Iterative Channel Decoding of FEC-Based Multiple Descriptions using LDPC-RS Product Codes

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Abstract
Product code has been proposed as a promising technique for cloud transmission of multimedia information, because of its superior error correcting capabilities. In this paper we study product code based on a vertical low-density parity check (LDPC) code and horizontal Reed-Solomon (RS) code for transmission of progressively coded image and propose an iterative decoding algorithm. The transmitter consists of FEC-based multiple description encoder where multimedia information is encoded with varying RS parity levels depending on the relative importance of symbols in message stream. Columns of RS symbols are appended with CRC and LDPC coded before being OFDM modulated. The proposed algorithm utilises the correctly decoded RS coded bits for enhancing the error correcting capability of LDPC codes at the next iteration of the algorithm. An intra-description interleaver is placed between RS codes and LDPC code distributes the bits of correctly decoded RS code symbols uniformly over the entire LDPC code. The performance of the algorithm is evaluated over different fading channels for OFDM system. The simulation results show that the performance of the proposed system is significantly improved over existing and baseline schemes.

Keywords: Multiple description coding, iterative decoding, product code, OFDM, FEC, LDPC code

INTRODUCTION
The development of portable devices and technologies has led to the expansion of demand for multimedia services such as image and video over wireless channels. This has invoked intense research in the field of multimedia transmission over mobile wireless channels exhibiting time-varying channel quality. Considering the unreliable nature of the wireless channel progressive mode of transmission is employed such that as more and more bits are received, the source can be reconstructed with better quality. Typically, an error in the coded bit stream may cause misinterpretation of later bits, but is better than rendering the whole bitstream useless. Earlier research considered unequal error protection method for transmitting progressively coded images. As different source packets differ in importance, the application of unequal error protection for channel coding provided better performance than applying equal protection to all the packets. For example, [1] considered the transmission of a progressively coded bitstream using rate-compatible punctured convolutional codes. Banister et al. [2] used trellis-based optimization for rate-compatible turbo code for transmission of JP2K images over binary symmetric channel. Pan et al. in [3-4] proposed a fast trellis based rate allocation algorithm for LDPC codes for transmission of progressively coded image over wireless channel. In [5], authors consider punctured irregular repeat-accumulate (IRA) codes for scalable image and video transmission over BSC. However, such schemes were susceptible to packet loss during deep fades in slow fading channel.

To improve the performance against deep fades, forward error correction (FEC)-based multiple description coding [6]-[11] has emerged as an attractive framework for multimedia transmission over wireless channel. Multiple descriptions of the source are generated such that each description independently describe the source with certain fidelity. When minimum numbers of packets or descriptions are available at the receiver, the descriptions can be synergistically combined to enhance the quality [12]. Due to this nature, the loss of some of descriptions will not jeopardize decoding of correctly received descriptions. Sachs et al. [13] proposed one of the earliest scheme on FEC-based multiple description using product code structure of RS and convolutional code. In this scheme, contiguous bits from a progressively coded source are spread across multiple packets (or descriptions) instead of being placed in a single packet. The information symbols are protected from erasures using systematic RS codes, with level of protection depending on importance of the information symbols. To find the optimal allocation of RS party symbols, Mohr et al. adopted a hill climbing optimization approach in [6]. Puri and Ramachandran [14] provided a Lagrangian approach to optimizing the level of protection for FEC based multiple description codes. After horizontal coding with RS code (FEC), descriptions are usually coded with equal rate channel code (e.g. convolutional code) along the columns. Bais et al. [9] proposed unequal level of protection for channel code also, since equal protection of balanced MDC packets is not necessarily optimal for stationary wireless channels. Orthogonal frequency division multiplexing (OFDM) is being considered for large number of applications in the field of telecommunication and terrestrial television broadcast
systems, for its ability to combat inter-symbol interference over frequency selective fading channel, compared to single carrier communication. Song et al. [15] proposed OFDM based transmission of progressive image using space-time block code. In [7] authors proposed a 2-D channel coding scheme for image transmission using OFDM which employ time and frequency diversities simultaneously. Chang et al. [12] analyzed the performance of n-channel symmetric FEC-based multiple description coding for a progressive mode of transmission over OFDM networks. In [8] algorithms for iterative decoding of FEC-based multiple description coding scheme described in [7], [12] were presented. In this scheme the information of correctly decoded RS codewords is exploited to enhance the error correction capability of the Viterbi algorithm at the next iteration of decoding. The performance of the algorithm is evaluated over OFDM system demonstrating significantly improved performance. In [11] authors proposed a different approach to iterative decoding of FEC-based multiple description codes. The iterative decoder exchanges soft extrinsic information between Reed-Solomon code across packets and convolutional coded descriptions transmitted over wireless channels, in contrast to existing approaches where hard decision is performed on the outcome of the inner channel code and applied to RS decoder. 

Recently, a new robust transmission system-Cloud Transmission [16] has been proposed for broadcasting and point-to-multipoint services. The purpose of cloud transmission is to use radio frequency spectrum more efficiently and to have high degree of robustness to co-channel interference. These advantages are to be achieved using suitable error correction code in low coding rate at low SNR range, along with other techniques [17]. In contrast to convolutional code, LDPC code can provide remarkable performance very close to Shannon limit. In [17], [18], authors apply LDPC code of the DVB-S system to product code structure with RS code used as outer code for cloud transmission system. This product code structure removes error-floor phenomena with the aid of RS code and does not require any complex interleaver for stable reception under fading channel.

In this paper, we propose an iterative decoding algorithm for recovering progressively coded image information transmitted using LDPC-RS product code. OFDM is considered for transmission over flat and frequency selective fading wireless channels. The proposed algorithm takes advantage of correctly decoded output of RS decoder to enhance the error correction capability of the LDPC decoder at the next iteration of sum-product algorithm (SPA). The algorithm works by selectively enhancing the magnitude of log-likelihood ratios of the identified reliable bits. An important feature of proposed algorithm is the use of hard-decision LDPC decoder used in conjunction with SPA decoder for LDPC code for further enhancing the error correcting capability of LDPC code. In addition we use simple random intradescription interleaver, in contrast to a deterministic interleaver proposed in [8], and show that there is marked improvement in bit-error-rate performance. Overall, we show that the proposed iterative LDPC-RS product code based progressive image transmission scheme performs significantly better than baseline LDPC-RS coding scheme without iterative decoding. We also compare the proposed system to a similar iterative design for transmission of progressive image using RSCC-RS product code in [8] and demonstrate improvement in performance.

![Figure 1: Stream of symbols from a progressively coded source.](image)

We organize the rest of this paper as follows. In next section we describe the preliminaries of FEC based multiple description coding and explain the encoder structure in the proposed system which uses LDPC-RS product code. After that, we present the system model and proposed decoding algorithm. The simulation results are presented in subsequent section. Finally, a conclusion is presented.

### PRELIMINARIES

We briefly describe FEC-based multiple description coding [6]-[13] in which systematic RS erasure correction codes are used. An \((N, k)\) RS code is called a maximum distance separable (MDS) code if \(d_{\text{min}}=N-k+1\), where \(d_{\text{min}}\) is referred to as minimum distance of the code. An \((N, k)\) RS code is a construction where \(k\) information symbols are encoded into \(N\) channel symbols and reception of any \((N-d_{\text{min}}+1)\) of the \(N\) channel symbols enables \(k\) information symbols to be recovered. In RS code, each symbol is of \(m\) bits and source symbols are formed by grouping \(m\) bits into RS code symbols. Let \(S=[S_1, S_2, \ldots]\) be such a stream of symbols from a progressively coded source. The source can be reconstructed progressively from the prefixes of the symbol stream \(S\), while an error renders the subsequent symbols useless. For example, if there is an error in \(i\)-th symbol \(S_i\), source can be decoded using the symbols \([S_1, S_2, \ldots, S_{i-1}]\) and symbols subsequent to \(S_i\) cannot be utilized in the process of decoding. Fig. 1 shows such a symbol stream which has been segmented into sections of unequal length. The corresponding rate and distortion resulting in reception of all the symbols up to a particular segment is also indicated in the figure.

An \(N\)-channel FEC-based multiple description code is obtained by applying unequal FEC to different parts of symbol stream with the level of protection depending on the relative importance of the information symbols. The realization of \(N\)-channel FEC based multiple description code using RS code is shown in Fig. 2, where rows are RS code of length \(N\) but containing different number of information symbols. Let \(L\) be the number of RS code required to encode all the information symbols and \(k_l\) denote the number of information symbols in RS codeword \(l\), where \(l=1, \ldots, L\). The information symbols are provided with unequal error protection using \((N, k_l)\) systematic RS codes, where \(1 \leq k_l \leq N\). Thus, each RS code can correct up to \(N-k_l\) erasures. Since information symbols at the end of the stream \(S\) are less important than the symbols appearing before them, error
protection decreases for RS codewords as \( k_1 \leq k_2 \leq \cdots \leq k_L \).
For example, in Fig. 2, first RS codeword \((l=1)\) consists of first two information symbols \( S_1, S_2 \) and rest of the symbols being RS parity. For RS codeword at \( l=3 \), information symbols are \( S_5, S_6, S_7 \) and the rest being parity symbols. Since vertical columns of symbols form the descriptions, the information symbols \( S_5, S_6, S_7 \) and parity symbols present in RS codeword are distributed among \( N \) different descriptions. Hence, conversion of progressive symbol stream into multiple descriptions (columns) spreads the contiguous information symbols across descriptions and any RS codeword can be recovered completely if number of lost descriptions (lost columns) is not more than \( N-k \). A concatenation of CRC and LDPC code is applied on each description for transmission over wireless channel. Finally, individual descriptions are mapped to \( N \) subcarriers of the OFDM frame. At the receiver, after LDPC decoding, CRC is used to check the integrity of the descriptions and if CRC check fails, the description is declared lost or erased.

Thus, depending on the quality of channel, decoding of some of the descriptions may fail. This will result in decrease in quality of image or video and will depend on the probability of receiving a description correctly. Let \( D(x) \) denote the rate-distortion function of the source and \( D(0) \) indicate the distortion when decoder reconstructs the image with no received information. Rate-distortion function indicates the resulting distortion \( D \) of the source if \( x \) bits of information is received. Average distortion \( E(D) \) is given as [8]

\[
E(D) = D(0) \Pr(0) + \sum_{l=1}^{L} \left( D \left( \sum_{p=1}^{L} mk_p \right) \Pr \left( \sum_{p=1}^{L} mk_p \right) \right)
\]

where \( \Pr(x) \) is the probability that \( x \) number of progressive source bits are received without encountering error. \( E(D) \) can also be expressed in terms of number of correctly received description. Let \( P(i) \) denote the probability that number of correct descriptions is \( i \), then

\[
E(D) = D(0) \sum_{i=0}^{k_1-1} P(i) + \sum_{l=1}^{L} \left( D \left( \sum_{p=1}^{L} mk_p \right) \sum_{i=1}^{k_{L+1}-1} P(i) \right)
\]

**PROPOSED DECODING ALGORITHM**

The proposed system model is shown in Fig. 3. The encoder structure is similar to the one given in [7], [8], [12], [13], except for channel code which in the proposed scheme is LDPC code. This is in accordance with newer research in the field of cloud transmission and terrestrial video broadcasting [17], [18]. The receiver on the other hand is significantly different from the FEC-based MDC decoders proposed in literature. Besides the use of LDPC codes, the proposed scheme uses a random outer interleaver and an additional LDPC hard-decision decoder at the last stages of decoder. We next describe in detail the system model considered in this paper.

The encoder, as depicted in top part of Fig. 3, consists of a progressive source encoder (e.g. SPIHT) followed by RS encoder. The RS code based multiple description encoder, described in earlier section, generates \( N \) equally important descriptions. The outer interleaver \( \Pi_1 \) is a bit level interleaver in contrast to the symbol-level interleavers used in FEC based multiple description coding literature. Another major difference is that compared to deterministic interleaver proposed in [8], \( \Pi_1 \) is a simple random interleaver and is discussed in later paragraphs. CRC is calculated for each description or packet and attached at the end of each packet. Each description is then individually encoded with systematic LDPC code and bit level random inner interleaver \( \Pi_2 \) is applied on the LDPC coded packet. The encoded descriptions constitute a matrix of bits as shown in Fig. 2, and at the last stage OFDM frame is formed from QPSK symbols extracted from the matrix in row-by-row order.

We next describe the proposed iterative decoding scheme depicted in the lower part of Fig. 3. After OFDM demodulator and inner deinterleaver, logarithmic domain sum-product algorithm (log-SPA) is run for decoding LDPC code. This
process is repeated one by one for all the $N$ columns of LDPC code. CRC decoder then classifies each description as correct or erroneous. Irrespective of the correctness of the description, the bits within each description are deinterleaved by the outer deinterleaver $\Pi_1$. As already mentioned $\Pi_1$ is a bit level intradescription interimleaver and has no contribution in improving the number of correctly decoded descriptions. But in an iterative system like the one proposed in Fig. 3, the interleaver has special function in the subsequent iterations. After RS decoding, let $C$ be the number of correctly decoded RS codewords. Because of unequal nature of error protection, after RS decoding, let $\Pi_1$ be applied on the each of the columns of bits and for decoding success, the corresponding bit in $\text{flags}_{\text{rd}}$ is set. Then all the codewords are decoded successfully or maximum number of iterations is reached. After completion of iteration loop, output of RS decoder is applied to LDPC hard-decision decoder. This further improves the error performance and owns a much lower computational complexity compared to SPA.

In the following, we evaluate the difference in packet error rate performance of the proposed system with a random interleaver and the interleaver proposed by Chang et al [8]. A LDPC code with rate $\frac{1}{2}$ and codeword length of 576 is employed over an AWGN channel. The (116, 128) RS code symbols are from $\text{GF}(2^8)$ and description size in terms of RS code symbols is $L=32$. The CRC bits are of length 32. We assume that $C=8$, i.e. 64 bits are correctly available in a description or packet. The interleaver of [8] is a block interleaver with a specific permutation pattern. It was designed considering Viterbi decoder in consideration and distributed all the $mC$ correct information bits uniformly along the convolutional code. Considering the random interleaving nature of LDPC code we propose to use a random pattern of interleaving for outer bit-level interleaver $\Pi_1$. The performance advantage of a random interleaver compared to a uniform interleaver of [8] in the proposed system setup is shown in Fig. 4. We can observe a gain of 0.25 dB in $E_b/N_0$ at packet error rate of $10^{-3}$ and hence random interleaver is used in the proposed scheme.

The implementation of the proposed algorithm proceeds as given in Algorithm 1. In the algorithm we assume that the output of the OFDM demodulator is given as $\lambda_{\text{ch}}$, where $\lambda_{\text{ch}}$ is an LLR matrix consisting of columns of interleaved LDPC codes and is of the form similar to Fig. 2. Step 1 of the algorithm initializes the flags indicating the decoding status of LDPC and RS codes. The $N$ bits in $\text{flags}_{\text{ldpc}}$ and $L$ bits in $\text{flags}_{\text{rs}}$ are initialized to zero, indicating that corresponding codes has not yet been decoded successfully. In step 2, columns of the initial channel LLR matrix $\lambda_{\text{ch}}$ are deinterleaved with $\Pi_1^{-1}$. Step 3 is the iterative part of the algorithm and is run for $\text{max iter}$ number of times. Sum-product algorithm is applied on the each of the columns $\lambda_{\text{ch}}[\text{col}]$ containing the LLR values for the purpose of decoding the LDPC code. The hard decision decoded codeword is saved as $\text{DEC}_{\text{ldpc}}[\text{col}]$ for use in later stages. If decoding is successful, LDPC flag $\text{flags}_{\text{ldpc}}[\text{col}]$ value is set to 1. The LDPC decoded bits $\text{DEC}_{\text{ldpc}}$ are of the form $[I, P]^T$, where $I$ and $P$ are information and parity part of LDPC code, respectively and superscript $T$ indicates transpose operation. At step 3.3, deinterleaver $\Pi_1^{-1}$ is applied on the columns of systematic part $I$ and RS code symbols are obtained by combining $m$-bits in the columns. Step 3.4 consists of Berlekemp-Messy hard decision decoder for RS code. In case of successful decoding of rows of RS symbols (see Fig. 2), the corresponding bit in $\text{flags}_{\text{rs}}$ is set. If all the RS codewords are decoded successfully, decoding process is exited at Step 3.5. At steps 3.6-3.8, RS symbols are translated to bits, interleaved and appended with LDPC parity bits $P$, which had been removed at step 3.3. Hard decision LDPC decoder is applied on the columns of bits and for decoding success, the corresponding bit in $\text{flags}_{\text{ldpc}}$ is set. Again, if all the bits in $\text{flags}_{\text{ldpc}}$ are set, we exit the decoding process. In step 3.9, channel LLR values $\lambda_{\text{ch}}$ are modified using Algorithm 2 using the bits in $\text{flags}_{\text{ldpc}}$ and $\text{flags}_{\text{rs}}$. The objective of soft value modification (Algorithm 2) is to modify channel LLR values corresponding to most reliable bits to a preset maximum. The bits in RS codeword which have been successfully decoded (indicated by $\text{flags}_{\text{rs}}$) are declared reliable and their absolute LLR values is changed to $\lambda_{\text{max}}$. This will accelerate the convergence of SPA decoder and provide better error performance. Note that LLR of symbols are modified only in columns for which $\text{flags}_{\text{ldpc}}[\text{col}] = 0$ and the corresponding bit in $\text{flags}_{\text{rs}}$ is set to 1. The decoding iterations in step 3 are run till all the RS codewords are decoded or maximum number of iterations is reached. Finally, bit output from LDPC hard decision decoder are applied for source decoding.

![Figure 4: Packet error rate evaluation of two different types of interleavers for $\Pi_1$ block. (116, 128) RS code was used for evaluation with 8 RS code codewords assumed error free.](image-url)
Algorithm 1
- Definition:
\( \lambda_{ch} \): LLR at the output of OFDM demodulator in matrix form of Fig. 1
\( \text{col} \): variable indicating column
\( \text{row} \): variable indicating row
\( \text{flags}_{ldpc} \): array of flags indicating the decoding success of LDPC codes
\( \text{flags}_{rs} \): array of flags indicating the decoding success of RS codes
1. Initialize:
   \( \text{iteration} = 1 \)
   For \( \text{col} \in [1, N] \), \( \text{flags}_{ldpc}[\text{col}] = 0 \).
   For \( \text{row} \in [1, L] \), \( \text{flags}_{rs}[\text{row}] = 0 \).
2. For each column \( \text{col} \in [1, N] \), apply deinterleaver \( \Pi_{i}^{-1} \) on \( \lambda_{ch}[\text{col}] \).
3. While (iteration \( \leq \) max_iter) do
   3.1 For each column \( \text{col} \in [1, N] \), apply sum-product algorithm on channel LLR \( \lambda_{ch}[\text{col}] \) in column \( \text{col} \) as input to decode the LDPC code and save the decoded word in \( \text{DEC}_{ldpc}[\text{col}] \). For each successful decoding of LDPC code in column \( \text{col} \), assign \( \text{flags}_{ldpc}[\text{col}] = 1 \).
   3.2 If for all \( \text{col} \in [1, N] \), \( \text{flags}_{ldpc}[\text{col}] = 1 \), exit the while loop.
   3.3 Extract matrix \( M \) from \( \text{DEC}_{ldpc} = \begin{bmatrix} I \end{bmatrix} \), where \( I \) and \( P \) are information and parity part of LDPC code, respectively. For each column \( \text{col} \in [1, N] \), apply deinterleaver \( \Pi_{i}^{-1} \) on \( I[\text{col}] \) and after forming RS symbols of \( m \) bits, save the result in \( \text{SYM}_{rs}[\text{col}] \).
   3.4 For each \( \text{row} \in [1, L] \), if \( \text{flags}_{rs}[\text{row}] = 0 \), then compute Reed Solomon decoded output as \( \text{dec} = \text{Berlekemp Algorithm}(\text{SYM}_{rs}[\text{row}]) \). If decoding is successful, assign \( \text{DEC}_{rs}[\text{row}] = \text{dec} \) and \( \text{flags}_{rs}[\text{row}] = 1 \); else, \( \text{DEC}_{rs}[\text{row}] = \text{SYM}_{rs}[\text{row}] \).
   3.5 If for all \( \text{row} \in [1, L] \), \( \text{flags}_{rs}[\text{row}] = 1 \), exit the while loop.
   3.6 For each \( \text{col} \in [1, N] \), translate RS symbols \( \text{SYM}_{rs}[\text{col}] \) to column of bits \( \text{BITS}_{rs}[\text{col}] \) and interleave using \( \Pi_{i} \) the bits of column \( \text{BITS}_{rs}[\text{col}] \).
   3.7 Append the LDPC parity bits \( P \) to \( \text{BITS}_{rs} \) to form array of LDPC codes \( \text{BITS}_{ldpc} = \begin{bmatrix} \text{BITS}_{rs} \\ P \end{bmatrix} \).
   3.8 For each column \( \text{col} \in [1, N] \), decode LDPC code \( \text{BITS}_{ldpc}[\text{col}] \) using hard-decision LDPC decoder and save the decoded word in \( \text{DEC}_{ldpc}[\text{col}] \). For each successful decoding of LDPC code in column \( \text{col} \), assign \( \text{flags}_{ldpc}[\text{col}] = 1 \).
   3.9 If for all \( \text{col} \in [1, N] \), \( \text{flags}_{ldpc}[\text{col}] = 1 \), exit the while loop.
3.10 Modify LLR \( \lambda_{ch} \) using soft value modification algorithm (Algorithm 2).
3.11 \( \text{iteration} = \text{iteration} + 1 \).
End while
4. Source symbols can be then decoded using bits extracted from \( \text{BITS}_{rs} \).

Algorithm 2
- Definition:
\( \lambda_{ch} \): LLR at the output of OFDM demodulator
\( \lambda_{r} \): RS code part of \( \lambda_{ch} = \begin{bmatrix} \lambda_{r} \\ \lambda_{p} \end{bmatrix} \); i.e. LLR matrix from the systematic part of LDPC code LLR values \( \lambda_{ch} \).
\( \lambda_{max} \): maximum magnitude of LLR values
1. Extract RS code part \( \lambda_{r} \) from LLR matrix \( \lambda_{ch} \) and apply deinterleaver \( \Pi_{i}^{-1} \) on the columns of \( \lambda_{r} \).
2. For \( \text{col} \in [1, N] \) and \( \text{row} \in [1, L] \)
   If \( \text{flags}_{ldpc}[\text{col}] = 0 \) and \( \text{flags}_{rs}[\text{row}] = 0 \)
   Set \( \lambda_{r}(\text{col}, i) = \begin{cases} -\lambda_{max}, & \lambda_{r}(\text{col}, i) < 0 \\ \lambda_{max}, & \lambda_{r}(\text{col}, i) \geq 0 \end{cases} \)
   \( \text{rows} = [(\text{row} - 1) \mod (m + 1), \text{row} \times m] \)
End if
End for

SIMULATION RESULTS
In this section we evaluate the performance of the proposed iterative decoding algorithm. The images are encoded using the well known SPIHT algorithm [19] to produce a progressively coded bitstream. The bitstream was converted into a stream of GF(256) symbols, where each symbol was obtained by combining \( m = 8 \) bits. This serial stream was converted into 128 parallel bitstreams using FEC-based multiple description encoder algorithm by Mohr et al. [6]. Mohr’s algorithm provides the values of \( k_{i} \) for the RS codes using a hill climbing optimization approach. The multiple description encoder uses \( (N, k_{i}) \) RS code, where \( N = 128 \) and the description size is 32 RS code symbols (i.e. \( L = 32 \)). The packet or description size is set to 288 bits, which includes an additional 32 bits appended as CRC. Each packet is then encoded with \( (576, 288) \) LDPC code from IEEE 802.16e standard. The 128 descriptions are mapped to the OFDM system with 128 subcarriers. As can be seen in Fig. 2 RS code is used in frequency domain and LDPC code is used in time domain.

In Fig. 5 to 7, we show results of the simulations carried out on SPIHT coded, standard 8 bits-per-pixel (bpp) 128 × 128
Lena image transmitted with a rate of 2 bpp. The maximum number of iterations the algorithm is run (variable \textit{max\_iter} in step 3 of Algorithm 1) is 5, whereas SPA decoder is run for maximum of 25 iterations. In these figures, peak signal-to-noise ratio (PSNR) is used as a measure of reconstruction quality and is plotted against average received channel SNR. For each simulation point, 300 trials have been performed in order to average statistical variations. In Fig. 5, PSNR performance of the three schemes is compared for transmission over Jakes fading channel. It is evident that the proposed system outperforms both the reference schemes significantly in terms of average PSNR performance. The maximum improvement in PSNR is of 5 dB compared to existing scheme of [8] and is obtained at channel SNR of 7 dB. The improvement is more marked when compared to LDPC-RS tandem scheme, where there is an average PSNR gain of 6 dB at channel SNR of 7 dB. Fig. 6 shows improvement obtained using the proposed decoder over Vehicular A channel. The LDPC-RS tandem decoder performs better in the mid range of channel SNR compared to RSCC-RS based reference scheme. With the proposed LDPC-RS iterative decoder, there is a maximum gain of 8 dB in average PSNR over the RSCC-RS based reference scheme at channel SNR of 6 dB. Next Fig. 7 presents the simulation results for transmission over Pedestrian A channel. Since Pedestrian A channel is a slow fading channel, diversity gain is no longer significant resulting in reduced improvement in average PSNR values. Compared to reference scheme [8] there is a maximum gain of 4 dB in average PSNR for channel SNR values of 6-8 dB. Compared to baseline RDPCC-RS tandem scheme, a PSNR gain of 5 dB is obtained at 6 dB. From the results in Fig. 5 to 7, it can be concluded that the proposed schemes outperforms the reference schemes in all the three examples of fast and slow fading channels.

Furthermore, the superiority of our method is seen even more distinctly when comparison is made in terms of cumulative quality distributions. Fig. 8 gives the cumulative quality distribution obtained for the Lena image transmitted over Rayleigh fading channel modelled with Jakes’ simulator, at average channel SNR values of 10 dB and \( f_d T_s = 10^{-3} \). As shown in Fig. 8, the proposed method produces low-quality images far less than the baseline scheme and scheme proposed in [8]. Even though the maximum value of PSNR obtained is same for all the three methods, the variance in PSNR is far less in the proposed scheme compared to both the reference schemes. Decoded Lena image received at different channel SNR values is shown in Fig. 9 as example. In Table I, we compare the decoded image PSNR with the baseline scheme for different SPIHT coded images of size 256 × 256 and SPIHT coded at rate 1. Because of difference in rate-distortion curves, the allocation of RS parity bits is different for different images. This results in different overall code rate for the images, which is also mentioned in the table. It can be observed that the proposed scheme outperforms the baseline scheme for all the test images.

CONCLUSION
In this paper, we have presented a novel method to iteratively decode FEC-based multiple description code transmitted over fading channel. The proposed scheme employs RS codes to form multiple descriptions and each description is channel coded with LDPC code. The descriptions are OFDM modulated and transmitted over wireless channel. The proposed decoding scheme considers the bits present in RS codewords, which have been decoded successfully, to be highly reliable and uses those bits to improve the decoding convergence of inner LDPC code. Since, different LDPC decoding methods have different speciality, LDPC hard decision decoder is also applied for improving the decoding performance for hard decoded bits at the output of RS decoder. On the other hand, sum-product algorithm based LDPC decoder to the soft output of OFDM demodulator. The resulting system was evaluated for the transmission of SPIHT coded images over different fading wireless channels. Experimental results showed the superiority of the proposed scheme in comparison to similar well known decoding scheme.
Figure 7: Performance comparison of the proposed scheme with two reference schemes for Lena 128 × 128 image transmitted Pedestrian A frequency selective fading channel.

Figure 8: Cumulative distribution of decoded PSNR for Lena 128 × 128 image transmitted over Jakes’ fading channel with SNR=10 dB.

Table I: PSNR performance of the proposed scheme with different test images

<table>
<thead>
<tr>
<th>Test image</th>
<th>Channel SNR in dB</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<tr>
<td>Cameraman</td>
<td>0.285</td>
</tr>
<tr>
<td>Baboon</td>
<td>0.305</td>
</tr>
<tr>
<td>Boat</td>
<td>0.288</td>
</tr>
<tr>
<td>Peppers</td>
<td>0.305</td>
</tr>
</tbody>
</table>

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