

CONSTANT-RATE TURBO-CODED ORTHOGONAL FREQUENCY DIVISION MULTIPLEX VIDEOPHONY OVER UMTS

P. Cherriman, T. Keller, and L. Hanzo

Dept. of Electronics and Computer Science,
University of Southampton, SO17 1BJ, UK.
Tel: +44-703-593 125, Fax: +44-703-594 508
Email: lh@ecs.soton.ac.uk
<http://www-mobile.ecs.soton.ac.uk>

ABSTRACT

The ability of a Universal Mobile Telecommunications System (UMTS) framework [1] to support interactive video communications is evaluated employing the inherently error sensitive, but high-compression H.263 video codec. A Constant Bit Rate (CBR) is maintained and error-resilience is achieved by invoking a packet acknowledgement scheme, instructing both the local and remote reconstruction buffer to leave picture areas un-updated, if the packet was corrupted. Orthogonal Frequency Division Multiplexing (OFDM) [3] is employed to deliver the video signal over the dispersive worst-case Bad Urban COST 207 channel [14], assisted by binary Bose-Chaudhuri-Hochquenghem (BCH) [11] and turbo codes [12]. These channel codes are investigated comparatively, with the conclusion that due to the high error-resilience of the video packetisation and acknowledgement regime the increased power of the higher complexity turbo codec does not translate to substantially improved overall system robustness, although the bit error rate and acknowledgement flag error-rate is significantly reduced. The system is also compared to a 155 Mbps wireless ATM scheme [9]. The video transceiver parameters are summarised in Table 1.

1. BACKGROUND

While the penetration of second generation voice- and data-oriented wireless systems is increasing at an unprecedented rate, the wireless communications community is studying a range of third-generation standard proposals, which are summarised for example by Ojanpera in [1]. One of the four Universal Mobile Telecommunications System (UMTS) proposals in Europe is based on Orthogonal Frequency Division Multiplexing (OFDM) suggested by Telia in Sweden [2, 3], which is studied in this treatise in the context of the framing structure suggested by the Pan-European FRAMES consortium [4] at a transmission rate around 2 Mbps using the system parameters of Table 1, which will be detailed during our forthcoming elaborations. The basic philosophy of

A RANGE OF VIDEO DEMONSTRATIONS SUPPORTING THIS TREATISE CAN BE FOUND UNDER
[HTTP://WWW-MOBILE.ECS.SOTON.AC.UK/PETER/ROBUST-ED63/ROBUST.HTML](http://www-mobile.ecs.soton.ac.uk/peter/robust-ed63/robust.html)
GLOBECOM'98, SYDNEY, AUSTRALIA

OFDM is that the dispersion-sensitive high-rate data signal is split in a high number of parallel, low-rate, non-dispersive sub-channels [3]. In contrast to conventional equalised serial modems [3], in OFDM modems channel equalisations does not necessarily have to take place, since typically all low-rate subchannels can be considered non-dispersive. If this does not hold, the number of subchannels can be increased in order to achieve non-dispersive transmission. The complexity of serial and OFDM modems was compared for example by Borowski et al [5]. Focusing on video coding, Ngan et al [6], Girod, Steinbach and Faerber [7] and others contrived a variety of transmission schemes for the H.263 codec [8, 9]. Various proprietary codecs were proposed in Reference [10], with the aim of comparatively studying the benefits of increased-compression, but error-sensitive fixed-rate codecs versus more error-resilient, but lower-compression codecs and transmission schemes.

2. SYSTEM ARCHITECTURE

In our proposed wireless videophone system the video signal is compressed using the H.263 video compression standard [7], which achieves a high compression ratio, however the resulting bitstream is extremely sensitive to channel errors. This sensitivity to channel errors is not a serious problem over benign wireline-based channels, such as conventional ATM links, but it is an impediment, when used over wireless networks. There have been several solutions suggested in the literature for overcoming this problem [6, 8].

Our system uses a feedback channel to inform the encoder of the loss of previous packets. However, we do not retransmit the corrupted packets, since this would reduce the system's teletraffic capacity by occupying additional transmission slots, while increasing the video delay. We found that simply dropping the corrupted packets at both the local and remote decoder results in an extremely high error resilience, in particular in high frame-rate systems, where 30 frames/s high-rate transmissions are facilitated [8, 9]. The rationale behind this is that un-updated video frame segments can only persist for 33 ms at 30 fps. This allows for the reconstruction frame buffer contents of the local and remote decoders to remain identical, which is essential for preventing error propagation through the reconstructed frame buffer. Then, when the instantaneous channel quality improves, the corrupted picture segments of the reconstructed frame buffers are replenished with more up-to-date

video information. The feedback channel is implemented by superimposing the packet dropping request on the reverse link [8, 9] of the proposed Time Division Multiple Access (TDMA), Time Division Duplex (TDD) system.

The video packetiser employed assembles the video packets for transmission, taking into account the packet acknowledgement feedback information. The corresponding packet disassembler algorithm at the receiver ensures that always an error-free H.263 bitstream is output to the video decoder, discarding any erroneously received packet and using only error-free packets to update the reconstructed frame buffer. Since the transmission packets contain typically fractions of video macroblocks at the beginning and end of the packets, a corrupted packet implies that the previously received partial macroblocks have to be discarded. The loss of the packet is then signalled via the feedback channel to the transmitter's video encoder and packet assembly blocks.

The lost macroblocks are not re-transmitted, but strongly error protected acknowledgement flags are inserted into the video bitstream to signify the macroblocks that have not been updated. This requires one bit per lost macroblock in the next reverse-direction packet of the given user. The decoded video stream is error-free, although certain parts of some video frames may be 'frozen' for a frame duration due to lost packets. These areas will be usually updated in the next video frame, and the effect of the lost packet will be no longer visible. Again, this packet loss has a prolonged effect for 100 ms at 10 fps, which is more perceivable than the losses at 30 fps. The aspects of the acknowledgement flag protection and the associated probability of correct flag reception are quantified in Figures 1 and 7, which will be discussed at a later stage.

The packetised video stream is then Forward Error Correction (FEC) coded, mapped to the allocated TDMA timeslot and transmitted using Differential Quaternary Phase Shift Keying (D-QPSK) between adjacent sub-carriers of the Orthogonal Frequency Division Multiplex (OFDM) scheme employed [3]. Again, it is important to strongly protect the binary acknowledgement flag from transmission errors, which prevents the remote decoder from updating the local reconstruction buffer, if the received packet was corrupted. Following a range of considerations, we opted for using a repetition-code, which was superimposed on the forthcoming reverse-direction packet in the proposed Time Division Duplex (TDD) scheme. The repetition-coded flag is then Majority Logic Decision (MLD) decoded at the receiver. The probability of correct decoding of the 5, 9, 18, and 27 bit majority logic codes was numerically evaluated for the range of bit error rates 0% to 50% using a random error distribution in Figure 1. On the basis of the results we opted for using the strongest MLD code of MLD(27,1,13), repeating the flag 27 times, which was hence able to correct up to 13 transmission errors or a channel BER of about 50%.

The transmission scheme used in our investigations was partially inspired by the ACTS FRAMES [4] Mode 1 proposal, which entails a time frame structure of 4.165ms, split in eight timeslots of 577 μ s duration each. However, instead of using the originally proposed DS-CDMA scheme with a chip-rate of 2.17Mchips/s, we have employed 1024 subcarrier OFDM, as it is shown in Figure 2. Hence we refer to this system as a Frames-like scheme. The modified timeslot contains a 1024-sample OFDM symbol, which is preceded by a cyclic extension of 168 samples length and followed

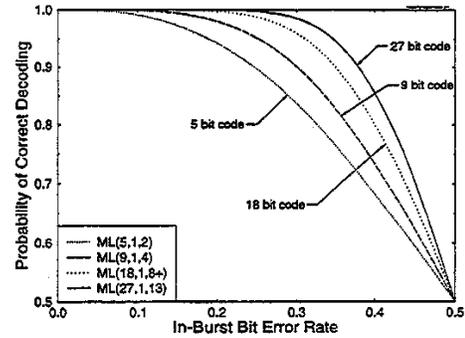


Figure 1: Numerical Evaluation of the probability of correct decoding (P_{CD}) of Majority Logic Codes

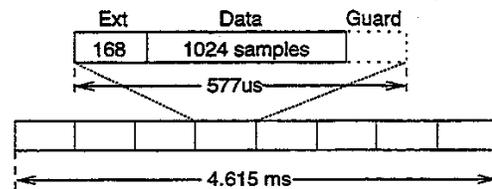


Figure 2: Schematic plot of the ACTS FRAMES Mode 1-like frame structure as used in this paper. A timeslot of 4.165ms duration is split into eight timeslots of 577 μ s. Each timeslot holds a 1024 point IFFT OFDM symbol with a cyclic extension of 168 samples.

by a guard interval of 60 samples. In order to maintain the Frames UMTS bandwidth of 1.6MHz, the 1024 subcarrier OFDM symbol contains 410 virtual subcarriers, therefore reducing the bandwidth to 1.3MHz and allowing for a modulation excess bandwidth. Let us now consider the corresponding channel models.

3. THE CHANNEL MODEL

The channel model used for our UMTS-type scheme was based on a COST 207 [14] Bad Urban conformant seven-path impulse response shown in Figure 3. Each of the impulses was faded independently according to a Rayleigh narrow band fading channel with a normalised Doppler frequency of $f'_d = 92.6\text{Hz}/2.17\text{MHz} = 4.267 \cdot 10^{-5}$, where the carrier frequency and vehicular velocity were set to 2 GHz and 30 mph, respectively. We note here that we also used a 155 Mbps Wireless Asynchronous Transfer Mode (WATM) benchmark system, operating at 60 GHz over a 7-path worst-case channel, corresponding to the four walls, ceiling and floor plus the line-of-sight (LOS) path in a 100x100m hall, which was characterised both in Figure 4 and in [9].

4. VIDEO TRANSCIVER PARAMETERS

In our UMTS-type scheme we opted for using the so-called high bitrate slot type [4], of which there can be a maximum

Feature	Value	
	BCH coding	Turbo Coding
Modulation	Differential-QPSK	
TDMA frame length	4.615ms	
Slots/Frame	8	
Slot length	577 μ s	
OFDM carriers	1024 (612 used + 2 pilots)	
System Bandwidth	1.6MHz	
System Symbol rate (symbols/sec)	2.17×10^6	
Normalised Doppler Frequency	4.267×10^{-5}	
Coded Bits/slot	1224 bits	
Feedback control bits	27	
H.263 Packetisation header bits	11	
Channel Coding ($\approx 1/2$ rate)	4 \times BCH(255,131,18) + 2 \times BCH(127,64,10) + BCH(63,30,6)	Turbo Coding using 612 bit random interleaver + 16bit CRC
Pre-FEC Bits per timeslot	618	594
Pre-FEC Bitrate	134Kbit/s	129Kbit/s
Video bits per timeslot (FEC)	580	556
Useful Video Bitrate (FEC)	126Kbit/s	120Kbit/s

Table 1: Summary of UMTS-like Parameters

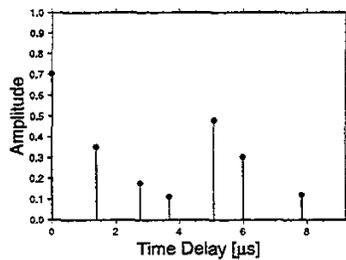


Figure 3: COST 207 Bad Urban compliant impulse response, used for the UMTS [14]

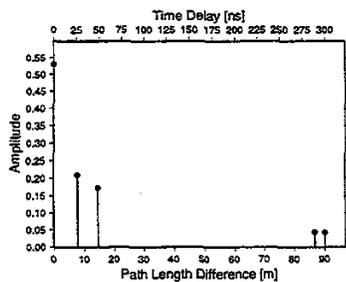


Figure 4: WATM five-path impulse response

of eight in each TDMA frame. The OFDM system designed for this scenario gave 1224 bits per timeslot, which yields a channel bitrate of 265Kbit/s or approximately 130Kbit/s before half rate FEC coding. This bitrate is suitable for high-quality 176x144 pixel Quarter Common Intermediate Format (QCIF) video or lower quality CIF video. Hence we limited our system-oriented investigations to QCIF resolution. Additionally, we invoked two different types of channel coding, BCH blocks codes [11], and turbo coding [12], which were also specified in Table 1. Since our system required an error detection facility for controlling the reconstruction frame buffer updates, the use of block codes was convenient due to their inherent error correction and detection capabilities. The parameters for the UMTS-type scheme are summarised in Table 1. Since turbo coding cannot provide error detection, to this effect a 16bit Cyclic Redundancy Checking (CRC) code was used. Given the 1224 bits/slot 'payload' per TDMA frame, before channel coding the number of bits per TDMA frame was constrained to 618 for BCH coding and 594 for turbo coding. Half-rate, memory-length $K = 3$ turbo coding was used, however two termination bits per slot were required for the convolutional encoders. Therefore the number of pre-FEC bits per transmission packet was $1224/2 - 2(\text{termination}) - 16(\text{CRC}) = 594$. This led to a pre-FEC bitrate of 134Kbit/s for BCH coding and 129Kbit/s for turbo coding. The additional system overhead required 27 bits per packet for the reverse link's acknowledgement flag and 11 bits for the H.263 packetisation header [8]. This led to a video bitrate of 126Kbit/s for BCH coding and 120Kbit/s for turbo coding. Having highlighted the salient video-specific system features, let us now consider the achievable system performance in the next Section. The parameters of the WATM benchmarker scheme were summarised in [9].

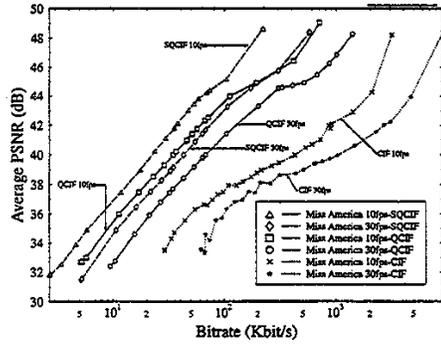


Figure 5: Image quality (PSNR) versus coded bitrate, for H.263 "Miss America" simulations at 10 and 30 frames/s.

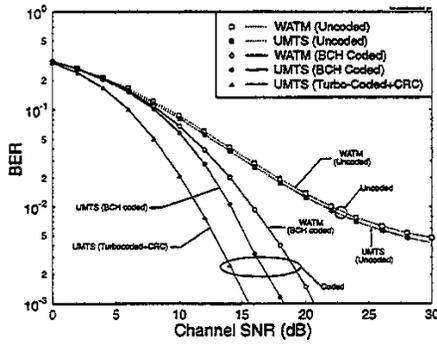


Figure 6: Uncoded channel BER and channel-decoded BER of the UMTS and WATM schemes over the wideband channel characterised by the impulse responses shown in Figures 3 and 4, respectively

5. SYSTEM PERFORMANCE

Again, in our system-oriented experiments we employed QCIF images, scanned at 30 frames/sec (fps). However, additionally we analysed the image quality versus bitrate performance of the H.263 codec for sub-QCIF and CIF resolution video sequences, in order to show the codec's ability to support various bitrates. The corresponding Peak Signal to Noise Ratio (PSNR) results are portrayed in Figure 5 as a function of bitrate and compression ratio, respectively, when using the Miss America sequence. The quadrupled number of pixels present in the CIF format resulted in an approximately four-fold increase of the bitrate. Observe, furthermore that the 30 frames/s (fps) scenarios required typically a factor of two higher bitrates in order to maintain a certain fixed PSNR, with respect to 10 fps.

Figure 6 portrays the bit error rate (BER) performance of both the UMTS and WATM candidate schemes over the wideband channels characterised by the impulse responses shown in Figures 3 and 4, respectively. It is interesting to observe that since the number of subcarriers was suf-

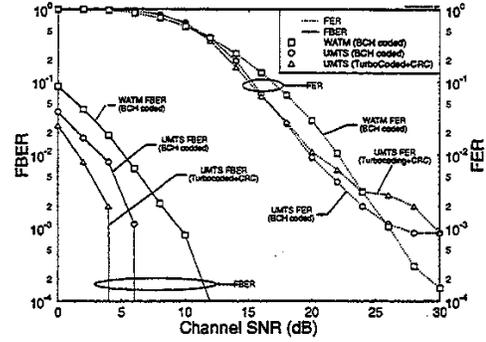


Figure 7: FER and FBER after channel decoding versus Channel SNR for the UMTS-type scheme using BCH codes or Turbo Coding plus CRC over the wideband channel characterised by the impulse response of Figure 3 and that of the WATM scheme over the channel of Figure 4

ficiently high in both systems for narrow-band subchannel conditions to prevail, the modem BER curves are fairly similar, irrespective of the different Doppler frequencies. Nevertheless, the slightly lower uncoded BER of the UMTS-type scheme manifested itself in a further improved FEC-decoded BER. Lastly, as expected, the similar-rate turbo codec outperformed the BCH codec in terms of BER.

Figure 7 portrays the transmission FER and the acknowledgement flag Feed-back Error Rate (FBER) performance of both systems. Despite the BER differences of the systems, their FER performances are fairly similar. This indicates that the UMTS-like scheme's lower average BER actually results in a similar FER, despite its lower in-burst BER, when a BCH codeword was overwhelmed by an excessive number of channel errors. However, the lowest in-burst BER of the turbo codec translated in a substantially reduced acknowledgement flag feedback error rate after MLD decoding. Since the FER of the turbo coded UMTS-like scheme in Figure 7 was not substantially lower than that of the BCH coded arrangement, the corresponding video PSNR performances are also quite similar, as evidenced by Figures 8 and 9. This is a consequence of the system's high error resilience. Hence in this system the added turbo coding complexity may not be justified. A similar video-rate WATM performance curve is also shown in the Figure.

6. CONCLUSIONS

In this contribution the expected video performance of a UMTS-type system was quantified and compared to that of a WATM system [9]. The high-efficiency H.263 video codec was employed to compress the QCIF video signal. The proposed system ensures robust video communications using both the WATM and the UMTS-type framework in a highly dispersive Rayleigh-fading environment even at a vehicular speed of 30mph, requiring channel SNRs in excess of only about 16dB for near-unimpaired video transmission. Despite the different propagation conditions the BER and FER modem performance of both systems was quite similar. Furthermore, due to the high error-resilience of the

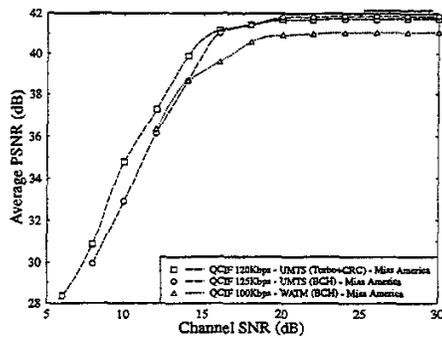


Figure 8: Video Quality in PSNR versus channel SNR for the QCIF "Miss America" video sequence at 30fps, using both the WATM system [9], and the UMTS-type System with Turbo coding and CRC or BCH coding over the COST 207 Bad Urban impulse response of Figure 3 and over that of Figure 4, respectively

video system the increased complexity of the turbo codec was not justified in video performance terms, although the acknowledgement flag FBER was significantly reduced.

7. ACKNOWLEDGEMENT

The financial support of Motorola ECID, Swindon, UK and that of the European Commission in the framework of the Median project is gratefully acknowledged. Sincere thanks are also due to the EPSRC, UK. The authors are indebted furthermore to Jason Woodard for his kind assistance in the field of turbo coding and to the Median and First Consortium partners for fruitful discussions and for their friendship.

8. REFERENCES

- [1] T. Ojanpera: Overview of research activities for third generation mobile communications; in S. G. Glisic, P.A. Leppanen (Ed.): *Wireless communications - TDMA versus CDMA*, Kluwer academic publishers, 1997, ISBN 0-7923-8005-3 pp 415-446
- [2] B. Engstroem, C. Oesterberg: A system for test of multiaccess methods based on OFDM, Proc. of VTC'94, Stockholm, Sweden, 1994, pp 1843-1847
- [3] W. Webb and L. Hanzo, *Modern Quadrature Amplitude Modulation: Principles and Applications for Wireless Communications*. IEEE Press-Pentech Press, 1994.
- [4] T. Ojanpera et al.: FRAMES multiple access technology, Proc. of ISSSTA'96, Vol.1, pp 334-338, Mainz, Germany, 1996
- [5] J. Borowski, S. Zeisberg, J. Huebner, K. Koora, E. Bogenfeld, B. Kull: Performance of the OFDM and comparable single carrier system in MEDIAN demonstrator 60 GHz channel, *ibid*, pp 653-658

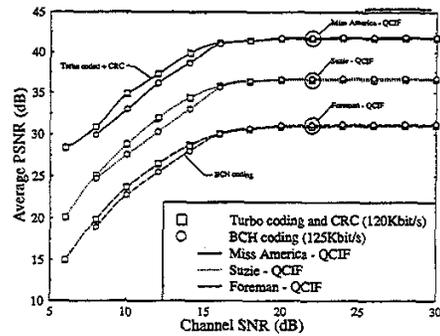


Figure 9: Video Quality in PSNR versus channel SNR for a variety of QCIF resolution video sequences at 30fps over the UMTS-type System with Turbo coding and CRC or BCH coding using the COST 207 Bad Urban impulse response of Figure 3 and that of Figure 4, respectively

- [6] K. Ngan, D. Chai, and A. Milin, "Very low bit rate video coding using H.263 coder," *IEEE Transaction On Circuits And Systems For Video Technology*, vol. 6, pp. 308-312, June 1996.
- [7] B. Girod, E. Steinbach, N. Faerber: "Performance of the H.263 Video Compression Standard" *Journal of VLSI Signal Processing: Systems for Signal, Image, and Video Technology. Special Issue on Recent Development in Video: Algorithms, Implementation and Applications*. Invited paper, to appear in 1997¹
- [8] P. Cherriman and L. Hanzo, "Programmable H.263-based wireless video transceivers for interference-limited environments." to appear in *IEEE Tr. on CSVT*, 1998²
- [9] P. Cherriman, T. Keller, L. Hanzo: Orthogonal Frequency Division Multiplex transmission of H.263 encoded video over highly frequency-selective wireless networks³, submitted to *IEEE Tr. on CSVT*, 1997
- [10] J. Streit, L. Hanzo: Vector-quantised low-rate cordless videophone systems, *IEEE Tr. on Vehicular Technology*, Vol. 42, No.2, May 1997, pp 340-357
- [11] K.H.H. Wong, L. Hanzo: Channel Coding, pp 347-489, Chapter 4 in R. Steele (Ed.) *Mobile Radio Communications*, IEEE Press-Pentech Press, London, 1992 ISBN 07 273-1406-8
- [12] C. Berrou, A. Glavieux, and P. Thitimajshima, "Near Shannon Limit Error-Correcting Coding and Decoding: Turbo-Codes", Proc. ICC 1993, pp. 1064-1070
- [13] L. Hanzo, P. Cherriman, J. Streit: *Modern Video Communications: Principles and applications for fixed and wireless channels*, IEEE Press, in preparation⁴
- [14] M. Failli: Digital land mobile radio communications COST 207, European Commission, 1989, EUR 12160 EN (1989) FS

¹<http://www-at.e-technik.uni-erlangen.de/girod/publications.ht>

²<http://www-mobile.ecs.soton.ac.uk>

³<http://www-mobile.ecs.soton.ac.uk/peter/robust-h263/robust.htm>

⁴Detailed contents: <http://www-mobile.ecs.soton.ac.uk>