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A Simple and Least Complex KV Transform Coding Technique with Low BER Performance at Low Eb/No for Multi-Tiered Applications in Power and Bandwidth Constrained MANET/Sensor Networks

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ABSTRACT:

This paper presents a novel idea of Koay-Vaman (KV) Transform coding technique which is based on block coding technique. It provides the ability to detect errors, correct errors and identifies the remaining block error in each of the transmission ensembles. Exploiting this property will allow design of bandwidth efficient MANET and sensor networks to support provisioning of multi-service applications. Moreover, KV Transform technique permits recovery of end user information at low Eb/N0 which is typically observed in a heavy multi-path fading environment, which is suitable for both in-door and out-door real time applications. It addresses the challenges of MANETs that require bandwidth and power efficiency, Quality of Service (QoS) provisioning of multi-services and scalability. KV transform technology is based on discrete sample orthogonal and invertible transform using time-frequency variation analysis. This paper presents BER performance ($< 10^{-7}$) on Rayleigh fading channel using the proposed KV transform technique with sample error correction, single selective retransmission of blocks that are in error and sample interleaving at very low Eb/No.

***Keywords**: KV Transform; Forward error correction; Selective single retransmission, sample interleaving; Single Retransmission, MANET and Sensor Networks; and Multi-path Interference.*

1.0 INTRODUCTION

Error detection techniques have been widely used in network centric architectures. Predominantly, the Cyclic Redundancy Check (CRC) has been used in packet networks for error detection and retransmission. CRC allows the detection of errors and does not have any knowledge of the location of errors. Therefore, for successful transmission of messages, it is important to request retransmission of the same packets until they are received correctly at the receiving side. While this technique reduces the undetected errors in the messages, the penalty in the network is the increased delay and thereby response time to the end user that affects the Quality of Service (QoS). In Mobile Ad Hoc Networks (MANETs), if this technique is used at the link layer, the overall throughput is significantly reduced. Also, if link by link is used for error handling in a multi-hop connected path, there is a significant increase in end-to-end delay significantly [1]. Forward Error Correction (FEC) has been used widely in many satellite and wireless channels. Many FEC techniques have been described significantly by many researchers [2, 3, 4]. FEC technique typically allows sending a separate error correcting code with the messages and at the receiving side the errors in the messages are corrected with the error correcting code using different statistical principles. The remaining errors are sent as undetected errors to a higher layer function, since the location of errors cannot be seen by the FEC, thereby increasing the processing delay.

Embedded transform coding techniques can be classified as FEC techniques with the exception that they are based on transform technique, where the user data is transformed and sent to the receiving side. The transformation allows for error correction with some side information. These techniques have been used extensively

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in image processing applications [5]. However, to the best of our knowledge, they have not been used for error correction in network centric architectures as part of the transport system.

In MANET/sensor networks, where *"power efficiency" and "real time performance"* are very critical to support provisioning of QoS assurance for multi-service applications, it is difficult to implement any of the above error detection/retransmission. They tend to increase the power of processing time due to coding complexity, or the remaining error goes as undetected due to lack of knowledge of location.

The compelling argument for KV transform coding is its simplicity of decoding and the ability to support key functions of MANET/Sensor networks in real time:

- Low Eb/No operation allows data exchange in multi-path interference environment [6].
- Real time measurement of "ensemble error rate at each ensemble" allows *"data fusion centers"* to take localized management actions are taken using this knowledge. One of the critical applications is to permit Non-Line-Of-Sight (NLOS) and Beyond-Line-Off-Sight (BLOS) lethality in either the battlefield theater for targeting the enemy or in peace keeping mission to protect a soldier when he/she is disruptively isolated from communications.
- The ensemble rate knowledge also allows the system to very the number of bits/sample (*increase the noise margin for detection of data)* without any change to the constellation size to handle severe impairments on the channel in a path or a node to ensure continuity of service provisioning or changing the path to maintain end-to-end Quality of Service (QoS) assurance for multi-hop communications.

MANET, Sensor and mixed MANET/Sensor networks tend to use peer-to-peer radio communications and multi-hop routes to exchange end user information. Maintaining bandwidth efficiency and power efficiency require algorithms used in the nodes (radios) to be simple, use minimal processing time and minimal real estate. Figure 1 illustrates a typical MANET/Sensor network architecture.

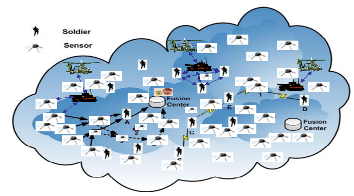

Fig.1 MANET/Sensor Network Architecture in typical Battlefield Theater

For a realistic operational scenario, the network in Fig. 1 is typically organized in terms of clusters of finite nodes (radios and sensors). Each cluster is managed locally by a cluster head (radio that has the management responsibility). This architecture is consistent with the tactical operations of the theater [7, 8]. The cluster heads ensure that association of the nodes within each cluster is maintained through management actions between cluster heads when nodes move out of cluster and reaches the next cluster. Since multi-path fading causes low Eb/N0 which is significant indoors and near the vicinity of buildings, attempting to estimate and model the multi-path fading to recover the information is difficult. However, by using the proposed KV transform (deployed at the physical layer in the node), it is possible to recover the information at very low Eb/N0. KV transform uses discrete samples (n bits/sample) as the input and produces orthogonal samples that also requires n bits for transmission. In addition, it sends two samples of over head for error correction. At the receiving side, each KV block with no more than 1 out of 4 samples are in error can be recovered exactly. Also, the receiver has the ability to identify the remaining errors and its location within each transmission ensemble, thus generates a channel condition as a ratio of number of KV blocks in error and the total number of KV blocks sent in an ensemble. This property can be used for localized action for dynamically changing the number of bits/ sample to increase or decrease the noise margin dynamically. The data recovery process can be effectively improved. In this paper, we present only KV system description and demonstrate its performance in terms of BER versus

Eb/N0. The use of dynamic channel condition for localization is not presented. The remainder of this paper is organized as follows: Section 2 describes the KV Transform techniques; Section 3 describes the KV System Performance; and Section 5 is the summary and conclusion.

2.0 KV TRANSFORM CODING TECHNIQUE

KV transform is a method of designing a set of "orthogonal basis functions" and they are used to transform a set of discrete input samples into a set of coefficient samples. The discrete input samples are created by using a set of digital bits (*n=5 is used for the implemented system*) from an input source. The coefficient samples are sent to the receiving side. Since the transform is invertible, the receiving side will estimate the discrete input samples and then recover the data bits. The KV transform technique also creates overhead samples for error correction where one out of four samples is corrected. This technique works as follows:

1. n bits from a digital source is used to create a discrete n bits/sample. In the proposed implemented system, we use n = 5 bits and four 5 bits/sample are created as input to the KV system.
2. The sending side creates 4 discrete coefficient samples using orthogonal set of basis vectors and generates two overhead samples for error correction.
3. At the receiving side, the system corrects one sample out of four samples exactly. It also identifies the blocks where it cannot correct errors. It also allows taking secondary actions to improve the performance. In the proposed system, one selective retransmission of KV blocks that were not corrected is used to improve the BER performance. That is, the sending side will be asked to retransmit the selected KV blocks in error (in the current ensemble) in the next transmission ensemble along with the samples of new KV blocks. While it improves the BER performance, the information encounters one additional transmission ensemble delay which is very small.
4. The system provides sample interleaving, where the coefficient samples of multiple KV blocks are created in parallel along with the overhead samples. Six message units (packets) are transmitted with the first samples of all KV blocks in the first packet, the second samples in second packet and so on. Also, the overhead samples are also sent from each block such that all of the first overhead samples from each block is sent together in a message block followed by the second block for second overhead samples. The sample interleaving significantly improves the performance of the KV system at low average Eb/No (< 10 dB).

Figure 2 illustrates the block diagram of the KV transform technique. The sample interleaved blocks including the overhead blocks are used to modulate the carrier using 32-ary PAM. At the receiving side the overhead samples are used to correct one out of four coefficient samples in each KV block and then inverse KV function is performed to recover the data. Appendix A illustrates the mathematical description of the KV transform technique.

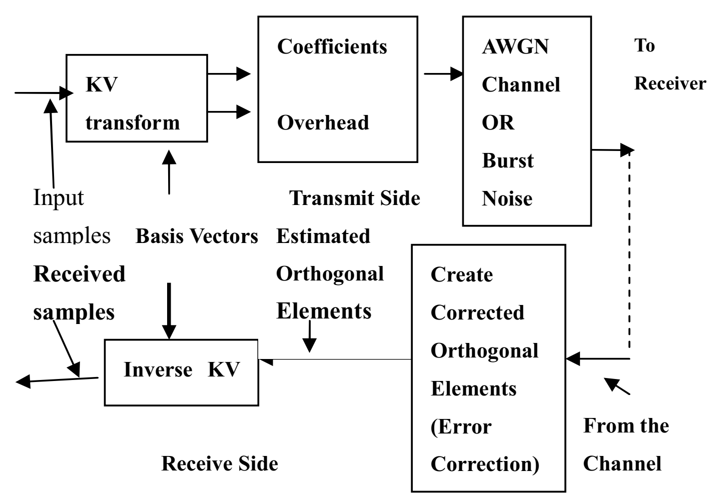

Fig. 2 Block Schematic Diagram of KV Transform Technique

2.1 PROPOSED KV SYSTEM IMPLEMENTATION

Figure 3 shows the implementation of the proposed KV transform coding. The input source is assumed to be digital and a sample is created using 5 bits of digital input.

Four samples, s1, s2, s3 and s4 are used as the input to the KV system which produces four coefficient samples, c1, c2, c3 and c4. In addition, it produced two overhead samples, d1 and d2 for correcting one sample out of four samples at the receiving side. Each input sample si has 32 discrete values. We further generate a set of samples, c1+c2, c1-c2, c3, c4, d1+d2 and d1-d2 which each contain 32 discrete values for all combinations of the input digital data. Each of these modified samples are coded with 5 bits and are transmitted over the channel.

For spreading the burst noise effect, we also considered using interleaving of samples of M KV blocks. Each KV block at the sending side produces six samples for transmission: c1+c2, c1-c2, c3, c4, and d1+d2, d1-d2. For interleaving of samples, the first message unit carries c1+c2 from each of M KV Blocks; the second unit carries c1-c2 from each of M KV blocks; the third unit carries c3 from each of the M KV blocks; the fourth unit carries c4 from each of the M KV blocks; the fifth unit carries d1+d2 from each of the M KV blocks and the sixth unit carries d1-d2 from each of the M KV blocks.

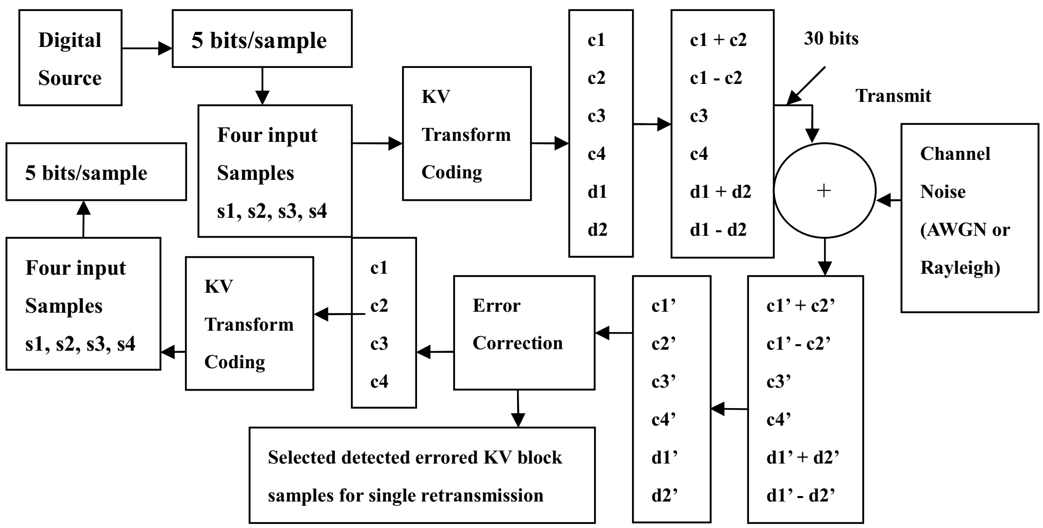

Fig. 3 KV Transform Block Diagram as Implemented using 4 bits/sample and using 4 samples transformation (code rate = 20/30)

At the receiving side, the input samples, si are estimated from the received coefficient samples using the inverse KV operation. From each estimated input sample, 5 bits of data are recovered after error correction of one sample in error out of four samples in a KV block.

2.2 ERROR CORRECTING TECHNIQUE

The proposed KV system implements two layers of error correction technique:

a. Forward Error Correction (FEC) Technique to correct 1 out of 4 samples in error within each KV block of 4 samples.
b. Selective Single Retransmission of KV Blocks in error whose samples are not correctable.

The intent is to minimize the impact of multi-path fading [9]. It is well known from Central Limit Theorem that interleaving of samples allows the error in samples of each KV block is spread and the channel appears as AWGN [10]. For our system, we have chosen M as 64 or 128. When M = 64, the impact of burst errors on samples from each KV block is minimized. In each KV block there are four input samples with each input sample carrying 5 bits. That is, each KV block processes 20 bits. The buffer size for 64 KV blocks would be 1280 bits and for 128 blocks it is 2560 bits.

For VOIP application, the data is being received at a rate 64 kbit/s, therefore the packet (message) generation time is kept between 20 ms and 40 ms (corresponds to buffer sizes of 1280 bits and 2560 bits respectively). For transmission, we need to consider the transmission of 6 packets instead of 4 since we send two additional packets for overhead samples. Therefore, VOIP transmission rate is increased to 96 kbit/s. For message unit sizes of 64 and 128 samples, the equivalent number of bits to be transmitted is equal to 320 bits (or 64 x 5 bits) and 640 bits (128 x 5 bits). The transmission time (at the transmission rate = 96 kbit/s) for the message units for sizes of 64 and 128 samples is 3.33 ms and 6.66 ms respectively. Since we transmit 6 samples for each KV block, these values corresponds to 20 ms and 40 ms of packet generation times respectively and is acceptable to VOIP system.

At the receiving side, the samples of each KV block and the corresponding digital bits are recovered after the error correction and inverse KV operation.

2.2.1 FORWARD ERROR CORRECTION (FEC) TECHNIQUE

From Figure 3, we assume that each sending side KV block transmits c1+c2, c1-c2, c3, c4, d1+d2, d1-d2 and the corresponding receiving side KV block receives c1'+c2', c1'-c2', c3', c4', d1'+d2' and d1'-d2' after the channel noise is added. From these received samples, c1' and c2' are computed using c1' + c1' and c1' – c2'. Similarly, d1' and d2' are computed using d1'+d2' and d1'-d2'.

We generate c1', c2', c3' c4', d1', d2' from above and perform error correction as follows:

Actual d1 and d2 are constructed from:

$$d1 = c1' + c2' + c4';\ d2 = c1' - c2' + c3' \quad (1)$$

Since we have the received values of d1' and d2', we now construct the following difference information:

$$\Delta 1 = d1 - d1';\ \Delta 2 = d2 - d2' \quad (2)$$

The error identification is done as follows:

1. IF Δ1 and Δ2 are both Zero:
THEN, there are no errors in any of the received coefficient samples.

2. IF Δ1 and Δ2 both increase OR decrease by the same amount, X
THEN coefficient sample c1 is in error.
   - ✓ Then SUBTRACT or ADD X to d1 and d2 to compute the correct value of c1.

3. IF Δ1 increases AND Δ2 decreases by the same amount, X
THEN coefficient sample c2 is in error.
   - ✓ Then SUBTRACT X from d1 and ADD X to d2 and compute the correct value of c2 [use (1) and (2)].

4. IF Δ1 = ZERO and Δ2 ≠ ZERO (no error),
THEN, c3 has error
   - ➢ IF Δ2 is < 0, the received value d2' is greater than the computed value by an amount X.
     - ✓ SUBTRACT X from c3' to correct it.
   - ➢ IF Δ2 is > 0, the received value d2' is less than the computed value by an amount X.
     - ✓ ADD X to c3' to correct it.

5. IF Δ1 ≠ ZERO (no error) and Δ2 = ZERO,
THEN, c4 has error
   - ➢ IF Δ1 is < 0, the received value d1' is greater than the computed value by an amount X.
     - ✓ SUBTRACT X from c4' to correct it.
   - ➢ IF Δ1 is > 0, the received value d1' is less than the computed value by an amount X.
     - ✓ ADD X to c4' to correct it.

6. If Δ1 and Δ2 do not satisfy the above 5 sets, then the KV block cannot be corrected and therefore needs to be retransmitted. This condition can occur if d1', d2' are received in error or more than one coefficient sample out of four are received in error.

2.2.2 BLOCK TRANSMISSION OF KV BLOCKS AND PERMIT SINGLE RETRANSMISSION OF EACH KV BLOCK WHEN THE SAMPLES ARE NOT CORRECTABLE

When the coefficient and overhead samples are received at the receiver, there are three conditions that are likely to occur:

- ✓ All samples are received correctly
- ✓ One of four coefficient samples is received in error
- ✓ Two or more samples out of four samples are in error or the overhead samples are received in error.

With sample interleaving, the probability of occurrence of the third event above is greatly reduced.

3.0 KV SYSTEM PERFORMANCE

The overall KV system has been implemented using MATLAB/SIMULINK for deriving the real time performance in terms of BER versus Eb/N0. We used a basic Pulse Amplitude Modulation (PAM) for the transmission system for transmission of KV coefficient samples and overhead samples each of which is coded with 5 bits/sample. The performance of KV/32-ary PAM with single retransmission and interleaving is compared with 32-ary PAM. Figure 3 is used as the system set up for performance comparison. It is possible to use more efficient digital modulation techniques for KV, but it is beyond the scope of this paper.

In a conventional 32-ary PAM system, all the samples are transmitted directly without KV and have no error correction capability. In 6 transmission cycles, 32-ary PAM can transmit 30 user data bits, whereas the KV/32-ary PAM system can transmit 20 user data bits in the same 6 transmission cycles.

Figure 4 illustrates BER versus Eb/N0 comparing "KV/32-ary PAM system with single retransmission and interleaving"; "KV/32-ary PAM system with single retransmission"; and "32-ary PAM system". The "KV/32-ary PAM system with single retransmission and interleaving" achieves BER performance of $< 10^{-7}$ at Eb/N0 < 10 dB. Fig. 5 illustrates the performance of these two systems transmitting JPEG picture for different conditions.

4.0 SUMMARY AND CONCLUSION

In this paper, we proposed a novel KV transform technique and demonstrated its performance to achieve a BER of $< 10^{-7}$ at Eb/N0 < 10 dB when implementing "KV/32-ary PAM system with single retransmission and interleaving". This proposed system can be applied to MANET and sensor network for handling Rayleigh fading channels for data transmission.

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$$\Phi(t)=\begin{cases}1 & 0\le t<\frac{1}{2}\\ -1 & \frac{1}{2}\le t<1\\ 0 & otherwise\end{cases} \qquad (A2)$$

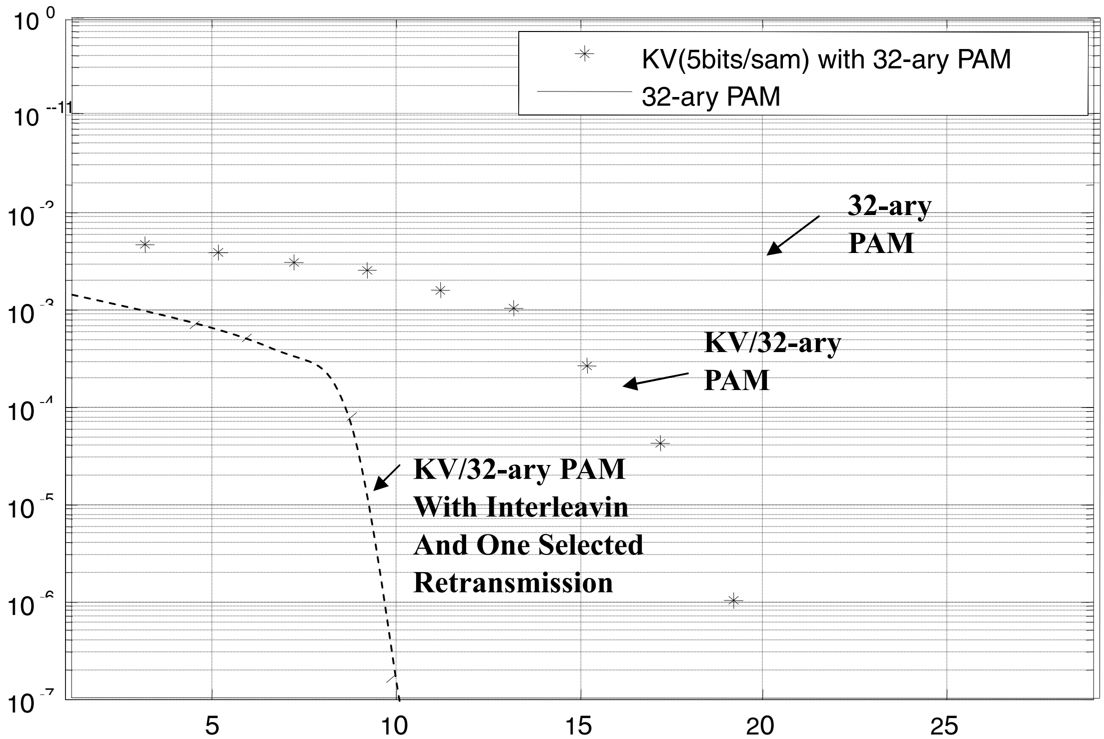

Fig. 4 KV/32-ary PAM with Single Error Correction, Single Retransmission of Selected KV

APPENDIX A: PRINCIPLES OF KV TRANSFORM CODING

We assume that the input source is in digital form. 5 bits of data in our proposed system is used to create an discrete input sample to the KV operation. Four samples are created:

[s1 s2 s3 s4] (A-1)

Then, we construct a set of orthogonal basis functions using the fundamental basis function

For constructing the other orthogonal basis functions, we use the following steps of first time-shifting and then time-scaling operations as shown below:

$$\Phi(t)\rightarrow\Phi(2^j t-i)$$

$$\Phi(t)\xrightarrow{t\rightarrow t-i}\Phi(t-i)\xrightarrow{t\rightarrow 2^j t}\Phi(2^j t-i)$$

$$\Phi_i^j(t)=\Phi(2^j t-i) \qquad (A3)$$

where i = 0, 1,2,..,2^j -1; j = 0,1,2,..,k; k = $\log_2$ n – 1;

and n is the number of 2^m digits (or samples) in a data sequence, where m = 1, 2, 3, …..

Each basis function is a vector of length, n = 4. For transformation on the input samples, 4 x 4 basis matrix is created using 4 normalized orthogonal vectors. The latter can be easily obtained by simply multiplying each orthogonal vector by a scalar $\sqrt{\frac{n}{2^j}}$. Collectively, they form n x n (4x4) matrix and used to transform the input vector of n samples into coefficient samples. The 4 orthogonal basis functions were generated using:

$$U(t),\ \Phi_{i=0}^{j=0}(t), \Phi_{i=0,1}^{j=1}(t) \qquad \text{(A-4)}$$

The dot product of the input vector of [s1, s2, s3 and s4] and the 4x4 normalized orthogonal basis function matrix generates 4 KV coefficient samples:

[c1 c2 c3 c4] (A-5)

These 4 KV coefficient samples are transformed further into a set of samples {c1+c2; c1-c2; c3; c4} for transmission. They are used at the receiver to generate {c1, c2, c3, c4}. The product of these coefficient samples and the 4x4 orthogonal basis function matrix generates 4x4 Decision Matrix, [Dij] for i = 1 – 4 and j = 1 – 4.

The original discrete samples, s1, s2, s3 and s4 are recovered by adding the elements of each column in [Dij]. The corresponding digital data from each sample are sent to the destination.

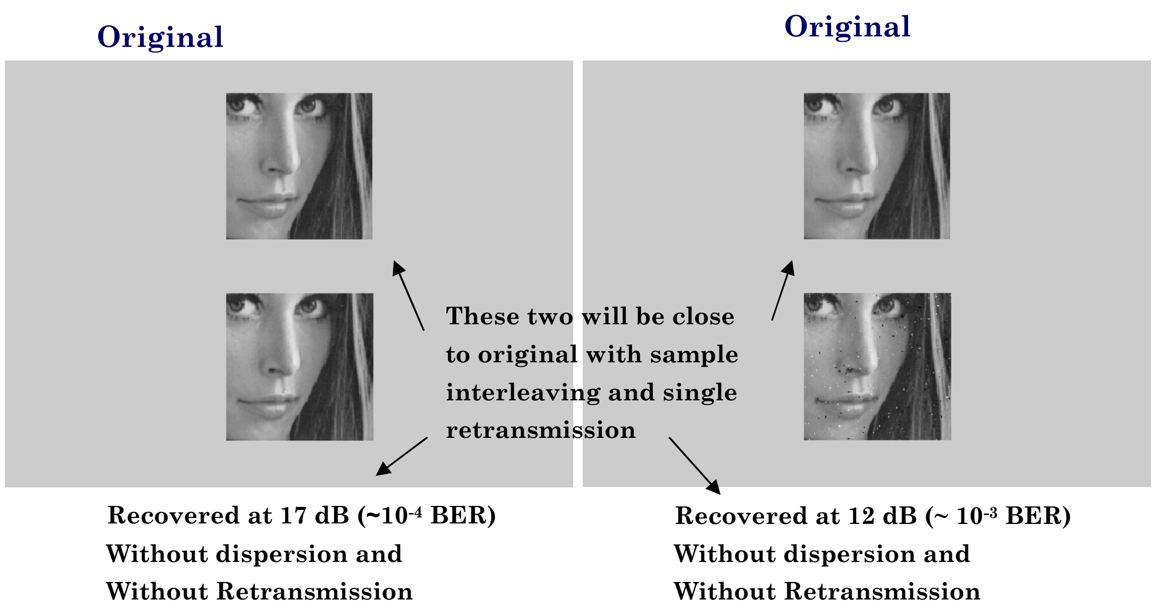

Fig. 5 Performance of KV/32-ary PAM using JPEG Video Clip