LDPC and Turbo Coding Assisted Space-Time Block Coded OFDM for H.26L Compressed Wireless Video Telephony

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Abstract— **In this contribution we propose an LDPC assisted Space-Time Block Coded OFDM transceiver designed for wireless video telephony and characterise its performance when communicating over the UTRA wideband vehicular fading channels. Low Density Parity Check (LDPC) and turbo channel coding schemes are invoked. By concatenating a space-time block coded OFDM scheme with powerful channel codes, the performance of the system can be substantially enhanced. The LDPC codec outperformed the turbo codec in terms of both the achievable video and transmission frame error rate performance.**

I. INTRODUCTION

In wireless video telephony a low transmission frame error rate (FER) is required for maintaining a high video quality. However, owing to the scarcity of radio spectrum, a bandwidth-efficient implementation is required so that a low FER can be achieved despite maintaining a high transmission bit rate, which necessitates the employment of multi level modulation schemes. Orthogonal Frequency Division Multiplexing (OFDM) is an attractive technique that can be invoked for high-bit-rate data transmission, especially in a highly dispersive multipath-fading environment that inflicts inter-symbol interference (ISI) [1,2].

A considerable amount of research has been invested into the design and implementation of space-time block coded (STBC) techniques in the context of OFDM systems [3,4]. Specifically, STBC invokes antenna array aided spatial diversity and achieves significant diversity gains in wireless channels. For the sake of further improving the attainable performance, Forward-Error Correction (FEC) schemes such as Turbo Codes (TC) [3] and Reed-Solomon codes [3] may be invoked for protecting the OFDM subcarriers against frequency-selective fading in an OFDM environment.

In recent years, the family of Low Density Parity Check (LDPC) codes [5] has re-emerged as an attractive alternative to turbo coding [3]. LDPC codes were originally proposed by Gallager [5] in 1962. Owing to the codes' capability of approaching Shannon's performance limits, LDPC codes have been applied in conjunction with BPSK for transmission over both AWGN and frequency selective fading channels in conjunction with OFDM systems [6]. It has also been shown in [4] that LDPC-based space-time coded OFDM systems are capable of efficiently exploiting the achievable spatial diversity in wireless channels.

In this contribution, we studied the H.26L video standard combined with LDPC assisted space-time block coded OFDM using Alamouti's $\mathbf{G_2}$ space-time block code [7]. We investigated the performance when transmitting over frequency selective fading channels, in particular over the UTRA channel [8]. This contribution is structured as follows. The description of the video-system is given in Section II. This is followed by the overview of the channel model and system parameters in Section III. Our simulation results and discussions are provided in Section IV. Finally, we conclude our discourse in Section V.

II. VIDEO TRANSMISSION

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
Data Symbols	234			
K, uncoded information	240	480	720	1200
N, LDPC coded bits	480	720	960	1440
TC(2,1,4) interleaver length	240	480	720	1200
Coding Rate	1/2	2/3	3/4	5/6
Information Bits/Symbol	1	2	3	5
Unprotected bitrate (kbit/s)	24.0	48.0	72.0	120.0
Video packet CRC (bits)	16			
Feedback protection (bits)	9			
Video packet header (bits)	11	12	12	13
Video bits/packet	204	443	683	1162
Effective Video-rate (kbit/s)	20.4	44.3	68.3	116.2
Video framerate (Hz)	30			

TABLE I
OPERATIONAL-MODE SPECIFIC TRANSCEIVER PARAMETERS.

Video sequences having 176x144-pixel Quarter Common Intermediate Format (QCIF) resolution scanned at 30 frames/s and transmitted using space-time block coded OFDM are employed in our study. The OFDM modem can be configured as a 2, 3, 4 or 6 bit/symbol scheme. The proposed video transceiver is based on the H.26L video codec [9]. The associated codec parameters are summarised in Table I. The H.26L video codec employs variable-length compression techniques and therefore achieves a high compression ratio. However, as all entropy and variable-length coded

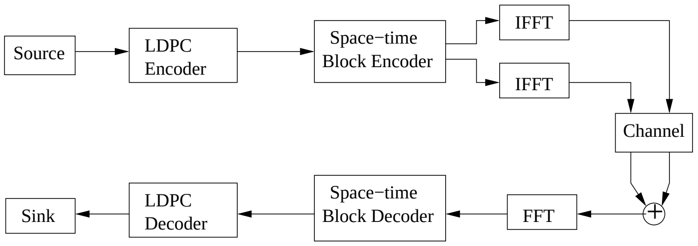


Fig. 1. System overview of one-receiver LDPC assisted $\mathbf{G}_2$ space-time block coded OFDM.

bit streams, its encoded bits are potentially sensitive to transmission errors.

In the first one of our prototype systems which we refer to as **System 1**, this error sensitivity has been counteracted by invoking a packetization and packet dropping technique [10], where we refrained from decoding the corrupted video packets in order to prevent error propagation through the reconstructed video frame buffer. Hence the corrupted video packets were dropped at both the transmitter and receiver and the video codec's reconstructed frame buffer was not updated, until the next error-free video packet replenished its contents.

When a packet is transmitted, the packetization algorithm receives feedback from the receiver concerning the success or failure of the packet concerned with the aid of a highly protected feedback channel, which is integrated into the reverse link. The use of these packet acknowledgement flags allows the video encoder and the remote decoder to keep synchronised, operating on the basis of identical reconstruction frame buffer contents without the need of packet retransmissions, which are wasteful in terms of bandwidth efficiency and transmission delay [10].

By contrast, in our second prototype system referred to as **System 2**, we omit the above-mentioned packet transmission feedback from the system. To elaborate a little further, when using the packet transmission feedback, the receiver invokes one of the three following types of feedback messages: (1) Packet received without error. (2) Packet received with error, retransmission request. (3) Packet received with error, packet dropping request. In the receiver of System 2, which uses no transmission feedback, the entire video packet is dropped, when it was corrupted and no retransmission is required in this case. In case of packet corruption, both System 1 and 2 conceals the packet loss by replacing the affected area of the picture with the corresponding area from the previous video frame. However, owing to the lack of a feedback flag, the encoder of System 2 remains unaware of receiving a corrupted packet and hence cannot leave the corresponding video frame area un-updated.

III. CHANNEL MODEL AND SYSTEM PARAMETERS

The architecture of our system is shown in Figure 1. At the transmitter, the video encoder generates the video information data bits. The information bits are then encoded by the LDPC encoder. It has been shown in [11] that in the investigated scenario the LDPC codec performed better than turbo convolutional codes in terms of the achievable Frame Error Rate (FER). We invoked an (N, K) LDPC code defined by the $(M \times N)$-dimensional parity-check matrix [5], where $K = (N - M)$ is the uncoded-information block length. LDPC codes belong to the family of linear block codes. These codes are defined as codes using a sparse parity-check matrix having the same number of logical 1s per column (column weight, k) and the same number of logical 1s per row (row weight, j), where both of these numbers are small compared to the LDPC block length N. In our simulations we chose k and j values of 3. The code rate, R, of the LDPC codes is given by $R = K/N$. The appropriate values of K and M can then be calculated for the different values of N and R.

Parameter	Value
OFDM subcarriers	256 (16 virtuals)
Space-time code	$\mathbf{G}_2$
Channel coding	LDPC
Column weight, j	3
Maximum iterations	25
Channel type	UMTS Vehicular Channel A
Number of paths	6
Carrier frequency	1.9 GHz
Vehicular speed	30 mph
Normalized Doppler	2.21×10^{-5}

TABLE II

COMMON TRANCEIVER AND CHANNEL PARAMETERS.

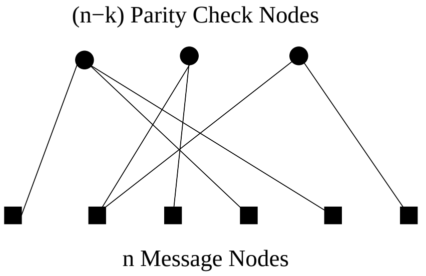


Fig. 2. Factor Graph representation of the parity-check matrix.

An example of the parity check matrix is given by:

$$\mathbf{C} = \begin{array}{c} \longleftarrow \quad N \quad \longrightarrow \\ \left[\begin{array}{cccccccccc} 0 & 1 & 1 & 0 & 0 & 0 & 1 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 & 1 & 1 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 1 & 0 & 1 & 1 & 0 \\ 0 & 1 & 0 & 1 & 0 & 0 & 1 & 0 & 0 & 1 \\ 1 & 0 & 1 & 0 & 1 & 0 & 0 & 0 & 1 & 0 \end{array}\right] \end{array} \begin{array}{c} \uparrow \\ N-K \\ \downarrow \end{array} \tag{1}$$

LDPC codes can be represented by a Factor Graph that contains two types of nodes: the "bit nodes" and the "check nodes". Each bit node corresponds to a column of a parity-check matrix, which also corresponds to a bit in the codeword. Each check node corresponds to a row of a parity-check matrix, which represents a parity-check equation. An edge between a bit node and a check node exists if and only if the bit participates in the parity-check equation represented by the check node, i.e. by a non-zero entry in the parity-check matrix. Figure 2 shows an example of a Factor Graph.

The output bits of the LDPC channel encoders are then passed to the space-time block encoder of Figure 1. In our system, we employed Alamouti's $\mathbf{G_2}$ space-time block code since it was shown in [3] that from the specific set of schemes investigated, the best performance was achieved by concatenating the space-time block code $\mathbf{G_2}$ with channel codes. The $\mathbf{G_2}$ space-time block code is associated with a twin-transmitter-based scheme, whose generator matrix is defined as follows:

$$\mathbf{G_2} = \begin{pmatrix} x_1 & x_2 \\ -\bar{x}_2 & \bar{x}_1 \end{pmatrix}. \qquad (2)$$

The output of the space-time encoder is then OFDM modulated with the aid of the Inverse Fast Fourier Transform (IFFT) blocks of Figure 1 and transmitted by the corresponding antenna. The number of transmit antennas is fixed to two, while the number of receive antennas constituted a design parameter. We used an OFDM system having 256 subcarriers. However, since only 240 data symbols are being transmitted, the remaining 16 subcarriers were used as virtual subcarriers. Virtual subcarriers are usually used for accommodating a frequency-domain raised-cosine Nyquist-filtering based roll-off of the OFDM signal and to avoid a direct current (DC) offset in the demodulation process. The utilization of virtual subcarriers appears in most of wireless LAN standards, such as, IEEE 802.11a [2], and in the High Performance Local Area Network type 2 (HiperLAN/2) [2].

At the receiver, the signal of each receive antenna is OFDM demodulated. Figure 1 shows the example of a one-receiver based system. For the two-receiver system two FFT blocks are required at the receiver, thus increasing its complexity. The demodulated signals of the receiver antennas are then fed to the space-time block decoder of Figure 1. The space-time decoders apply the Logarithmic Maximum A-Posteriori (Log-MAP) decoding algorithm [3] for providing soft outputs for the channel decoders. The LDPC code can be decoded by the so-called sum-product algorithm [12] or by belief propogation [13]. The decoded bits are then fed to the video decoder.

For our simulations, we used the multi-path channel model characterized by the UTRA vehicular channel A. The corresponding channel impulse response is shown in [8], where each path is faded independently according to the Rayleigh distribution. Table II shows the corresponding tranceiver parameters and channel parameters employed.

IV. Simulation Results And Discussions

In this section, we provide our simulation results for the modulation schemes specified in Table I using the space-time block coded OFDM modem concatenated with LDPC coding, when transmitting over the UTRA channel detailed in Table II. We will first characterise the achievable FER versus channel SNR performance expressed in dB, followed by the video quality results.

A. FER using fix modulation schemes

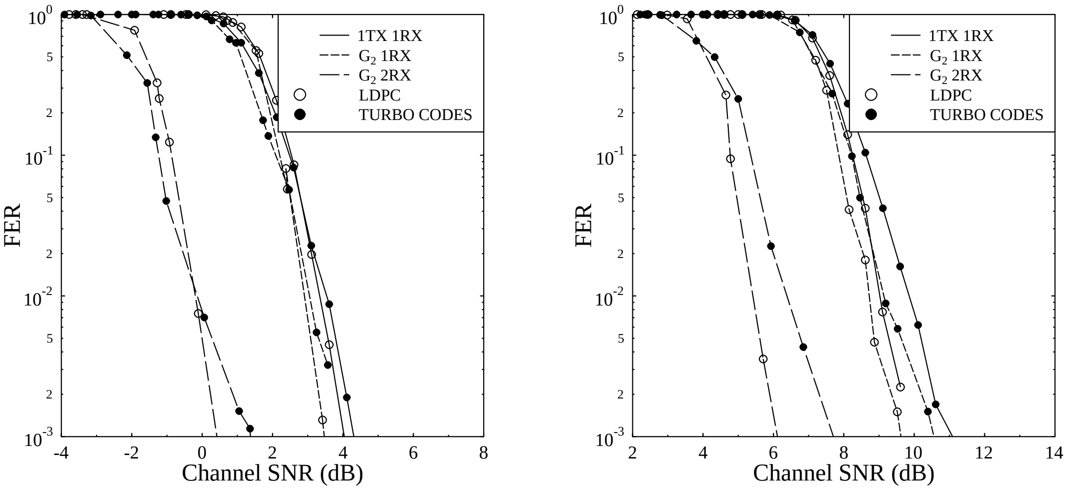
Initial simulations were performed using the transceiver configured in the four fixed modulation modes of Table I. Figure 3 portrays the achievable FER for each of the modulation modes employed versus the channel SNR.

We can see from Figure 3 that the performace of the system improved, although only slightly, when we employed the $\mathbf{G_2}$ space-time block code using one receiver antenna. The reason for this modest improvement was that when using two transmit antennas, the power of the individual antennas has to be halved for the sake of fair comparison. On the other hand, the attainable improvement increased significantly, when two receiver antennas were used. This is because, the employment of two receiver antennas allows the space-time block codes and the channel decoder to decode the incoming frames more reliably, thus significantly reducing the FER even at a low SNR. However, this improvement comes at the expense of an increased receiver complexity, since twice as many FFT blocks will be required.

As we reported in [11], it is shown in Figure 3 that LDPC codes may perform better than turbo convolutional codes (TC) in terms of the achievable FER, especially at high coding rates. In the investigated scenario the ratio of the estimated complexity of the LDPC codes of Table I to the TC(2,1,4) code's complexity was $1125/2576 \approx 0.44$, which was estimated for 25 LDPC iterations and 8 TC iterations. In other words, the LDPC codec's complexity is about half of that of the TC(2,1,4) code. For example, in Figure 3(d), when using the 5/6 rate-coded 64-QAM, LDPC coding has a 2.5, 4.5 and 3.5 dB better SNR than TC at a FER of 10^{-3} in the STBC transceiver using two receiver antennas, one receiver antenna and no STBC, respectively. The differences are smaller in the 1/2 rate-coded 4-QAM situation characterized in Figure 3(a), where LDPC coding performs better than TC by about 1, 0.5 and 0.5 dB at a FER of 10^{-3} in the context of the STBC system using two receiver antennas, one receiver antenna and no STBC, respectively. Therefore, the employment of LDPC is more beneficial in video telephony, where the video codec is very sensitive to the transmission errors experienced in a frame.

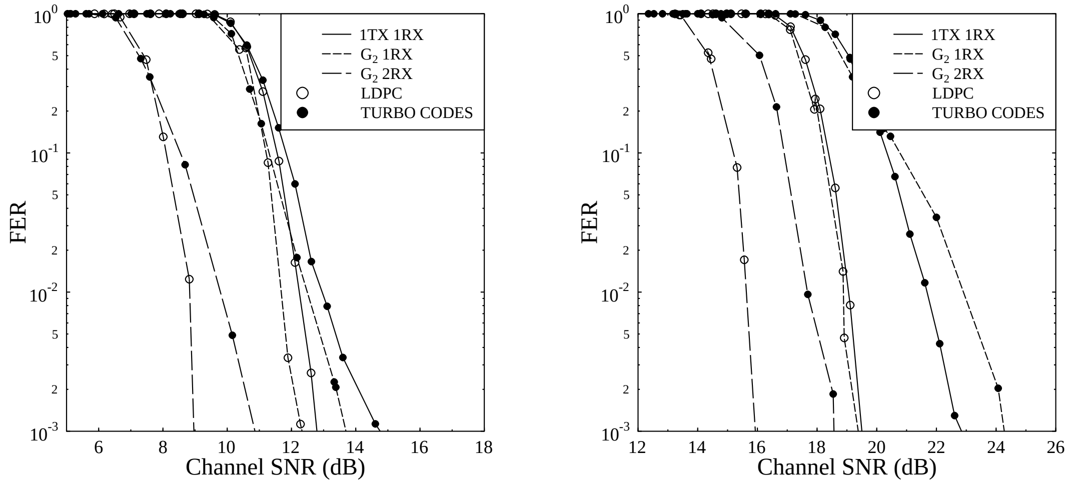
B. Video performance

The various transmission scenarios were also studied in terms of their video PSNR performance using the LDPC assisted $\mathbf{G_2}$ space-time block coded OFDM system assisted by one and two receiver antennas for transmission over the UTRA channel. Experiments using one transmitter and one receiver antenna were also conducted for the sake of comparison. Figure 4 shows the achievable video quality expressed in terms of the PSNR versus the channel SNR for each of the modulation modes of the system. As expected, the higher throughput bitrate of the 64QAM mode provides an inherently better video quality than that of the lower-throughput but more robust video modes. However, as the channel quality degrades, the attainable video quality of the 64QAM mode degrades rapidly. In our previous work [10], it has found that in order to ensure a tolerable degradation of the video quality as the channel SNR reduced, it was beneficial to switch to a more robust modulation mode, when the FER exceeded 5%. Although this inherently reduced the video bitrate and the associated video PSNR, this was less objectionable in subjective video quality terms, than a FER in excess of 5% would have been.



(a) 1/2 Coded 4-QAM

(b) 2/3 Coded 8-PSK



(c) 3/4 Coded 16-QAM

(d) 5/6 Coded 64-QAM

Fig. 3. FER versus channel SNR performance for (a) 1/2-rate coded 4-QAM, (b) 2/3-rate coded 8-PSK, (c) 3/4-rate coded 16-QAM, and (d) 5/6-rate coded 64-QAM using the LDPC and TC assisted $\mathbf{G_2}$ space-time block coded OFDM system employing 1 and 2 receiver antennas for transmission over the UTRA channel. A one-transmitter and one-receiver antenna aided benchmarker system is also shown for comparison.

As discussed in Section IV-A, the system using LDPC codes performs better than the one that employs TC, hence we concentrate our attention on the LDPC coded video scenario. Three transmission schemes have been characterised in Figure 4, which are the system using one transmitter and one receiver, one transmitter as well as two receivers, and two transmitters as well as two receivers. It can be seen from Figure 4 that the PSNR video performance curves are similar for the 1TX, 1RX and for the $\mathbf{G_2}$, 1RX transmission systems, but both of them are outperformed by the two-transmitter and two-receiver system.

For the sake of comparison, Figures 5 and 6 show the video performance in terms of both PSNR as well as FER versus channel SNR for the transmission schemes using LDPC assisted $\mathbf{G_2}$ space-time block coded OFDM in conjunction with one and two receiver antennas, respectively. The corresponding PSNR and FER results of the video transmission Systems 1 and 2 operating with and without transmission feedback, respectively are also depicted in both figures. As seen from Figures 5 and 6, Systems 1 and 2 have a similar performance. For each of the modulation modes, System 1, which invokes transmission feedback has a marginally lower video quality, when the FER is relatively low, i.e. the SNR is high. However, it has a slightly better video quality than that of System 2, which was using no transmission feedback, when the FER is high.

Observe furthermore that the video quality degradation of System 1 is more visible in the lower throughput modulation mode of 4QAM, than in the 64QAM mode. As shown in Table I, in our experiments we use 9 bits for the repedition coded transmission feedback. By contrast, in System 2 using no transmission feedback, an extra 9 bits have been added to the video bitrate budget. In the case of 4QAM there are 240 bits per packet, and 9 bits constitute a relatively higher portion of the total payload of a packet in the 4QAM mode, than in 64QAM, which transmits 1200 bits per packet.

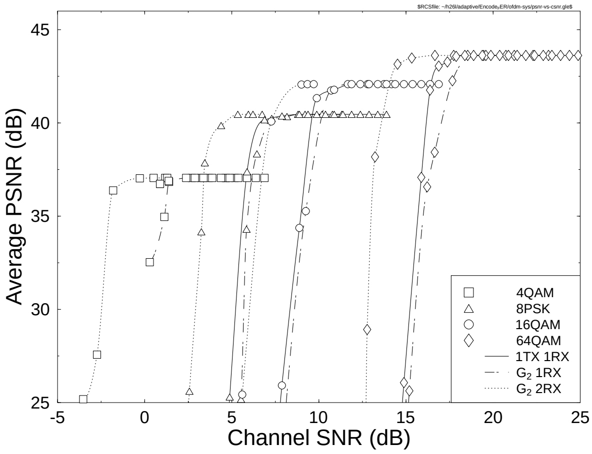


Fig. 4. Average PSNR versus channel SNR for the four fixed OFDM modes using the LDPC assisted $\mathbf{G_2}$ space-time block coded OFDM System 1 assisted by one and two receiver antennas for transmission over the UTRA channel. The performance of a one transmitter and one receiver antenna aided system is also shown for comparison. The Miss America QCIF video sequence scanned at 30 frame/s was used in our experiments.

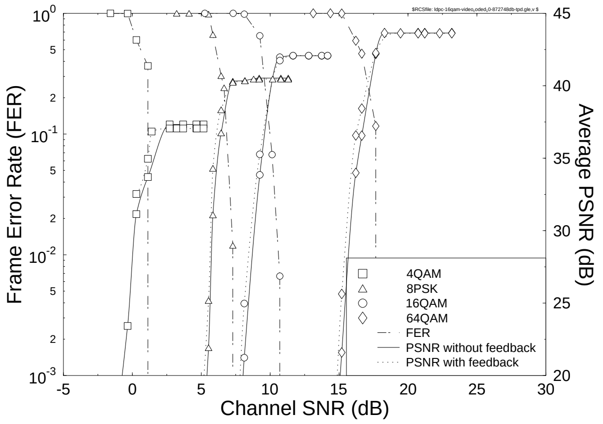


Fig. 5. Average PSNR and FER versus channel SNR for the four fixed modulation modes using the LDPC assisted $\mathbf{G_2}$ space-time block coded OFDM system relying on one transmitter and two receiver antennas for transmission over the UTRA channel. The QCIF Miss America video sequence scanned at 30 frame/s was used in our experiments.

V. CONCLUSION

An LDPC and turbo coding assisted $\mathbf{G_2}$ space-time block coded OFDM video transceiver was proposed. In the 4QAM mode a reasonable video quality can be achieved at low SNRs. By contrast , the video quality can be substantially increased in the 64 QAM mode, when the channel SNR is sufficiently high. No significant performance difference was observed between System 1 and 2, indicating that the employment of transmission feedback is not necessitated.

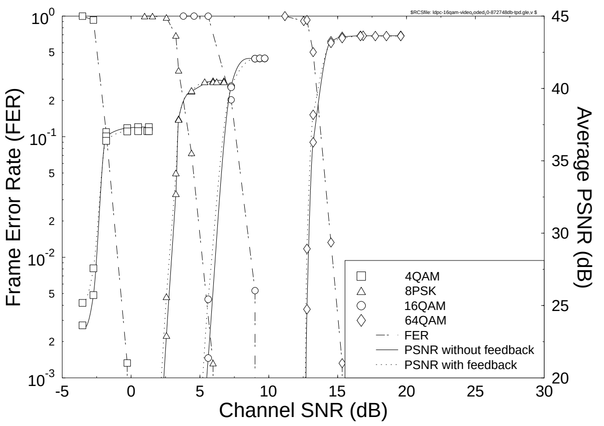


Fig. 6. Average PSNR and FER versus channel SNR for the four fixed modulation modes using the LDPC assisted $\mathbf{G_2}$ space-time block coded OFDM system relying on two transmitters and two receivers antennas for transmission over the UTRA channel. The QCIF Miss America video sequence scanned at 30 frame/s was used in our experiments.

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