Joint TTCM-VLC-Aided SDMA for Two-Way Relaying Aided Wireless Video Transmission

Abdulah Jeza Aljohani, Soon Xin Ng, Robert G. Maunder and Lajos Hanzo
School of Electronics and Computer Science, University of Southampton, SO17 1BJ, United Kingdom.
Tel: +44-23-8059 3125, Fax: +44-23-8059 4508
Email: {ajra1c09,sxn,rm,lh}@ecs.soton.ac.uk, http://www-mobile.ecs.soton.ac.uk

***Abstract*— An iterative Joint Source and Channel Coded Modulation (JSCCM) scheme is proposed for robust video transmission over two-way relaying channels. The system advocated was designed for improving the throughput, reliability and coverage area compared to that of conventional one-way relaying schemes. We consider a two-user communication system, where the users exchange their information with the aid of a twin-antenna Relay Node (RN). For each user the proposed lossless video scheme is comprised of a Variable Length Code (VLC) encoder and two Turbo Trellis Coded Modulation (TTCM) encoders one at the Source Node (SN) and one at the RN. The spatio-temporal redundancy of the video sequence is exploited for reducing the iterative decoding complexity. The decoding convergence behaviour of the decoder as well as the power sharing ratio between the two SNs and the RN are characterized with the aid of EXtrinsic Information Transfer (EXIT) charts. Our proposed scheme exhibits an SNR gain of 9 dB compared to the non-cooperative scheme, when communicating over Rayleigh fading channels.**

***Index Terms*— Two-way relaying, Turbo Trellis Coded Modulation, Joint Video Coding, Variable Length Codes.**

I. Introduction

Recently, two-way or bi-directional relay systems have drawn increasing research attention, since they overcome the potential spectral efficiency loss of one-way relaying [1]. Both systems have two user terminals that want to exchange their information with the aid of a Relay Node (RN). In the conventional one-way relaying schemes four time slots are required to accomplish full information exchange. By contrast, two-way relaying requires only two time slots for duplex information exchange. A significant bit error ratio (BER) improvement was recorded in [2] where Turbo Trellis Coded Modulation (TTCM) of [3] aided bi-directional relaying scheme based on power allocating technique was investigated.

Joint video Source and Channel Coding (JSCC) techniques have been designed for limited-delay, limited-complexity video systems communicating over wireless channels because in this practical scenario Shannon's source and channel coding separation theorem [4] has a limited validity. This is due to many reasons. Firstly, the channel-induced error statistics are not random as in AWGN channels, but bursty. Secondly, owing to the complexity-and delay-limitations, the video coded sequence usually exhibits residual correlation [5], which cannot be exploited by a separate source-channel coding scheme. The JSCC schemes are typically constituted of serially-concatenated iterative decoders, aiming for exploiting the unintentional residual redundancy of the video source and the intentionally imposed redundancy of the channel codes. More specifically, the inner and outer iterative decoding stages are composed respectively from the channel-and source-decoder, where extrinsic information is iteratively exchanged between both decoders.

Lossless Variable Length Codes (VLCs) constitute a family of low-complexity source compression schemes. To exploit the residual redundancy of VLCs, several JSCC techniques have been proposed. More specifically, the JSCC scheme of [6] employs a bit-based trellis structure in its decoder based on a reversible VLC [7] which is concatenated with a convolutional inner code. Recently, Joint Source/Channel Coding and Modulation (JSCM) schemes were studied in [8], which were further extended to a one-way cooperative scenario in [9].

Against this background, in this treatise we propose an energy-efficient video codec, rather than the still-image-based scheme of [10] that can exploit the spectral efficiency of the two-way relaying concept as well as the both residual redundancies of the video source and/or the channel encoder. Symbol-based EXtrinsic Information Transfer (EXIT) chart was invoked to optimize both the transmitting power during each time slots as well as the computational complexity of the decoder components as it will be described in Section III. Furthermore, a low-complexity source encoder [10] based on exploiting the correlations amongst the adjacent and prior video pixels is invoked to further reduce the VLC decoding complexity considerably.

The rest of the paper is organized as follows. The system model is described in Section II. Furthermore, the analysis of the proposed scheme is provided in Section III and its performance is evaluated in Section IV. Finally, our conclusions are offered in Section V.

II. System Description

A. System Model

In the following, we consider the bi-directional wireless relay-aided system shown in Fig. 1, where Mobile Stations $(\text{MS})_a$ and MS_b exchange their information with aid of a RN. The two users may also be treated as a single two-transmitter distributed $virtual$ SN, while, we consider a two-antenna aided RN. Assuming a free-space path-loss model,

The financial support of the Saudi Ministry of Higher Education and that of the European Union's Seventh Framework Programme (FP7/2007-2013) under the auspices of the CONCERTO project (grant agreement no 288502) of the RC-UK's India-UK Advanced Technology Centre (IU-ATC) as well as of the European Reasearch Council's Advanced Fellow grant is greatly appreciated.

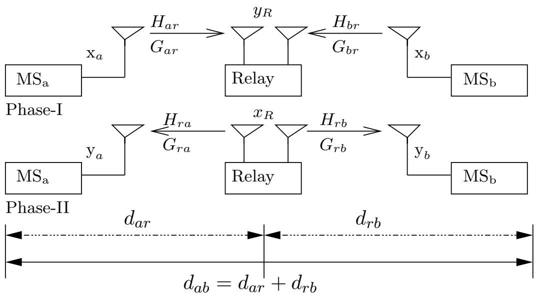

Fig. 1: The schematic of a two-hop relay-aided system, where d_{ab} is the geographical distance between node MS_a and node MS_b.

the corresponding Reduced-Distance-Related Path-Loss Reduction (RDRPLR) factor experienced by both the Source-Relay (SR) and Relay-Destination (RD) links with respect to the Source-Destination (SD) link as a benefit of its reduced distance and path-loss, can be calculated, respectively, as [10], [11]:

$$G_{ar} = \left(\frac{d_{ab}}{d_{ar}}\right)^2 \;;\; G_{rb} = \left(\frac{d_{ab}}{d_{rb}}\right)^2 \;, \tag{1}$$

It is convenient for our discussions to define the term, transmit SNR,[1] as the ratio of the power transmitted from node MS_a to the noise power experienced at the receiver of node MS_b as [11]:

$$\gamma_T = \frac{P_{t,a}}{N_0}. \tag{2}$$

Thus, γ_T is related to the receive SNR, γ_R, as:

$$\gamma_R \;=\; \gamma_T \; G_{ab}, \tag{3}$$

which can be expressed in dB as:

$$\Gamma_R \;=\; \Gamma_T + 10\log_{10}(G_{ab}) \text{ [dB]} \;, \tag{4}$$

where we have $\Gamma_R = 10\log_{10}(\gamma_R)$ and $\Gamma_T = 10\log_{10}(\gamma_T)$.

The Phase-I transmission may be viewed Space-Division Multiple Access (SDMA) system supporting $L = 2$ MSs, each equipped with a single antenna and a RN receiver equipped with $P = 2$ receive antennas. Hence, the channel can be characterized by $(P \times L)$-dimensional channel matrix $\mathbf{H}$, where the received signal may be written as:

$$\mathbf{y} = \mathbf{H}\mathbf{x} + \mathbf{n}, \tag{5}$$

where the transmitted symbol, $\mathbf{x}$ is an $(L \times 1)$-dimensional vector $\mathbf{x} = [x_0, x_1, \cdots, x_{L-1}]^T$, while the received signal $\mathbf{y} = [y_0, y_1, \cdots, y_{P-1}]^T$ is an $(P \times 1$)-dimensional vector and $\mathbf{n}$ represents the complex-valued AWGN having a variance of $N_0/2$ per dimension. Therefore, the channel matrix of the Phase-I link of our system may be expressed after we incorporated the RDRPLR [12], [11] as:

$$H = \begin{bmatrix} \sqrt{G_{ar_1}}\sqrt{P_{T,a}}h_{ar_1} & \sqrt{G_{br_1}}\sqrt{P_{T,b}}h_{br_1} \\ \sqrt{G_{ar_2}}\sqrt{P_{T,a}}h_{ar_2} & \sqrt{G_{br_2}}\sqrt{P_{T,b}}h_{br_2} \end{bmatrix}, \tag{6}$$

where the subscript r_i denotes the ith receive antenna of the RN, while $P_{T,a}$ ($P_{T,b}$) signifies the power transmitted from MS_a (MS_b), while h_{ar_1} (h_{br_1}) represents the CIR coefficient between MS_a (MS_b) and the first receive antenna of the RN.

The RN invokes three types of MUDs, namely the optimum but relatively complex Maximum Likelihood (ML) MUD, the Minimum Mean-Square Error-based Interference Cancellation (MMSE-IC) scheme [2] and the sub-optimum Zero Forcing (ZF) MUD. However, during the second time slot, Phase-II, the scheme may be viewed as an SDMA system relying on two transmit antennas and a receive antenna, as illustrated in Fig 1. Hence, we only consider the ML MUD in the challenging rank-deficient Phase-II link, because the MMSE and ZF MUDs require that the number of receive antennas should be at least equal to the number of transmit antennas [2], [13]. We assume that the receiver knows the channel state information perfectly.

B. Videophone Structure

The block diagram of the proposed TTCM-assisted VLC (TTCM-VLC) videophone arrangement implemented in a two-way relay-aided system[2] is shown in Fig. 2. During the first phase, the system may be viewed as an up-link (UL) transmission scheme supporting two MSs, where each user aims for transmitting to the RN simultaneously. Each MS employs a serially-concatenated trellis-based reversible VLC and a TTCM scheme. More specifically, we have opted for TTCM, since the TTCM-VLC arrangement was found to be the best choice from a range of other schemes in [14]. We consider a (176 × 144)-pixel Quarter Common Intermediate Format (QCIF) YUV video clip [5], where each frame is encoded row-by-row from the top-left pixel to the bottom-right pixel.

Prior to the VLC encoder, a low-complexity technique [10] was invoked for video compression through representing the video's pixels with less codewords. Consider the simplest source mapping, where each video pixel is represented by 8-bits. Then the alphabet size of the source will be $2^8 = 256$ symbols. However, this would lead to a complex VLC trellis structure having 965 states, which is associated with an excessive decoding complexity. Let us assume for a moment that the encoder is processing the pixel $\mathbf{u}^i_{x,y}$, which is represented by the shaded small box in Frame i of Fig. 2, where the subscripts x and y represent the height and width of each frame, respectively. Then, the current pixel $\mathbf{u}^i_{x,y}$ will be predicted by averaging the adjacent left and the adjacent top pixels as well as the pixel in previous frame in the same position with reference to the current pixel as:

$$\mathbf{u}^P_1 = \frac{1}{3}\left[\mathbf{u}^{i-1}_{x,y} + \mathbf{u}^i_{x-1,y} + \mathbf{u}^i_{x,y-1}\right]. \tag{7}$$

As shown in Fig. 2, the difference $\mathcal{D}$ between the current and the predicted pixels will then be fed into a lossless quantizer Q_L [10, fig. 10] for generating the 'pixel-difference' symbols $\mathbf{u}_1$ as follows:

if $|\mathcal{D}| \geq \frac{(V-1)}{2}$; **then**

if $\mathcal{D} \geq 0$; **then**

[1]However, the concept of transmit SNR [11] is unconventional, as it relates quantities to each other at two physically different locations, namely the transmit power to the noise power at the receiver

[2]Note that the second user has similar SN and DN arrangement, hence we only draw them for the first user as shown in Fig. 2

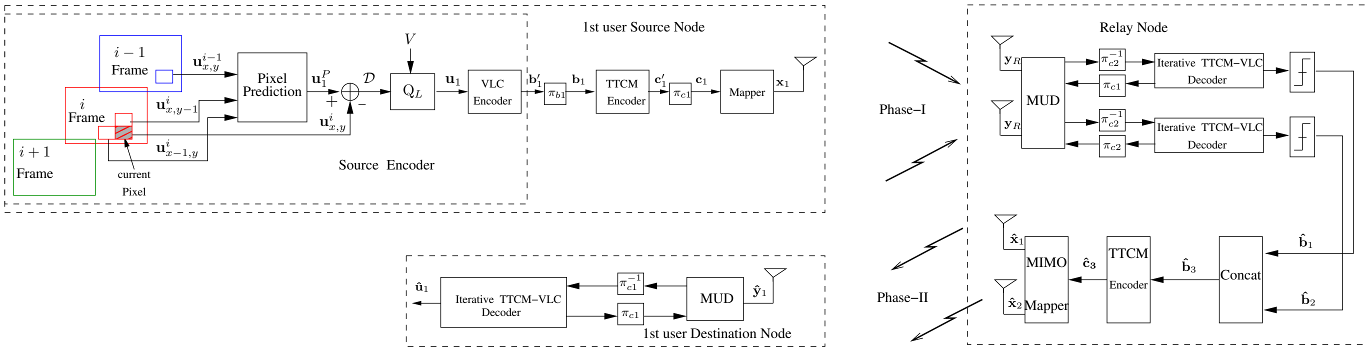

Fig. 2: The schematic of the joint TTCM-VLC-aided SDMA based two-way relay system, where "Q_L" is a loss less quantizer [10, fig. 10]. Note that, 2nd user has similar SN and DN arrangement.

$\mathbf{u}_i \leftarrow (1)$
$\mathcal{D} = \mathcal{D} + (V-2);$
else
$\mathbf{u}_i \leftarrow (V)$
$\mathcal{D} = \mathcal{D} - (V+2);$
end if
else
$\mathbf{u}_i \leftarrow \left(\mathcal{D} + \frac{(V+1)}{2}\right).$
end if

The size of the alphabet is controlled by the variable V and here we have opted for $V = 9$, since this choice strikes a good trade-off between the bit-rate and the VLC complexity. The VLC decoding complexity is reduced remarkably as the number of legitimate symbols is decreased from $2^8 = 256$ to $V = 9$. As a consequence, the number of VLC trellis states is reduced from 965 to 12.

Similar to [14], each MS employs the reversible VLC [3] of [7]. A $V = 9$-entry codebook was invoked and the occurrence probability of each symbol of the entries was evaluated. The associated entropy is $L_s = 2.95$ bits/symbol and the calculated average codeword length is $L_{vlc} = 3.09$ bits/VLC symbol, giving a VLC code rate of $R_{vlc} = L_s/L_{vlc} = 0.95$ bits/symbol. Then, the VLC-coded and interleaved bit sequences $\mathbf{b}_1$ of the first user and $\mathbf{b}_2$ of the second user are encoded by the two $R_{TTCM} = 2/3$-TTCM encoders, one for each user. Memory-three TTCM codes having an octally represented generator polynomial of $[11 \quad 2 \quad 4]_8$ and M_{TTCM} =8PSK modulation are employed. The estimated information sequences $\widehat{\mathbf{b}}_1$ and $\widehat{\mathbf{b}}_2$ of both MSs are obtained by exchanging *extrinsic* information between the MUD and the iterative joint TTCM-VLC decoders, as shown in the upper right part of Fig. 2. The scheme's operation during Phase-II is shown in the lower part of Fig. 2, where the RN concatenates the two decoded N-bit sequences into a $2N$-bit sequence, yielding $\widehat{\mathbf{b}}_3 = [\widehat{\mathbf{b}}_1 \ \ \widehat{\mathbf{b}}_2]$. Then, the combined sequence $\widehat{\mathbf{b}}_3$ is encoded by a TTCM encoder before it is broadcast from the RN back to the two MSs. The overall throughput of this two-way relay scheme is given by $\eta = R_{vlc} \times R_{TTCM} \times \log_2(M_{TTCM}) = 1.9$ bit/s/HZ. Note that the SNR per bit is defined as $E_b/N_0[dB] = \text{SNR}[dB] - 10\log_{10}(\eta)$.

[3]Our design is applicable to any VLCs. However, the trellis based reversible VLCs are particularly suitable for iterative detection, because they have a minimum free distance of 2, as detailed in [14]. This allows the iterative detector to approach a vanishingly low BER.

III. Design and Analysis

First, we have to find the minimum required received SNRs at both the RN and DNs in order to minimise the overall transmit power, while ensuring that both links achieve the required target reliability. These receive SNRs can be found either form the BER curves or from the EXIT chart, as detailed in [9].

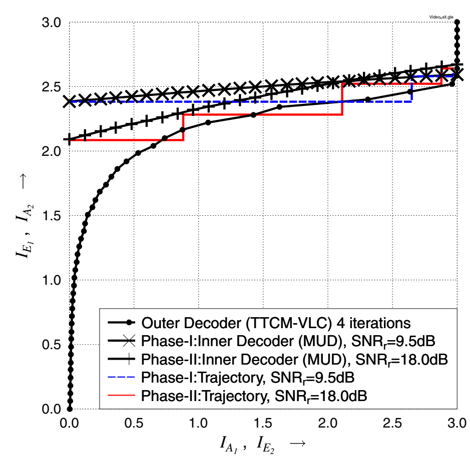

Fig. 3: The EXIT curves of the TTCM-VLC-aided SDMA per-receiver antenna performance scheme for the "*Akiyo*" video sequence and for a non-cooperative scenario.

In our analysis and simulations we use the 45 frames/s grey-scale QCIF "*Akiyo*" video test sequence. Our simulation parameters are summarised in Table I. Moreover, the number of inner iterations exchanging *extrinsic* information the between the TTCM and VLC decoders is always set to four, unless otherwise specified. The non-binary EXIT chart technique of [16] is used for visualising the input/output characteristics of the symbol-based TTCM-VLC-aided SDMA decoders in terms of their average mutual information transfer. EXIT charts are capable of providing accurate predictions of the required SNR for achieving an infinitesimally low BER when iterative decoding between two constituent decoders is invoked. The EXIT chart recorded for the classic non-cooperative scenarios for both the SR and RD links is displayed in Fig. 3, i.e. when there is no RDRPLR, i.e. $G_{ar} = G_{br} = G_{ra} = 1$. Note that, the outer curve for both phases are the same since the outer decoder is SNR independent.

TTCM-VLC Parameters	
VLC type	RVLC
CM type	TTCM
Modulation level	8-PSK
symbol per frame	2048
Decoding algorithm	Approximated Log-MAP [15]
Source to Relay transmission:Phase-I	
Channel	Rayleigh Fading 2×2 MIMO
MUD Type	ML,MMSE-IC and ZF
G_{ar}	4 (6.02dB)
Relay to Destination transmission:Phase-II	
Channel	Rayleigh Fading 2×1 MIMO
MUD Type	ML
G_{rb}	4 (6.02dB)

TABLE I: SYSTEM PARAMETERS.

As shown in Fig. 3, an open EXIT tunnel leading to the right-hand axis is achieved for the Phase-I transmission at $\text{SNR}_r = 9.5$ dB indicating decoding convergence at the RN after three decoding iterations between the TTCM-VLC decoder and the MUD during Phase-I transmission. The "TTCM-VLC-ML:Phase-I" label in Fig. 4 represents the BER performance of TTCM-VLC-aided SDMA for the Phase-I link employing four decoding iterations, which verifies the EXIT chart prediction of Fig. 3. Phase-II link, however, requires a $\text{SNR}_r = 18.5$ dB with four decoding iteration to attain a an infinitesimally low BER as shown in Fig. 3. It can be seen from the EXIT chart that there is a significant difference in terms of the $\text{SNR}_r = 18.5 - 9.5 = 9$ dB required for attaining a low BER between the Phase-I and Phase-II transmissions. Thus, the transmitted power has to be beneficially shared between the SN and the RN through using the power sharing technique employed in [10] [2].

Without any loss of generality, we can denote the transmit SNRs of MS_a, MS_b and RN as $\gamma_{T,a}$, $\gamma_{T,b}$ and $\gamma_{T,r}$. In our two-way relaying scheme, the RN location is at the half-way position in the middle of the two user nodes. Hence, the transmitted SNRs of both the MS_a and MS_b nodes are equal, i.e. we have $\gamma_{T,s} = \gamma_{T,a} = \gamma_{T,b}$. The average transmit SNR of the two phases is given by [10] [2]:

$$\begin{aligned} \overline{\gamma}_T &= \frac{\gamma_{T,s} + \gamma_{T,r}}{2}, \\ &= \frac{10^{\frac{\Gamma_{T,s}}{10}} + 10^{\frac{\Gamma_{T,r}}{10}}}{2}, \end{aligned} \quad (8)$$

where $\Gamma_{T,s} = 10\log_{10}(\gamma_{T,s})$ and $\Gamma_{T,r} = 10\log_{10}(\gamma_{T,r})$. The power sharing mechanism aims to distribute the transmit power between the SN and the RN, while maintaining a vanishingly low BER of approximately 1×10^{-6} at the lowest possible transmit SNR. First, the minimum receive SNR required for the SR link for achieving a BER of 1×10^{-6}, namely $\Gamma_{R,s} = 10\log(\gamma_{R,s})$, and that of the RD link, $\Gamma_{R,r} = 10\log(\gamma_{R,r})$ are obtained. The difference between these receive SNRs can be expressed as:

$$\begin{aligned} \Gamma_{R,\Delta} &= \Gamma_{R,r} - \Gamma_{R,s} \\ &= (\Gamma_{T,r} + 10\log_{10}(G_{rb})) - (\Gamma_{T,s} + 10\log_{10}(G_{ar})), \\ &= \Gamma_{T,r} - \Gamma_{T,s} \text{ [dB]}, \end{aligned} \quad (9)$$

where $\Gamma_{R,\Delta} = 10\log_{10}(\gamma_{R,\Delta})$. Hence, the transmit SNR difference in non-logarithmic domain is given by:

$$\gamma_{R,\Delta} = \frac{\gamma_{T,r}}{\gamma_{T,s}}. \quad (10)$$

Using Eq. (8) and Eq. (10), the new transmit SNR of the SN may be formulated as:

$$\gamma_{T,s} = \frac{2\overline{\gamma}_T}{1 + \gamma_{R,\Delta}}. \quad (11)$$

Upon invoking our power-sharing method the transmit SNR of the RN is given by:

$$\gamma_{T,r} = \frac{2\overline{\gamma}_T \gamma_{R,\Delta}}{1 + \gamma_{R,\Delta}}. \quad (12)$$

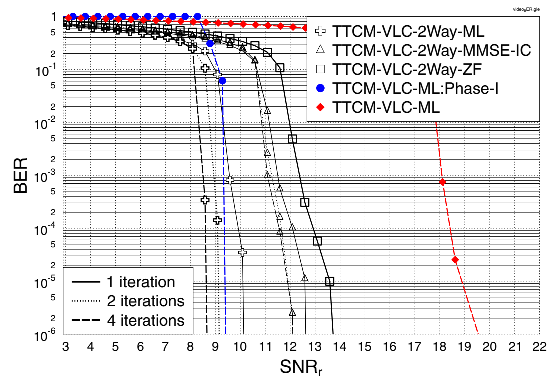

Fig. 4: BER versus received SNR_r performance of TTCM-VLC-aided SDMA for Phase-I and Phase-II as well as the for the proposed two-way relaying schemes using "*Akiyo*" sequence.

IV. Performance Evaluation

The attainable BER performance of the proposed two-way relaying videophone-aided system is shown in Fig. 4, where an "iteration" refers to the outer iteration between the TTCM-VLC decoder of Fig. 2 and the MUD. The single user performance of a non-cooperative scheme is considered as our benchmarker, which is termed as the "TTCM-VLC-ML" scheme, where a single user transmits to a single receiver. Three different MUD techniques, namely the above-mentioned ML, the MMSE-IC and the ZF arrangement were invoked in the RN during the first time slot, while only the ML was used at the DN during the second time period. A significant improvement is exhibited by the BER curves, when the two-way relaying system is employed. More specifically, the "TTCM-VLC-2Way-ML-4-iteration" relaying scheme requires approximately $19.6 - 8.6 = 11$ dB lower SNR than that of the non-relaying benchmark scheme arrangement, when aiming for a BER of 10^{-6}. By contrast, the MMSE-IC and ZF MUD based schemes have a relaying gain of 7.5 dB and 6 dB at a BER of 10^{-6}, respectively, in comparison to the benchmarker. Observe in Fig. 4, a marked improvement is exhibited for ML-based scheme when the number of outer iterations is increased. Four outer iterations require 1.5 dB lower SNR than a single iteration. A slight improvement can be seen in Fig. 4 for MMSE-IC-based scheme when increasing the outer iterations. However, additional iterations of the ZF-based scheme no longer improve the attainable performance, as the interfering signal has already been removed.

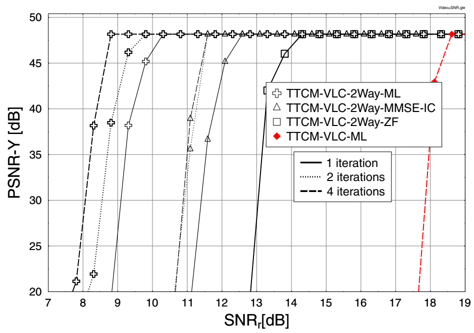

Fig. 5: PSNR-Y versus SNR$_r$ of TTCM-VLC-aided SDMA for two-way relaying system over Rayleigh fading channel using "$Akiyo$" sequence, where the iterations represents outer iteration.

Furthermore, the Peak Signal to Noise Ratio (PSNR) versus SNR$_r$ performance curves are portrayed in Fig. 5. The maximum value of the PSNR is set to $PSNR_{\max} = 10\log_{10}\left(2^8\right)^2 = 48.16$ dB. Without this normalization, we would have $PSNR_{\max} = \infty$ when there are no errors in the reconstructed pixels, because the VLCs employed constitute lossless codes.

(a) **ML:SNR**$_r$ $= 8.5$dB (b) **MMSE-IC:SNR**$_r$ $= 11.5$dB (c) **ZF:SNR**$_r$ $= 14.0$dB

Fig. 6: Subjective video quality of the 10$^{\text{th}}$ frame of "$Akiyo$" video when the $\mathbf{ML}$, $\mathbf{MMSE-IC}$ and $\mathbf{ZF}$ with 1 iteration are invoked at the RN with different SNR$_r$, respectively.

In line with the BER results, significant SNR gains can be observed for all two-way relaying schemes compared to the non-relaying benchmarker. More explicitly, the proposed systems based on the ML, MMSE-IC and ZF detectors require SNR of 8.5 dB, 11.5 and 14 dB, respectively, to achieve the maximum, attainable PSNR associated with an infinitesimally low BER, as seen in the corresponding subjective video quality results of Fig. 6. Additionally, the effects of the number of outer iterations for ML-based scheme is shown in Fig. 7, where the reconstructed frame is totally corrupted after the first iteration, as shown in Fig. 7(a). By contrast, using four iterations will lead to a perfect video recovery, as seen in Fig. 7(c).

V. Conclusions

In this paper we have proposed an optimised end-to-end joint source-coding, channel-coding and modulation scheme for video transmission in a two-way relaying aided system. This system enabled us to reduce the number of time slots required from four to two, in comparison to the conventional network coding aided relaying scheme, while maintaining the same normalised per-user throughput. We used EXIT charts for investigating the iterative decoding behaviour as well as the for optimizing the overall relaying regime power. Substantial BER, PSNR and subjective video quality improvements performances were attained.

(a) First iteration (b) Second iteration (c) Fourth iteration

Fig. 7: Subjective video quality of the 10$^{\text{th}}$ frame of "$Akiyo$" video of the TTCM-VLC-aided SDMA for two-way relaying when communicating over uncorrelated Rayleigh fading channels. When SNR$_r$ $= 8.5$ dB and $\mathbf{ML}$ is invoked in the RN and the number of outer iterations between the TTCM-VLC decoder of Fig. 2 and the MUD detector are (from left) one, two and four, respectively.

References

[1] K. J. Lee, H. J. Sung, E. S. Park and I. K. Lee, "Joint optimization for one and two-way MIMO AF multiple-relay systems," *IEEE Transactions on Wireless Communications* , vol. 9, pp. 3671 –3681, Dec. 2010.

[2] W. Liang, S. X. Ng, L. Hanzo, "TTCM-aided SDMA-based two-way relaying," in *Proc. IEEE Vehicular Technology Conf.*, vol. 1, (San Francisco, USA), pp. 1–5, 5-8 Sept. 2011.

[3] P. Robertson and T. Wörz, "Bandwidth-efficient turbo trellis-coded modulation using punctured component codes," *IEEE J. Sel. Areas Commun.*, vol. 16, pp. 206–218, Feb. 1998.

[4] C. E. Shannon,, "A mathematical theory of Communication," *The Bell system technical journal*, vol. 27, pp. 379–423, July 1948.

[5] L. Hanzo, P. Cherriman and J. Streit, *Video Compression and Communications: From Basics to H.261, H.263, H.264, MPEG4 for DVB and HSDPA-Style Adaptive Turbo-Transceivers*. Wiley-IEEE Press, 2007.

[6] R. Bauer, J. Hagenauer, "On variable length codes for iterative source/channel decoding," in *IEEE Data Compression Conf.*, (UT, USA), pp. 273–282, 27-29 March 2001.

[7] Y. Takishima, M. Wada and H. Murakami, "Reversible variable length codes," *IEEE Trans. Commun.*, vol. 43, no. 234, pp. 158 –162, 1995.

[8] S. X. Ng, F. Guo, J. Wang, L-L. Yang and L. Hanzo, "Joint source-coding, channel-coding and modulation schemes for AWGN and Rayleigh fading channels," *Electron. Lett.*, vol. 39, pp. 1259–1261, Aug. 2003.

[9] S. X. Ng, K. Zhu and L. Hanzo, "Distributed source-coding, channel-coding and modulation for cooperative communications," in *IEEE Vehicular Technology Conf.*, (Ottawa, Canada), pp. 1–5, 6-9 Sept. 2010.

[10] A. J. Aljohani, S. X. Ng, R. G. Maunder and L. Hanzo, "EXIT-chart aided joint source-coding, channel-coding and modulation design for two-way relaying," *IEEE Trans. Vehicular Technol. (to be published.)*, 2013.

[11] H. Ochiai, P. Mitran and V. Tarokh, "Design and analysis of collaborative diversity protocols for wireless sensor networks," in *Proc. IEEE Vehicular Technology Conf.*, (Los Angeles, USA), pp. 4645–4649, 26-29 Sept. 2004.

[12] S. X. Ng, Y. Li and L. Hanzo, "Distributed turbo trellis coded modulation for cooperative communications," in *Proc. of International Conf. on Communications (ICC)*, (Dresden, Germany), pp. 1–5, 14-18 June 2009.

[13] L. Hanzo, M. Münster, B. Choi, and T. Keller, *OFDM and MC-CDMA for Broadband Multi-user Communications, WLANs and Broadcasting*. John Wiley & Sons, May 2003.

[14] S. X. Ng, F. Guo, J. Wang, L-L. Yang and L. Hanzo, "Jointly optimised iterative source-coding, channel-coding and modulation for transmission over wireless channels," in *Proc. IEEE Vehicular Technology Conf.*, (Milan, Italy), pp. 313–317, 17-19 May 2004.

[15] L. Hanzo, T. H. Liew, B. L. Yeap, R. Y. S.Tee and S. X. Ng, *Turbo Coding, Turbo Equalisation and Space-Time Coding: EXIT-Chart Aided Near-Capacity Designs for Wireless Channel*. New York, USA: John Wiley IEEE Press, 2011.

[16] J. Kliewer, S. X. Ng and L. Hanzo, "Efficient Computation of EXIT Functions for Non-Binary Iterative Decoding," *IEEE Trans. Commun.*, vol. 54, pp. 2133–2136, Dec. 2006.