Analysis of M-Ary Modulation with M-Ary LDPC Coding for DVC

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Abstract. In this paper we consider the issue of Distributed Video Coding (DVC) over practical channel which involves Gaussian noisy channel. Since the research on DVC over practical channel with respect to modulation is still incomplete this paper does a comprehensive study on DVC modulation techniques to fill the gap. It discusses the suitability of M-Ary modulation to DVC on the basis of energy consumption. The study covers both theoretical and practical aspects through the practical implementation of DVC encoder and decoder, the performance in terms of bit error rate, decoder complexity and data rate of M-Ary modulation techniques used with M-Ary LDPC coding

Keywords: DVC, M-Ary modulation, M-AryLDPC codes, S/W and WynerZiv coding.

1 Introduction

In a video compression process, one of the main tasks at the encoder side is motion estimation which is to extract the temporal correlation between frames which is a more complex process and leads to encoder complexity ten times more than the decoder. Distributed video coding is a new video coding paradigm where the encoder decoder complexity is reversed. The main reason behind DVC attraction is that the applicability of this new paradigm in the widely used video uplink applications such as wireless video cameras and video conferencing using mobile devices, applications. DVC is based on the information theoretic ideas of Slepian-Wolf and Wyner-Ziv theorems.The idea behind DVC goes back to the 1970s when Slepian and Wolf [1] proved that, if the source Y is compressed to its entropy limit H(Y), X can be transmitted at a rate very close to the conditional entropy H(X|Y), provided that Y is available at the receiver as side information for decoding X. Since H(X,Y) = H(Y) + H(X|Y), X and Y can be independently encoded and jointly decoded without any loss in the compression efficiency, compared to the case where both sources are jointly encodedand decoded. The application of this concept to lossy source coding is known

V.V. Das, E. Ariwa, and S.B. Rahayu (Eds.): SPIT 2011, LNICST 62, pp. 229–235, 2012.

as the Wyner-Ziv coding [2]. In practical DVC systems, a subset of frames, known as key frames, is usually compressed using traditional intra coding techniques. Frames following each key frame, known as Wyner-Ziv (WZ) frames, are then compressed either by sending the parity bits or syndrome bits. At the receiver side the previous frames are interpolated to give side information. Within the DVC framework there are multiple issues to be solved, here we restrict ourselves to discuss i) Compression rate ii) BER (Bit Error Rate) and iii) Data rate with respect to parity and syndrome approach. With the same base channel code (n, k) the two approaches gives different compression rate. The syndrome code's compression rate is $n - k/n$ which is much better than parity approach. With respect to error correction, parity approach can correct x number of bit error out of kbits while syndrome approach can correct same x number of bit error out of n bits. In short while the syndrome approach performs well in noiseless scenario the parity approach performs well in practical noisy channel conditions [3]. As there are other issues with parity approach as we discuss in section 4, which decreases the performance of parity approach, we choose the syndrome approach as an optimized one and hence we analyze the higher order modulation for syndrome based DVC.The reminder of the paper is as organized as follows, section 2 briefs DVC background, section 3 rationalizes the need for higher order modulation, section 4 discusses the higher order modulation approach section 5 evaluate the need for syndrome approach, and section 6 concludes with simulation results.

2 Reviews on DVC

DVC is a new compression technique where the correlation between two signals is utilized. The concept emerged from Slepian Wolf theory [5] which dates back to 1970s. Given two statistically dependent sources X and Y being separately compressed to its limit $H(Y), H(X), X$ can be transmitted at a rate very close to the conditional entropy $H(X/Y)$. This leads to effective compression of X with much less operational complexity, provided that Y is perfectly recovered at the receiver as side information. This characteristic of less complexity finds application in wireless sensor based multimedia and multimedia over low powered portable devices.The Slepian Wolf problem has been solved by two major research groups using two approaches namely DSC using syndromes (DISCUS) and DSC using parity (DISCUP). The optimality of DISCUS approach is proved in [4]. But thisapproach does not consider the practical channel with noise and it also does not consider the two channels involved for the channel code design.However if the syndrome based compressed bits are transmitted over noisy channel it is considered to be inefficient for the reason of loss of error resilience. It estimates a wrong sequence even for one bit of error in the syndrome. Recent developments [5] in S/W coding reveal that syndrome method also can provide better error resilience, but addresses only puncturing of syndromes and not the channel noise problems. This paper addresses the syndrome technique with channel noise problems.

3 Higher Order Modulation for Total Power Reduction

The basic need of a DVC system is less power consumption at the encoder as it finds its major application in Wireless sensor networks (WSN) and low power compression devices. At various levels of system design, various ways of optimizing it, from encoder complexity to wireless transmission models.As it is known that some of the modulation schemes are energy efficient than the others [6], it indeed becomes important in a WSN to use the optimum modulation scheme so as to increase energy efficiency and at the same time maximize data rates and minimize the bit error probability. This would result in reduction in the usage of battery and improvement in the system performance. The choice of a good modulation scheme is critical for reliable communication in a WSN.Several papers have studied the effect of modulation technique on power and efficiency. In [7] an optimal strategy to decrease the transmission energy per bit is studied. In [8] it is showed that M-Ary will be energy efficient than binary for small transmission on time. Optimum transmits on time and constellation size for different modulation techniques has been analyzed for both Rayleigh and AWGN channel in [9]. All these papers view modulation schemes from circuit standpoint rather than the traditional perspective of$Eb/N0$. Based on these analyses, we find M-Ary modulation is a low power high data rate transmitter.

4 M-Ary Modulation and M-Ary LDPC Codes

Non binary LDPC GF (q) codes are defined by similar sparse binary LDPC matrices except the fact that the members of the matrices are 0 to q-1.The LDPC codes designed over GF (2) has shown to approach near Shannon performance limit, when decoded using Belief propagation algorithm at the cost of large block lengths. But for small block lengths the error performance can be improved by increasing q [10][11]. To avoid bit errors and to increase spectral efficiency in data transmission it is efficient to combine non binary LDPC codes with higher order modulation in wirelesscommunication. As said in section 3 it also decreases the total power required in case of wireless sensor transmission.These non binary LDPC codes can be conveniently combined with multilevel modulation, which are capable of supporting high data rate transmission. It is beneficial to consider non binary QAM or QPSK schemes with equivalent matching non binary LDPC as it avoids symbol to bit de mapping (BPSK) or one grouping of bits to another grouping of bits to form another symbol (M-Ary PSK/QAM). Using LDPC with field order equal to the size of the constellation has a clear advantage as the encoder and modulator directly works with same symbols.

5 Encoding with Syndrome Technique

5.1 Problem Formulation

The comparative analysis between parity based and syndrome based DVC over noiseless environment is well explained in [12]. The factors for comparison are i) the compression rate ii) space partitioning code design iii) general implementation strategies iv) ability to handle source correlation. While the author discusses more on compression rate, space partitioning and implementation strategies favoring syndrome approach over noiseless channel he recommends parity based approach over noisy channel on the ground that parity approach has better ability to handle source correlation. But we put forth some of the other things which the author has not considered to prove syndrome technique is better.

5.2 Further Discussions and Solutions

Ourdiscussions are based on encoder complexity, ability to handle bit error and decoder complexity. For (n, k) LDPC parity check matrix to achieve the same compression rate approaching the S/W limit, the parity approach should have the code dimensions $(2n - k, n)$ [13] [14]. Firstly this dimension increases the complexity of both encoder as well as decoder due to longer channel code length. Secondly the parity check matrix factor graph will have short cycles in the design due to longer code length for the same number of check nodes. This can be explained with an example, we consider (7,4) syndrome code and the equivalent parity code should be (10, 7) to achieve the same compression rate. For the syndrome approach the number of check node is 3 for total of 7 variable nodes, while for parity approach 3 check nodes for 10 variable nodes. The theory is that as the number of bits participating in the check node increases its error correcting capacity increases, when it is done in parity method, 10 nodes instead of 7 has to join only 3 check nodes which results in short cycles which further increases the error rate. The bit error correcting capacity is more for parity check approach with respect to the hamming distance [12]. But the author does not take in to account the longer coderequired to achieve the same compression rate. With longer code length both approaches has the same bit error correcting capacity. We explain with the simple example here. Syndrome approach takes (7,4) code for code rate of 3/7 and its error correcting capacity is one out of 7 bits. To achieve the same code rate and error correction parity approach needs (10,7).

The compression rate cannot go below $1/2$ for parity approach if the code has to approach S/W limit [13]. As we need a variable rate code for DVC application, this gives the greatest limitation in the video transmission over variable correlation parameter channel. Finally we consider a point called channel estimation error in favor of syndrome approach, which no author has considered so far. The channel estimation error plays a role in the bit error in an indirect way, in parity approach both the parity bits and side information are involved in the initial log likelihood ratio side (LLR) calculation. As the parity bits and side information bits both belongs to different channel two different channel parameter estimation need to be done. The transmission channel estimation error leads to parity bit error which subsequently results in information bit error in decoding. The syndrome approach suffers from only single channel estimation error. This can be explained with the Belief propagation decoding algorithm for parity and syndrome approach. The algorithm described in

[15] is explained here with respect to the difference. While the step 1 and step 2 is same for both the techniquesthe step three is given by

$$\tan h\left(\frac{t_{j.m}^{out}}{2}\right) = \ (1-2s_j)\prod\nolimits_{i=1,i\neq m}^{r_j} \tan h\left(\frac{t_{i.m}^{in}}{2}\right)$$

$m = 1,2, \dots\dots r_j$ & $i = 1,2, \dots\dots n-k$ .The factor $1-2s_j$ accounts for the syndrome factor.In Parity approach the variable node is formed by side information which is under virtual channel and parity information under the actual channel.But in syndrome approach the syndromes are not the part of variable node and hence not involved in LLR calculation; this reduces the channel estimation error and hence we conclude syndrome approach is optimal for both noiseless and noisy S/W problem from the above discussions

6 Simulation Setup and Results

6.1 Simulation Setup and Results

As our research is to focus on modulation techniques for DVC rather than DVC itself, we simulated the DVC setup by image files in order to reduce the complexity of coding work. For a DVC setup to be created with bmp image, we need one actual frame and side frame. We simulated the side frame by corrupting the image with different cross over probabilities. AWGN channel is considered for wireless transmission. A LDPC matrix of (20000, 10000) for GF (2)-BPSK, (9000, 6000) for GF (4) -QPSK /QAM and (6000, 4000) GF (8)-8PSK is considered for Slepian wolf coding.Simulation results in Figure 1shows the Q2 LDPC DVC coding of parity and syndrome approaches. We see that the syndrome approach is as good as parity approach at higher SNR and lower SNR. This means that we have still room for improvement with syndrome approach for same compression ratio when we take in to account the LLR estimation going wrong in real time scenario. Figure 2 results show that the gray labeling of bit sequence improves a little less than one db coding gain. Similar results apply for 8 PSK 8 Ary LDPC. Figure 3 gives the comparison results of Q(2) Q(4) and Q(8) LDPC coded modulation results. We see that though higher modulation increases the Bit error rate the higher order LDPC coding reduces the bit error rate in such a way that almost 10db coding gain we geton comparing between Q(2) and the higher order one. But between Q(4) and Q(8) we get very little coding gain like 3 db. With respect to our simulations we believe that combination of M-Ary LDPC with M-Ary modulation syndrome based DVC will work comparatively with parity approach in a noisy environment. Our next work is to prove that syndrome approach in a noisy environment outperform parity approach when LLR estimation goes wrong in parity approach and also to combine a different labeling technique other than gray labeling.

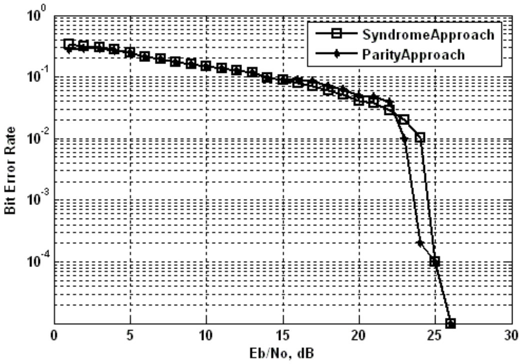

Fig. 1. Bit Error Probability Curve for Parity and Syndrome Approaches

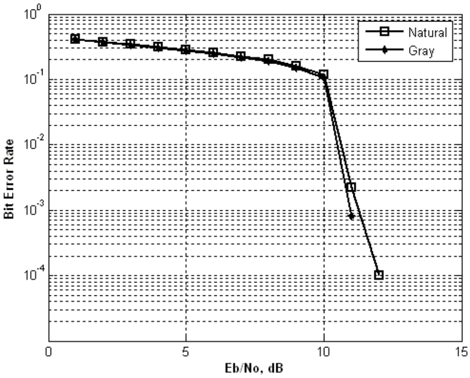

Fig. 2. Bit Error Probability Curve for 4Ary LDPC coded 4Ary Modulation

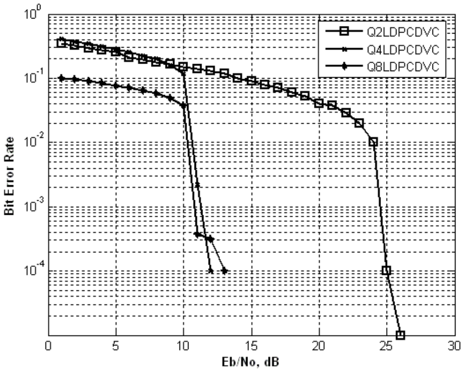

Fig. 3. Comparison of higher order LDPC coding with Binary LDPC

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