode is used to temporarily disable transmission under severely degraded instantaneous channel conditions.

Convolutional coding was invoked in order to reduce the effects of error propagation in the JD-MMSE-BDFE. This was achieved by embedding the convolutional decoder into the JD-MMSE-BDFE structure as shown in Figure 2. In this convolutional decoding assisted structure, the output of the convolutional decoder is utilized in the feedback filter of the JD-MMSE-BDFE [8] for the reference user. However, instead of a symbol by symbol feedback, sequence feedback was implemented where the JD-MMSE-BDFE's feedback filter inputs were replaced by a sequence of symbols output by the decoder, as proposed by Cheung in the context of a Continuous Phase Modulation (CPM) system in a noise limited environment [9]. Consequently, the input symbols of the feedback filter can be replaced **instantaneously** with more reliable information from the convolutional decoder on a burst-by-burst basis. **This will reduce the impact of error propagation through the feedback filter**. In our subsequent experiments, a half-rate Recursive Systematic Code (RSC) having constraint length $K = 5$ was utilized in conjunction with a Viterbi decoder.

3. FIXED MODULATION PERFORMANCE

In this section, we will analyse the performance of the fixed modulation schemes in the presence of a single dominant co-channel interferer, where the Signal to Interference Ratio (SIR) was varied from 10dB to 30dB. The results are depicted in Figures 3, 4 and 5 for BPSK, 4QAM and 16QAM respectively. In each figure, we compared the results achieved by the joint convolutional decoding assisted structure shown in Figure 2 (labelled as Joint Conv in the figures) with the conventional structure (labelled as Conv in the figures) where the convolutional decoder was not embedded into the JD-MMSE-BDFE structure, it was rather used as an independent decoder. The single user performance was also shown for comparison. Referring to these figures, we can observe that at low SNRs, where noise was dominant, the performance of all modulation modes approached the single user bound. However at higher SNRs the co-channel interference became dominant, resulting in an error floor.

The joint convolutional decoding assisted structure produced a better BER performance, when compared to the conventional scheme for all modulation modes. This was attributed to the reduction of error propagation due to the sequence based feedback of more reliable symbols into the feedback filter. Futhermore, we observed a greater performance degradation for the 16QAM modulation mode at low SIRs, as a result of the reduced Euclidean distance of its constellation points. Consequently, the feedback filter of the JD-MMSE-BDFE was more susceptible to error propagation. Let us now consider the performance of the proposed AQAM scheme.

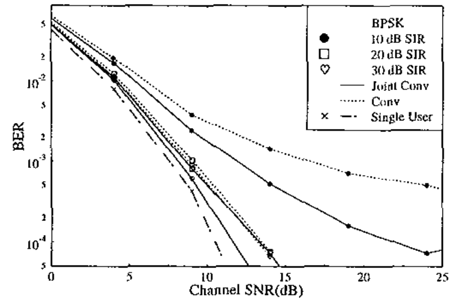

Figure 3: Performance of the fixed BPSK modulation mode over the COST 207 **TU Rayleigh fading channel** of Figure 1 in the presence of a single BPSK interferer for various SIRs. The performance was evaluated utilizing the joint convolutional decoding assisted structure (Joint Conv) of Figure 2 and the conventional - separately decoded - DFE structure (Conv).

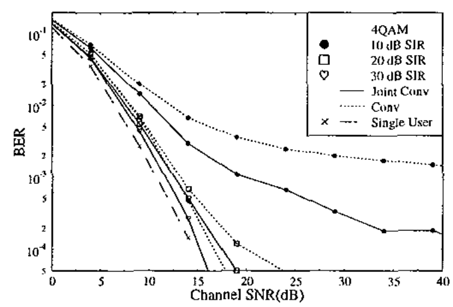

Figure 4: Performance of the fixed 4QAM modulation mode over the COST 207 **TU Rayleigh fading channel** of Figure 1 in the presence of a single BPSK interferer for various SIRs. The performance was evaluated utilizing the joint convolutional decoding assisted structure (Joint Conv) of Figure 2 and the conventional - separately decoded - DFE structure (Conv).

4. AQAM PERFORMANCE

In these experiments the wideband AQAM system was manually conditioned for an interference limited environment in order to achieve target BERs of approximately 1% and 0.01%. The corresponding switching level thresholds, f_n, for each SIR are shown in Tables 1 and 2. The joint convolutional decoding assisted structure was utilized for the AQAM system and the results are depicted in Figures 6 and 7 for the target BERs of 1% and 0.01%, respectively. We have also assumed that the receiver has perfect knowledge of the modulation mode utilized by the transmitter and the most appropriate modulation mode was selected for the next transmission burst.

In these figures the BER performance is depicted along with the corresponding Bits Per Symbol (BPS) throughput. In Figure 6, the target BER of approximately 1% was achieved for SIRs of 10, 20 and 30dBs. The BPS performance improved, as the channel SNR increased due to the application of the higher order modulation modes at high channel SNRs and it converged to 2.0, corresponding to the half-rate coded throughput of the 16QAM modulation mode. At an SIR of 10dB, the BPS throughput was reduced, when compared to the performance achieved at 20dB and 30dB SIRs. This reflected the conservative approach of the AQAM switching regime, where the switching thresholds were increased, in order to mitigate the effects of

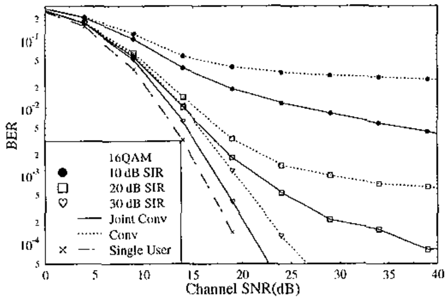

Figure 5: Performance of the fixed 16QAM modulation mode over the COST 207 **TU Rayleigh fading channel** of Figure 1 in the presence of a single BPSK interferer for various SIRs. The performance was evaluated utilizing the joint convolutional decoding assisted structure (Joint Conv) of Figure 2 and the conventional - separately decoded - DFE structure (Conv).

SIR	f_1(dB)	f_2(dB)	f_3(dB)
10dB	0.0	2.0	12.0
20dB	−1.0	2.0	6.0
30dB	−1.0	2.0	6.0

Table 1: The AQAM switching thresholds of Equation 1, which were adjusted manually in order to achieve a target BER of approximately 1%.

SIR	f_1(dB)	f_2(dB)	f_3(dB)
20dB	2.0	5.0	12.0
30dB	2.0	5.0	10.0

Table 2: The AQAM switching thresholds of Equation 1, which were adjusted manually in order to achieve a target BER of approximately 0.01%.

co-channel interference at the expense of a lower BPS throughput. The AQAM system targeted at a BER of approximately 0.01% exhibited similar results and characteristics, as shown in Figure 7. However, at an SIR of 10dB, the target BER was not achieved and hence the performance was shown at 20dB and 30dB SIRs only.

The BPS throughput of the fixed and AQAM schemes are compared in Tables 3 and 4 for a BPS performance of 0.5 and 1.0, respectively. These throughput values are equivalent to the half-rate coded throughput of BPSK and 4QAM. In these tables, the channel SNRs required to achieve a BPS performance of 0.5 and 1.0 were recorded for various SIRs at BERs of 1% and 0.01%. Referring to Table 3, for a target BERs of 1% and 0.01%, gains of approximately 2 - 4dBs and 7 - 9dBs were observed for the AQAM system. Similarly, when the target number of BPS was 1, gains of approximately 2 - 3dBs and 6 - 8dBs were recorded for the AQAM system for target BERs of 1% and 0.01%, respectively, as evidenced by Table 4.

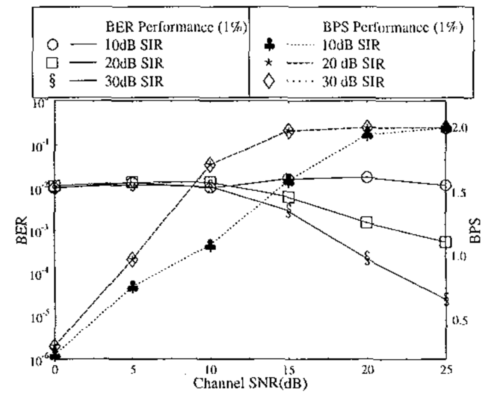

Figure 6: Performance of the wideband AQAM scheme over the COST 207 **TU Rayleigh fading channel** of Figure 1 in the presence of a single BPSK interferer for various SIRs. The joint convolutional decoding assisted structure of Figure 2 was utilized and the switching methodology was characterized by Equation 1. The switching thresholds listed in Table 1 were chosen in order to achieve a BER of 1% in an interference limited environment.

SIR(dB)	10	20	30
Fixed (1%)	5.50dB	4.50dB	4.50dB
AQAM (1%)	2.50dB	1.30dB	1.30dB
Fixed (0.01%)	-	14.10dB	11.80dB
AQAM (0.01%)	-	5.00dB	5.00dB

Table 3: The approximate channel SNRs required, in order to achieve a Bits Per Symbol (BPS) throughput of **0.5** for the fixed modulation mode system and the AQAM system in an interference limited environment. The required channel SNRs were extracted for an approximate BER of 1% and 0.01% from Figures 3, 4, 6 and 7.

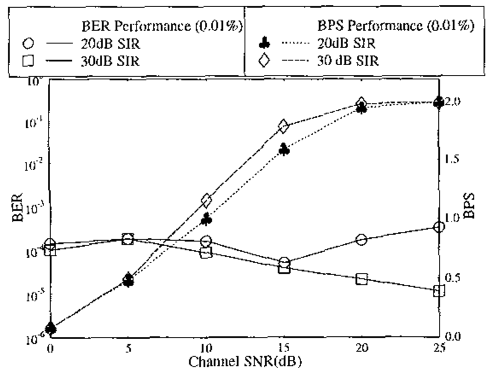

Figure 7: Performance of the wideband AQAM scheme over the COST 207 **TU Rayleigh fading channel** of Figure 1 in the presence of a single BPSK interferer for various SIRs. The joint convolutional decoding assisted structure of Figure 2 was utilized and the switching methodology was characterized by Equation 1. The switching thresholds listed in Table 2 were chosen in order to achieve a BER of 0.01% in an interference limited environment.

SIR(dB)	10	20	30
Fixed (1%)	10.50dB	7.50dB	7.00dB
AQAM (1%)	8.70dB	5.00dB	5.00dB
Fixed (0.01%)	-	17.5dB	15.5dB
AQAM (0.01%)	-	10.00dB	8.80dB

Table 4: The approximate channel SNRs required, in order to achieve a Bits Per Symbol (BPS) throughput of **1.0** for the fixed modulation mode system and the AQAM system in an interference limited environment. The required channel SNRs were extracted for an approximate BER of 1% and 0.01% from Figures 3, 4, 6 and 7.

5. CONCLUSION

In this contribution we have compared the performance of an AQAM - and various fixed modulation mode based systems in an interference limited environment. In these schemes we have invoked JD-MMSE-BDFE and convolutional encoding, in order to mitigate the effects of the co-channel interference. Explicitly, we have embedded the convolutional decoder into the JD-MMSE-BDFE resulting in the combined structure shown in Figure 2 in order to reduce the effects of error propagation. In terms of BER performance, we have recorded gains when we compared the joint convolutional decoding assisted structure and the conventional structure, as evidenced by Figures 3, 4 and 5. Finally, the BPS performance gains of the AQAM system when compared to the fixed modulation schemes are shown in Tables 3 and 4.

Acknowledgement

The financial support of the European Union under the auspices of the Pan-European FIRST project and that of Motorola ECID, Swindon UK is gratefully acknowledged. The authors also wish to thank the members of the FIRST consortium for helpful discussions and for their friendship.

6. REFERENCES

[1] W.T. Webb and R. Steele, "Variable Rate QAM for mobile radio," *IEEE Transactions on Communications*, vol. 43, pp. 2223 - 2230, July 1995.

[2] S. Sampei, S. Komaki and N. Morinaga, "Adaptive Modulation/TDMA scheme for large capacity personal multimedia communications systems," *IEICE Transactions on Communications*, vol. E77-B, pp. 1096–1103, September 1994.

[3] A. Goldsmith and S. G. Chua, "Variable Rate Variable Power MQAM for Fading Channels," *IEEE Transactions on Communications*, vol. 45, pp. 1218 - 1230, October 1997.

[4] J.M. Torrance and L. Hanzo, "On the Upper bound performance of adaptive QAM in a slow Rayleigh fading," *IEE Electronics Letters*, pp. 169 - 171, April 1996.

[5] C. H. Wong and L. Hanzo, "Upper-bound performance of a wideband burst-by-burst adaptive modem," *Proc. of the IEEE VTC'99, Houston, USA*, pp. 1851 - 1855, May 1999.

[6] Office for Official Publications of the European Communities, Luxembourg, *COST 207: Digital land mobile radio communications, final report*, 1989.

[7] A. Klein, G.K. Kaleh and P.W. Baier, "Zero forcing and minimum mean square error equalization for multiuser detection in code division multiple access channels," *IEEE Trans. on Veh. Tech.*, vol. 45, pp. 276 - 287, May 1996.

[8] A.Hafeez and W.E.Stark, "Combined decision-feedback multiuser detection/soft-decision decoding for CDMA channels," *Proc. of the IEEE VTC'96*, pp. 382 - 386, 1996.

[9] J. Cheung and R. Steele, "Soft-decision feedback equalizer for CPM signals," *International Conference on Communications, ICC '91*, pp. 46.2.1 - 46.2.5, June 1991.