Burst-by-Burst Adaptive Coded Modulation-Aided Joint Detection-Based CDMA for Wireless Video Telephony

J.Y. Chung, S.X. Ng, E.L. Kuan and [1]L. Hanzo

Dept. of ECS, University of Southampton, SO17 1BJ, UK.
Tel: +44-23-8059 3125, Fax: +44-23-8059 4508
Email: [1]lh@ecs.soton.ac.uk, http://www-mobile.ecs.soton.ac.uk

Abstract— **In this contribution we propose a Burst-by-Burst Adaptive Coded Modulation-Aided Joint Detection-Based CDMA (ACM-JD-CDMA) scheme for wireless video telephony and characterise its performance when communicating over the UTRA wideband vehicular fading channels. The coded modulation schemes invoked in our fixed modulation mode based systems are Trellis Coded Modulation (TCM), Turbo TCM (TTCM), Bit-Interleaved Coded Modulation (BICM) and Iterative-Decoding assisted BICM (BICM-ID). When comparing the four schemes at a given complexity, TTCM was found to be the best scheme and the performance of the TTCM-assisted ACM-JD-CDMA system was evaluated using a practical modem mode switching regime.**

I. INTRODUCTION

The radio spectrum is a scarce resource. Therefore, one of the most important objectives in the design of a digital cellular system is the efficient exploitation of the available spectrum in order to accommodate the ever-increasing traffic demands. Trellis Coded Modulation (TCM) [1], which is based on combining the functions of coding and modulation, is a bandwidth efficient scheme that has been widely recognised as an excellent error control technique suitable for applications in mobile communications. Turbo Trellis Coded Modulation (TTCM) [2] is a more recent channel coding scheme, which has a structure similar to that of the family of power efficient binary turbo codes [3], but employs TCM codes as component codes. In our TCM and TTCM schemes, random symbol interleavers were utilised for both the turbo interleaver and the channel interleaver.

Another powerful Coded Modulation (CM) scheme utilising bit-based channel interleaving in conjunction with Gray signal labelling, which is referred to as Bit-Interleaved Coded Modulation (BICM), was proposed in [4]. It combines conventional non-systematic convolutional codes with several independent bit interleavers. The number of parallel bit-interleavers used equals the number of coded bits in a symbol [4]. Recently, iteratively decoded BICM using Set Partitioning (SP) based signal labelling, referred to as BICM-ID has also been proposed [5].

However, the above fixed mode transceivers failed to adequately counteract the time varying nature of mobile radio channels. By contrast, in Burst-by-Burst (BbB) adaptive schemes [6] a higher order modulation mode is employed, when the instantaneous estimated channel quality is high in order to increase the number of Bits Per Symbol (BPS) transmitted and conversely, a more robust lower order modulation mode is employed, when the instantaneous channel quality is low, in order to improve the mean Bit Error Ratio (BER) performance. Both uncoded adaptive schemes [6] and coded adaptive schemes [7] have been widely investigated for transmissions over narrowband fading channels in the context of both single- and multi-carrier modems. They are however also powerful in the context of Direct Sequence Code Division Multiple Access (DS-CDMA) transceivers, which perform best in conjunction with Joint Detection (JD) of all users.

Joint detection [8] receivers are derivatives of the well-known single-user equalizers, which were originally designed for equalizing signals that have been corrupted by Inter-Symbol Interference (ISI) due to the multipath effect of wireless channels. The Minimum Mean Square Error Decision Feedback Equalizer (MMSE-DFE) based JD (JD-MMSE-DFE) scheme constitutes a powerful approach to mitigating the effects of multi-user interference (MUI) and ISI [9], while at the same time improving the system's performance by benefiting from the multipath diversity effects of the channels.

In this contribution, a BbB Adaptive Coded Modulation-Aided Joint Detection-Based CDMA (ACM-JD-CDMA) scheme is proposed for wireless video telephony and characterised in performance terms when communicating over the UMTS Terrestrial Radio Access (UTRA) wideband vehicular fading channel. The BbB-Adaptive Coded Modulation (ACM) scheme is assisted by a JD-MMSE-DFE based receiver, when transmitting over the dispersive Rayleigh fading channels of a multiuser CDMA system. In our practical approach, transmitter A obtains the channel quality estimate generated by receiver B upon receiving the transmission of transmitter B. In other words, the modem mode required by receiver B for maintaining a certain target integrity is signalled to transmitter A by superimposing it on the transmission burst of transmitter B. Hence a delay of one transmission burst duration is incurred.

The rest of this treatise is organised as follows. Our system overview is presented in Section II, while the associated video aspects are summarised in Section III. The channel model and the system parameters are described in Section IV. Our simulation results are discussed in Section V and finally our conclusions are offered in Section VI.

II. System Overview

The information bits generated by the video encoder are first channel encoded in order to generate non-binary symbols according to the Coded Modulation (CM) mode chosen. The CM-encoded symbols are then spread with the aid of the spreading code assigned to the user, modulated on to the carrier and transmitted. At the receiver, the data symbols of all the users are detected jointly, employing the MMSE-BDFE and the detected symbols are channel decoded by the corresponding CM decoder, before they are processed by the video decoder.

Joint detection CDMA is suitable for combining with ACM, because the joint detection algorithms operate in a symbol by symbol basis and hence they do not require any knowledge of the modulation mode used. The system matrix required for joint detection is constructed by using only the Channel Impulse Response (CIR) estimates and the spreading sequences of all the users. Therefore, the joint detection receiver does not have to be reconfigured, when the modulation mode is switched and its complexity is essentially independent of the modulation mode used or the number of bits per symbol.

In joint detection systems the SINR of each user at the output of the MMSE-BDFE can be calculated by using the channel estimates and the spreading sequences of all the users. By assuming that the transmitted data symbols and the noise samples are uncorrelated, the expression for calculating the SINR γ_o of the n-th symbol transmitted by the k-th user was given by Klein *et al.* [10] as:

$$\begin{aligned}\gamma_o(j) &= \frac{\text{Wanted Signal Power}}{\text{Res. MAI and ISI Power + Eff. Noise Power}} \\ &= g_j^2[\mathbf{D}]^2_{\mathbf{j,j}} - \mathbf{1}, \qquad \text{for } \mathbf{j = n + N(k-1)}, \quad (1)\end{aligned}$$

where SINR is the ratio of the wanted signal power to the residual MAI and ISI power plus the effective noise power. The number of users in the system is K and each user transmits N symbols per transmission burst. The matrix $\mathbf{D}$ is a diagonal matrix that is obtained with the aid of the Cholesky decomposition [11] of the matrix used for linear MMSE equalization of the CDMA system [10]. The notation $[\mathbf{D}]_{\mathbf{j,j}}$ represents the element in the j-th row and j-th column of the matrix $\mathbf{D}$ and the value g_j is the amplitude of the j-th symbol.

After the JD's output SINR is calculated, the best-matching modulation mode is chosen by receiver B accordingly and communicated by transmitter B to transmitter A. Let us designate the choice of modulation modes to be V_m, where the total number of modulation modes is $M = 4$ and $m = 1, 2, \ldots, M$. The modulation mode having the lowest number of constellation points is V_1 and the one associated with the highest is V_M. The rules used for switching the modulation modes are as follows:

$$\begin{array}{rcl}\Gamma_o(k) \le t_1 & \Longrightarrow & V_1 = 4QAM \\ t_1 < \Gamma_o(k) \le t_2 & \Longrightarrow & V_2 = 8PSK \\ t_2 < \Gamma_o(k) \le t_3 & \Longrightarrow & V_3 = 16QAM \\ t_3 \le \Gamma_o(k) & \Longrightarrow & V_4 = 64QAM,\end{array}$$

where $\Gamma_o(k)$ is the SINR of the k-th user at the output of the MMSE-BDFE, which was calculated by using Equation 1 and $\Gamma_o(k) = \frac{1}{N}\sum_{n=1}^{N}\gamma_o(j)$, $j = n + N(k-1)$. The values $(t_1, \cdots, t_{M-1})$ represent the switching thresholds used for activating the modulation modes, where we have $t_1 < t_2 < \cdots < t_{M-1}$.

Features	Multi-rate System			
Mode	4QAM	8PSK	16QAM	64QAM
Transmission Symbols	240			
Bits/Symbol	2	3	4	6
Transmission bits	480	720	960	1440
Packet Rate	100/s			
Transmission bitrate (kbit/s)	48	72	96	144
Code Termination Symbols	6			
Data Symbols	234			
Coding Rate	1/2	2/3	3/4	5/6
Information Bits/Symbol	1	2	3	5
Unprotected bits	234	468	708	1170
Unprotected bitrate (kbit/s)	23.4	46.8	70.8	117.0
Video packet CRC (bits)	16			
Feedback protection (bits)	9			
Video packet header (bits)	11	12	12	13
Video bits/packet	198	431	671	1138
Effective Video-rate (kbit/s)	19.8	43.1	67.1	113.8
Video framerate (Hz)	30			

TABLE I

Operational-mode specific transceiver parameters for TTCM.

We invoke four channel encoders, each adding one parity bit to each information symbol, yielding the coding rate of 1/2 in conjunction with the modulation mode of 4QAM, 2/3 for 8PSK, 3/4 for 16QAM and 5/6 for 64QAM. The TCM scheme invokes Ungerböck's codes [1], while the TTCM scheme invokes Robertson's codes [2]. The BICM scheme was constructed using Paaske's non-systematic convolutional codes [12]. The rate 5/6 code of the BICM scheme was constructed using Paaske's rate 1/2 code and puncturing, following the approach of [13,14]. The BICM-ID scheme was created using Li's [5] approach.

Soft decision trellis decoding utilising the Log-Maximum A Posteriori (Log-MAP) algorithm [15] was invoked for the decoders. The Log-MAP algorithm is a numerically stable version of the MAP algorithm operating in the log-domain, in order to reduce the implementational complexity and to mitigate the numerical problems associated with the MAP algorithm [16].

III. Video Overview

In this study, we transmitted 176x144-pixel Quarter Common Intermediate Format (QCIF) resolution video sequences at 10 frames/s using a reconfigurable TDD/CDMA transceiver, which can be configured as a 2, 3, 4 or 6 bit/symbol scheme. The proposed video transceiver is based on the H.263 video codec [17].

The associated codec parameters are summarised in Table I. The channel-coded video coded bit stream is conveyed by an intelligent BbB adaptive wideband multi-mode modem [18]. This system would support an increased throughput expressed in terms of the average number of bits per symbol, when the instantaneous channel quality was high, leading ultimately to an increased video quality in a constant bandwidth.

Let us now highlight the philosophy of the video packetisation method. The size of the video packets varies depending on the current operating mode of the multi-mode modem. The proposed multi-mode system can be configured to switch amongst the 2, 3, 4 and 6 bit/symbol modulation modes based upon the near-instantaneous channel conditions. As seen in Table I, when the channel is benign, the video bitrate is approximately 113Kbps. However, as the channel quality degrades, the modem will switch to the 4QAM mode of operation, where the video bitrate drops to 19Kbps.

The video transmitter is informed of the packet's transmission success or failure with the aid of a highly protected binary feedback flag, which is superimposed on the reverse link's transmission [19]. More explicitly, the associated binary feedback flag is protected with the aid of a repetition code. The use of packet acknowledgement flags allows the video encoder and the remote decoder to keep synchronised, operating on the basis of identical video reconstruction frame buffer contents without the need of retransmissions, which are wasteful in terms of bandwidth efficiency and transmission delay.

IV. Channel Model and System Parameters

Parameter	Value
Carrier Frequency	1.9GHz
Vehicular Speed	30mph
Doppler frequency	85Hz
System Baud rate	3.84 MBd
Normalised Doppler frequency	85/3.84=2.21 $\times 10^{-5}$
Channel type	UMTS Vehicular Channel A
Number of paths in channel	6
Data modulation	Adaptive Coded Modulation (4QAM, 8PSK, 16QAM, 64QAM)
Receiver type	JD-MMSE-DFE
No. of symbols per JD block	15

TABLE II

Modulation and channel parameters

Table II shows the modulation and channel parameters employed. The multi-path channel model is characterised by its discretised chip-spaced UTRA vehicular channel A [20]. The corresponding channel impulse response is shown in Figure 1, where each path is faded independently according to the Rayleigh distribution. The transmission burst structure of the modified UTRA Burst 1 [19] using a spreading factor of eight is shown in Figure 2. The number of data symbols per JD block is 15, hence the original UTRA Burst 1 was modified to host a burst of 240 data symbols, which is a multiple of 15. The remaining system parameters are shown in Table III.

We compare the performance of TTCM employing constraint length three constituent TCM schemes using four

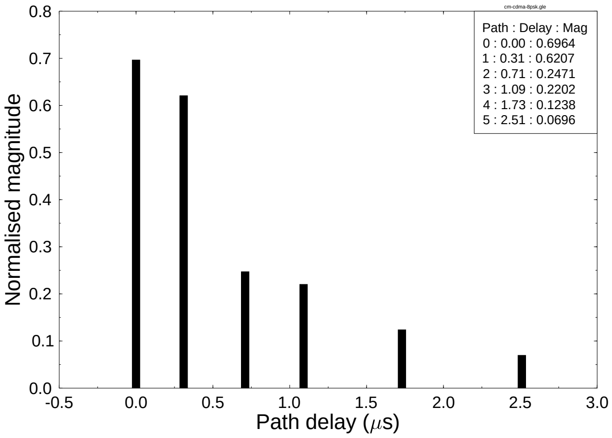

Fig. 1. UTRA vehicular channel A [20].

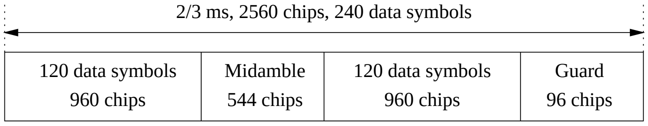

Fig. 2. A modified UTRA Burst 1 [19] with a spreading factor of 8. The original UTRA burst has 244 data symbols.

Features	Value
Multiple access	CDMA, TDD
No. of Slots/Frame	15
Spreading factor	8
Frame length	10ms
Slot length	2/3ms
Data Symbols/Slot	240
No. of Slot/User	1
User Data Symbol Rate (KBd)	240/10 = 24
System Data Symbol Rate (KBd)	24x15 = 360
Chips/Slot	2560
Chips/Frame	2560x15=38400
User Chip Rate (KBd)	2560/10 = 256
System Chip Rate (MBd)	38.4/10 = 3.84
System Bandwidth (MHz)	3.84 x 3/2 = 5.76
Eff. User Bandwidth (kHz)	5760/15 = 384

TABLE III

Generic system features of the reconfigurable multi-mode video transceiver, using the spread data burst 1 of UTRA [19, 20] shown in Figure 2.

iterations, to that of non-iterative TCM along with a constraint length of six. We also compare these results to non-iterative BICM employing a constraint length of six as well as BICM-ID in conjunction with a constraint length of three and using eight iterations. Hence the associated computational complexity of these four CM schemes expressed in terms of the number of trellis states is similar.

V. Simulation Results And Discussions

Initial simulations were performed using the transceiver configured in one of the four fixed modulation modes of Table I. Figure 3 portrays the Packet Loss Ratio (PLR) for the multi-mode system, in each of its modulation modes for a range of channel SNRs. It can be seen that for channel SNRs above 25dB the 64QAM mode offered an acceptable PLR of less than 5%, while providing a video rate of about 113Kbps. When the channel SNR drops below 25 dB, the multi-mode system is switched to 16QAM, then to 8PSK and eventually to 4QAM.

Figure 3 shows the PLR performance of the four different joint coding and modulation schemes for the four fixed modulation modes considered. It can be seen that the TTCM schemes have the best performance. This is because turbo decoding of the TTCM scheme is very effective in terms of reducing the number of bit errors to zero in packets exhibiting a moderate number of bit errors before decoding.

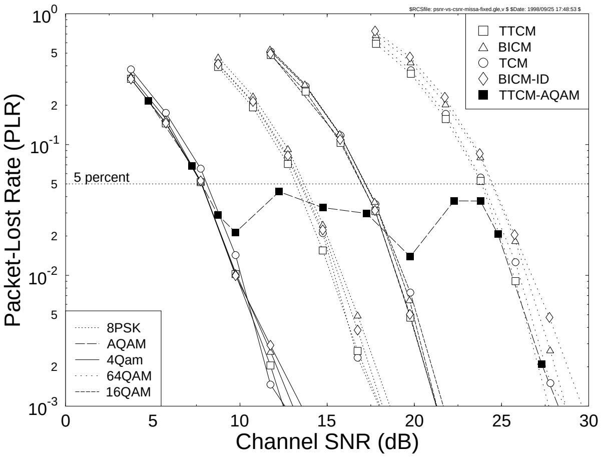

Fig. 3. Packet loss ratio versus channel SNR for the four fixed modem modes, using the four joint coding/modulation schemes considered, namely BICM-ID, BICM, TCM and TTCM, when communicating over the UTRA channel of Figure I.

The video quality is commonly measured in terms of the Peak-Signal-To-Noise-Ratio (PSNR). Figure 5 shows the video quality in terms of the PSNR versus the channel SNR for each of the modulation modes. As expected, the higher throughput bitrate of the 64QAM mode provides a better video quality. However, as the channel quality degrades, the video quality of the 64QAM mode is reduced and hence it becomes beneficial to switch from 64QAM to 16QAM, then to even lower throughput modulation modes, as the channel quality degrades.

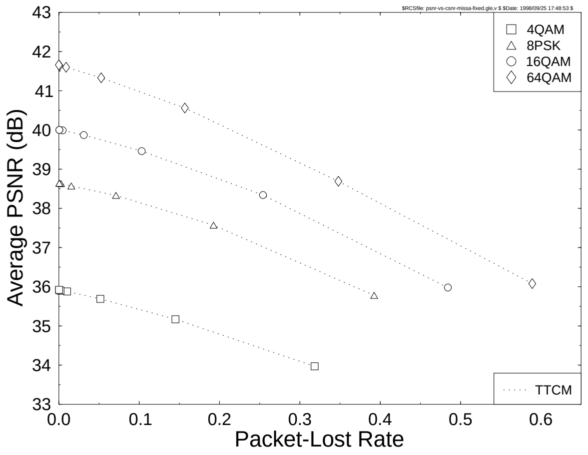

Fig. 4. Decoded video quality (PSNR) versus video packet loss ratio for the four modulation modes.

The effect of packet losses on the video quality is quantified in terms of the PSNR, as depicted in Figure 4. The figure shows how the video quality degrades, as the PLR increases. It has been found that in order to ensure a seamless degradation of the video quality as the channel SNR reduced, it was beneficial to switch to a more robust modulation mode, when the PLR exceeded 5%. Although this inherently reduced the bitrate and the associated video PSNR, this was less objectionable in subjective video quality terms, than a PLR in excess of 5% would have been.

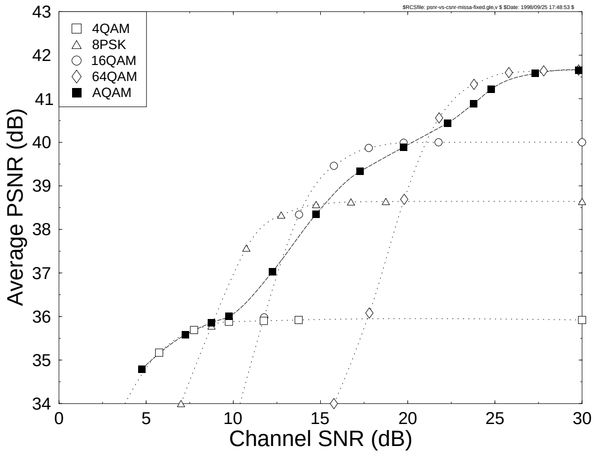

Fig. 5. Average PSNR versus channel SNR for the four fixed TTCM modes and for the four-mode TTCM AQAM scheme using the QCIF video sequence at 30 frame/s.

The mode switching operation of the adaptive scheme is characterised by a set of switching thresholds, by the delay imposed by the corresponding random TTCM symbol-interleavers and by the component codes, which has been also mentioned in Section II. The average PSNR versus channel SNR performance of the four fixed TTCM modes and also of the four-mode TTCM AQAM scheme is shown in Figure 5. Finally, Figure 6 portrays the average PSNR versus Channel SNR performance of the four-mode TTCM AQAM scheme for PLRs of 1%, 5% and 10%.

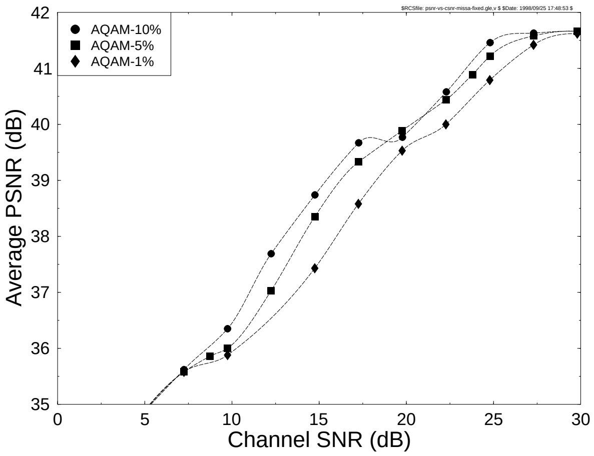

Fig. 6. Average PSNR versus channel SNR for four-mode TTCM AQAM scheme in 1%, 5% and 10% packet loss representation.

As expected, the figure portrays that the AQAM modem's video performance degrades smoothly, when the channel SNR degrades, while the fixed modem's video performance degrades more rapidly, when the channel SNR becomes insufficiently high for the specific modem mode concerned.

VI. Conclusion

In this contribution, various burst-by-burst adaptive coded modulation aided joint detection based CDMA video transceivers have been studied, when communicating over the UTRA wideband vehicular fading channel. The adaptive transceiver is capable of operating in four different coded modulation modes, namely using 4QAM, 8PSK, 16QAM and 64QAM.

Various coded modulation schemes were used in our experiments. The advantage of the adaptive coded modulation schemes, such as adaptive TTCM is that when invoking higher-order modulation modes in case of encountering a higher channel quality, the coding rate approaches unity. As a result, this would allow the video transceiver to maintain a high throughput and high video quality. In our case the bitrate of the 4QAM and 64QAM modes was 23.4Kbps and 117Kbps, respectively. The coding rate of 4QAM was 1/2, while that of 64QAM was 5/6. This supported effective video bitrates between approximately 20Kbps to 114Kbps.

The burst-by-burst adaptive modem guaranteed the same video performance, as the lowest- and highest-order fixed-mode modulation schemes at a range of low and high channel SNRs. However, between these extreme SNRs the effective video bitrate smoothly increased, as the channel SNR increased, whilst maintaining a near-constant PLR. By controlling the AQAM switching thresholds a near-constant PLR can be maintained.

VII. Acknowledgements

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