

# Multicasting Multiple Description Coding Using p-cycle Network Coding

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## **Abstract**

This paper deliberates for a multimedia transmission scheme combining multiple description coding (MDC) and network coding (NC). Our goal is to take advantage from the property of MDC to provide quantized and compressed independent and identically distributed (iid) descriptions and also from the benefit of network coding, which uses network resources efficiently to recover lost data in the network. Recently, p-cycle NC has been introduced to recover and protect any lost or distorted descriptions at the receiver part exactly without need of retransmission. So far, MDC have not been explored using this type of NC. Compressed and coded descriptions are transmitted through the network where p-cycle NC is applied. P-cycle based algorithm is proposed for single and multiple descriptions lost. Results show that in the fixed bit rate, the PSNR (Peak Signal to Noise Ratio) of our reconstructed image and also subjective evaluation is improved significantly compared to previous work which is averaging method joint with MDC in order to conceal lost descriptions.

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**Keywords:** Multiple Description Coding, Lloyd-max Quantization, p-cycle Network Coding, Wavelet Transform.

## 1. Introduction

**M**ultimedia streaming is a technique for transferring data. Streaming technologies are becoming increasingly important in line with the Internet grows (such as high bandwidth internet). In contrast, this high bandwidth is so expensive and quality of service (QoS) issues are not guaranteed. So a viable approach to combat these problems is streaming data along numerous paths, which increase the likelihood of successful data delivery at the receiver. MDC as source coding method encodes a media streaming into multiple independent and identically distributed (iid) descriptions. These descriptions transmitted over distinct paths in unreliable networks. In real-time communications, the quality of the transmitted signal is highly correlated to the number of available received descriptions [1]. Several methods such as quantization [2] and transformations of correlation [3] are introduced to prepare iid descriptions.

Consider a network in which a number of compressed multimedia descriptions stream has to be transmitted from a set of transmitters to a set of receivers. The basic theory of routing is referred as store-and-forward. Due to distortion and loss occurrence in the network; the retransmission of the transmitted data may significantly affect the time varying characteristics (capacity, delays, or losses) of each communication link. Thus, the quality of the decoded stream at each receiver is far from being deterministic. In this case, in order to prevent complex feedback system to retransmit data, network coding (NC) is used to recover data on the receiver part without retransmission. Alternatively, cooperative relay techniques in networks could be used to enhance the spectrum sensing algorithm to have higher throughput [4].

NC was proposed in 1998 both in the form of nonlinear [5] and the linear form [6]. Then formal literature appeared in [7] and [8], respectively. NC allows a node in the network to perform coding and data forwarding in the intermediate nodes simultaneously. Fig. 1 shows delivery of data by the conventional store-and-forward mode over the butterfly network. Two time slots need to deliver two data symbols  $X$  and  $Y$  from  $A$  to both  $B$  and  $C$ . In contrast; Fig. 2 uses linear NC to achieve the data delivery in just one time slot. It means in one time slot data of  $X$  and  $Y$  can be obtained in both  $B$  and  $C$  destination Nodes. In node  $B$  by *xoring*  $X$  and  $X \oplus Y$  from two incoming nodes,  $Y$  is obtained. Also in node  $C$  by *xoring*  $Y$  and  $X \oplus Y$ ,  $X$  is decoded as well. A fully distributed method to implement the opportunistic network coding scheme without the need of any feedback between two network nodes is presented in [9]. Additionally, In order to have two copies of the same signal on two disjoint paths, p-cycle NC is proposed in [10]. One path is the primary working path (data path). The second path, however, is in fact a virtual path (signal is transmitted with other signals), which is still disjoint from the first primary path. Since, these disjoint paths are independent of each other, so p-cycle NC could be applied to any type topology or even to varying topology network.

Several papers are issued for joint MDC and NC. In [11] combined method is used for video multicast in lossless network and also NC controlled centrally the quality of service. Work by [12-13] present image transmission by using MDC technique over various links in mesh networks while NC prepares protection paths. Joint multiple description lattice vector quantization and NC in [14] is employed to multicast image data over ad-hoc networks. Results shown that high image quality, lower failure rate and fewer energy consumptions are obtained. In [15] a systematic optimization approach based on joint source and NC is proposed.

Finally, a novel technique of video diffusion over ad-hoc networks based on the joint use of network coding and multiple descriptions coding is explained in [16].

The joint scheme takes advantage of merits of MDC and NC, providing strong robustness with lower failure rate and better reconstructed image quality against transmission losses. MDC based on p-cycle NC has not been investigated before. In this paper MDC as a source compression combined with p-cycle NC as a protection method is explored. The significance of using MDC is to compress input data (reduce redundancy) by using quantization method and to prepare several independent and identically distributed (iid) descriptions to balance the traffic of the network on the various numbers of primary links. In contrast, the p-cycle NC links are the protection links which carry the network coded data (xored data) from transmitting nodes to the receiver nodes, in order to protect and recover any loss happens in the network. These protection links (secondary links) are the redundancy or penalty which should be paid in order to recover perfectly the lost information in the receiver which leads to have a higher throughput. P-cycle Network coding techniques allow to achieve the min-cut capacity even when the topology is unknown. We consider a network where neither the sources, nor the receivers have knowledge of the network topology. It means the benefit of p-cycle NC is that for any topology of network, this process could be applied because only transmitter and receiver nodes need to know p-cycle NC protection links.

In the proposed algorithm, p-cycle links (protection links) are disjoint and independent of main data pass (primary links) which means it has no impact on data rate of the network and extra node, and links are not needed. Compared to [17] where averaging of received descriptions is done in order to substitute lost descriptions, the proposed MDC p-cycle based NC method is able to cover and conceal lost descriptions. Furthermore, compared to [12] the proposed method can recover any number of lost descriptions in the network. Even more, unlike [18], in this paper multiple pairs of p-cycle links are applied against multiple link failure in the primary links. The remainder of the paper elaborates the proposed MDC with p-cycle NC for the transmission of multimedia signal. Briefly, p-cycle NC is illustrated in section 2. Section 3 introduces the proposed method for MDC p-cycle based NC. Simulation results and figures are shown in section 4 While Section 5 concludes the paper.

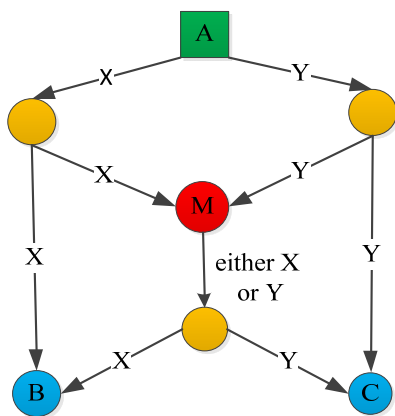


Fig. 1. Conventional store-and-forward.

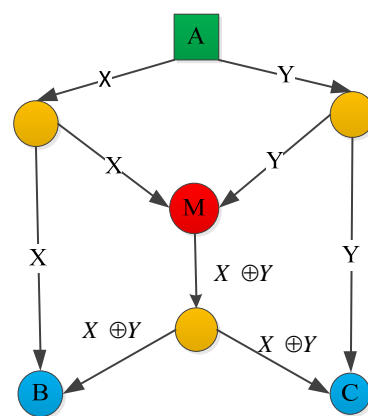


Fig. 2. Linear network coding.

## 2. P-cycle Network Coding

P-cycle NC was first introduced by [10] for protecting against link failures. Recently, a new 1+N protection scheme which is joint NC, and p-cycle is introduced against single link failure in [18].

**Fig. 3** shows an example of p-cycle with three unidirectional connections from source  $S_i$  to the destination  $T_i$ , for  $i = 1, 2, 3$ . For simplicity of the example, it is assumed that sources and their corresponding destinations are sorted from left to right. The capacity of each unit links are assumed unity and also suppose that data units  $d_1, d_2$  and  $d_3$  are sent on those links. As shown in the figure p-cycle is preconfigured to use all the three sources and destinations. Data unit of  $d_i$  will be transmitted three times: once on the primary working path, and twice, in opposite directions on the p-cycle. First time original data unit is transmitted by  $S_i$  on one of the p-cycle protection links and second time data units are transmitted by the receiver  $T_i$  on the other p-cycle protection link. We recognize between those two data units by referring to them as *transmitted* and *received*  $d_i$  units,  $d_i^t$  and  $d_i^r$ , respectively. On the p-cycle, the following procedure takes place:

- 1) data unit  $d_1^t$  is transmitted from  $S_1$  in the clockwise direction. Node  $S_2$  will add and XOR its own data unit,  $d_2^t$  to  $d_1^t$  that it is already received on the p-cycle (where the addition is modulo 2) then  $d_1^t + d_2^t$  is transmitted in clockwise direction on the p-cycle. Node  $S_3$  will repeat the same process, and will XOR  $d_3^t$  to  $d_1^t + d_2^t$  and transmits the result on the p-cycle. In this case node  $T_3$  receives  $d_1^t + d_2^t + d_3^t$  on the p-cycle, and in the clockwise direction.
- 2) On the same link of the p-cycle (clockwise direction), but at the destinations side, once node  $T_3$  receives  $d_1^t + d_2^t + d_3^t$  and also receives  $d_3$  on the working path, it adds or XOR  $d_3$  to  $d_1^t + d_2^t + d_3^t$  to get  $d_1^t + d_2^t$  and forwards it to  $T_2$ . Node  $T_2$  also add  $d_2$ , which is received on the working path, to  $d_1^t + d_2^t$  to obtain  $d_1^t$ , and again, it transmits the result on the same p-cycle to node  $T_1$ .  $T_1$  receives  $d_1^t$  from the clockwise cycle.
- 3) Furthermore, in the same situation when node  $T_1$  receives  $d_1$  on the primary path (working path), it transmits  $d_1$  on the p-cycle, but in the counter-clockwise direction (second p-cycle link). It is defined as  $d_1^r$ . Same as previous scenario on first protection link, again node  $T_2$ , when it receives  $d_2$  on the working path, it adds it to  $d_1^r$ , and transmits  $d_1^r + d_2^r$  on the second p-cycle link, also in the counter clockwise direction.

Based on the above explanations, it is clear that in the absence of failures, each destination node  $T_i$ , for  $i = 1, 2, 3$  receives two copies of  $d_i$ :

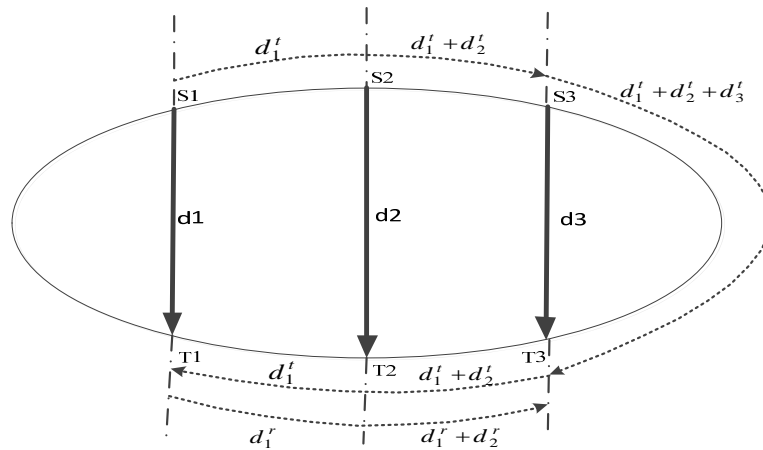
- 1) One copy from the working path, and

2) The second one is recovered by adding  $\sum_{j=1}^i d_j^t$  which is received on the clockwise p-cycle to  $\sum_{j=1}^{i-1} d_j^r$ , which is received on the counter-clockwise cycle. This is a *virtual copy* of  $d_i$  as we referred.

When a failure occurs, it affects working paths, e.g., working path  $i$ . In this case, we suppose that  $T_i$  will receive an empty data unit on the working path. Therefore,  $T_i$  will be able to recover  $d_i$  by using the second virtual copy explained above, i.e., by adding  $\sum_{j=1}^i d_j^t$  and

$$\sum_{j=1}^{i-1} d_j^r .$$

It can be concluded that a failure on the p-cycle will not interrupt communication on primary working paths because of independency of primary path and protection path. Also, it is supposed that there is no distortion or failure on the p-cycle protection links.



**Fig. 3.** An example of the use of network coding on p-cycles to protect against link failures

### 3. Proposed Method for MDC P-Cycle Based Network Coding

In the source coding section input image could be downsampled to  $l$  number of subimages on spatial domain. These subimages later are mapped to transform domain by WAVELET transform, and Lloyd-max quantized respectively to provide multiple *iid* descriptions. These descriptions are defined as  $x_1, x_2, \dots, x_l$ .  $x_i$  is a matrix of  $\alpha \times \beta$  ( $\alpha$  is row and  $\beta$  is the column of each description). For a network to be protected against a maximum of  $M$  link failures ( $M \leq l$ ), it employs  $M$  cycles, which are referred to by  $C_M$  for  $M = 1, 2, 3, \dots, l$ . Protection cycle  $C_l$  passes through nodes in  $S_l \subseteq S$  and  $T_l \subseteq T$  (node  $S_i \in S$  transmits

data units  $d_i$  on the primary paths to the corresponding receivers while node  $T_i \in T$  receives data units  $d_i$  on the primary paths from corresponding senders) where nodes in  $S_l$  communicate bidirectionally with the nodes in  $T_l$ . Note that  $\bigcup_{l=1}^M S_l = S$  and  $\bigcup_{l=1}^M T_l = T$ .

These  $C_l$  cycles (vectors in the space of  $l$ ) should be independent from each other. The  $l$  cycles must be link disjoint and they must be disjoint from primary paths (data links). The matrices of p-cycle links is defined as:

$$C = UP,$$

$$U = [U_1 \mid U_2], \text{ and } P = \begin{bmatrix} S \\ T \end{bmatrix},$$

then

$$C = [U_1 \mid U_2] \begin{bmatrix} S \\ T \end{bmatrix}. \tag{1}$$

The  $U$  is the transition matrix and  $P$  is the matrix of nodes that carries p-cycle protection links. The matrix of  $U$  is linearly independent (each row vectors is linearly independent from other row vectors) [19]. Moreover,  $U_1$  and  $U_2$  are same in size and all elements of  $U_1$  are one except on side diagonal which are zero but in  $U_2$  all the elements are one except on the main diagonal. Therefore, each  $C_l$  link that crosses transmitter nodes ( $S$ ) are symmetrically repeating in the receiver side on the corresponding nodes ( $T$ ).

$$\begin{array}{c}
 \left[ \begin{array}{c} C_1 \\ C_2 \\ \vdots \\ C_{\frac{l}{2}} \\ \vdots \\ C_{l-1} \\ C_l \end{array} \right]_{l \times l} = \begin{array}{c}
 \underbrace{\begin{bmatrix} 1 & 1 & \dots & 1 & \dots & 1 & 0 \\ 1 & 1 & \dots & 1 & \dots & 0 & 1 \\ \vdots & \vdots & & \vdots & & \vdots & \vdots \\ 1 & 1 & \dots & 0 & \dots & 1 & 1 \\ \vdots & \vdots & \dots & \vdots & \dots & \vdots & \vdots \\ 1 & 0 & \dots & 1 & \dots & 1 & 1 \\ 0 & 1 & \dots & 1 & \dots & 1 & 1 \end{bmatrix}}_{U_1 \text{ matrix of transmitter side}} \mid \begin{array}{c}
 \underbrace{\begin{bmatrix} 0 & 1 & \dots & 1 & \dots & 1 & 1 \\ 1 & 0 & \dots & 1 & \dots & 1 & 1 \\ \vdots & \vdots & & \vdots & & \vdots & \vdots \\ 1 & 1 & \dots & 0 & \dots & 1 & 1 \\ \vdots & \vdots & \dots & \vdots & \dots & \vdots & \vdots \\ 1 & 1 & \dots & 1 & \dots & 1 & 1 \\ 1 & 1 & \dots & 1 & \dots & 1 & 0 \end{bmatrix}}_{U_2 \text{ matrix of receiver side}} \\
 \underbrace{\hspace{10em}}_{\text{transmitter nodes =}} & \underbrace{\hspace{10em}}_{\text{receiver nodes =}} \\
 1 & 2 & \dots & \frac{l}{2} & \dots & l-1 & l & l & l-1 & \dots & \frac{l}{2} & \dots & 2 & 1
 \end{array}
 \end{array}
 \begin{array}{c}
 \left[ \begin{array}{c} S_1 \\ S_2 \\ \vdots \\ S_{\frac{l}{2}} \\ \vdots \\ S_{l-1} \\ S_l \\ T_l \\ T_{l-1} \\ \vdots \\ T_{\frac{l}{2}} \\ \vdots \\ T_2 \\ T_1 \end{array} \right]_{2l \times 1} \tag{2}
 \end{array}$$

Each of  $l$  cycles consists of two rotating directional cycles. These connections can be selectively protected against any number of  $M$  links failures where  $1 \leq M \leq l$ . Moreover, once  $M$  increases in the network, the calculation of reconstruction takes much time, which

means receiver nodes should buffer data while processing it. In our case, it is supposed that data is already buffered for processing.

In the following subsections  $l$  as a number of descriptions is supposed to equal 4. In this scenario, we have 1 to 4 lost descriptions. So, the equation (2) is simplified as below matrix for connection of nodes in order to protect against 4 lost descriptions. These 4 protection cycles are shown in Fig.5.

$$\begin{bmatrix} C_1 \\ C_2 \\ C_3 \\ C_4 \end{bmatrix}_{4 \times 1} = \begin{bmatrix} 1 & 1 & 1 & 0 & 0 & 1 & 1 & 1 \\ 1 & 1 & 0 & 1 & 1 & 0 & 1 & 1 \\ 1 & 0 & 1 & 1 & 1 & 1 & 0 & 1 \\ 0 & 1 & 1 & 1 & 1 & 1 & 1 & 0 \end{bmatrix}_{4 \times 8} \begin{bmatrix} S_1 \\ S_2 \\ S_3 \\ S_4 \\ T_4 \\ T_3 \\ T_2 \\ T_1 \end{bmatrix}_{8 \times 1} = \begin{bmatrix} S_1 + S_2 + S_3 + T_3 + T_2 + T_1 \\ S_1 + S_2 + S_4 + T_4 + T_2 + T_1 \\ S_1 + S_3 + S_4 + T_4 + T_3 + T_1 \\ S_2 + S_3 + S_4 + T_4 + T_3 + T_2 \end{bmatrix} \quad (3)$$

So as an example, subsection 3.1 describes one pair p-cycle link for single lost description. This lost could be any of 4 primary links ( $x_1, x_2, x_3$  or  $x_4$ ). Subsection 3.2 shows 4 pairs of p-cycle links in order to protect multiple lost descriptions (up to 4) simultaneously.

### 3.1 Proposed Method for Single Lost Description.

As Fig. 4 shows, coded descriptions ( $x_1, x_2, x_3$  and  $x_4$ ) are transferred through the mesh network and nodes. In the network, in order to combat losses, p-cycle NC is utilized in the nodes (green links are p-cycle NC links). Each pair of p-cycle links has two rotating links, one clockwise link and one counter clockwise link. E.g. in node  $S_1$ , the clockwise input protection link ( $x_4 \oplus x_3 \oplus x_2$ ) is xor with description  $x_1$  and transmitted to node  $T_1$  in clockwise direction. Also counter clockwise input protected link to node  $S_1$  ( $x_4 \oplus x_3 \oplus x_2 \oplus x_1$ ) is xor with the description of  $x_1$  and transmitted counter clockwise to node  $S_2$ . So by these two protection links any lost data can be reconstructed.

For example, if link route  $x_2$  is lost, in the node  $T_2$  by taking xor of two incoming protection link ( $x_4 \oplus x_3 \oplus x_2$  and  $x_4 \oplus x_3$ ) lost  $x_2$  signal is reconstructed. So any of data links ( $x_1, x_2, x_3$  and  $x_4$ ) are lost by using p-cycle NC lost data can be reconstructed exactly.

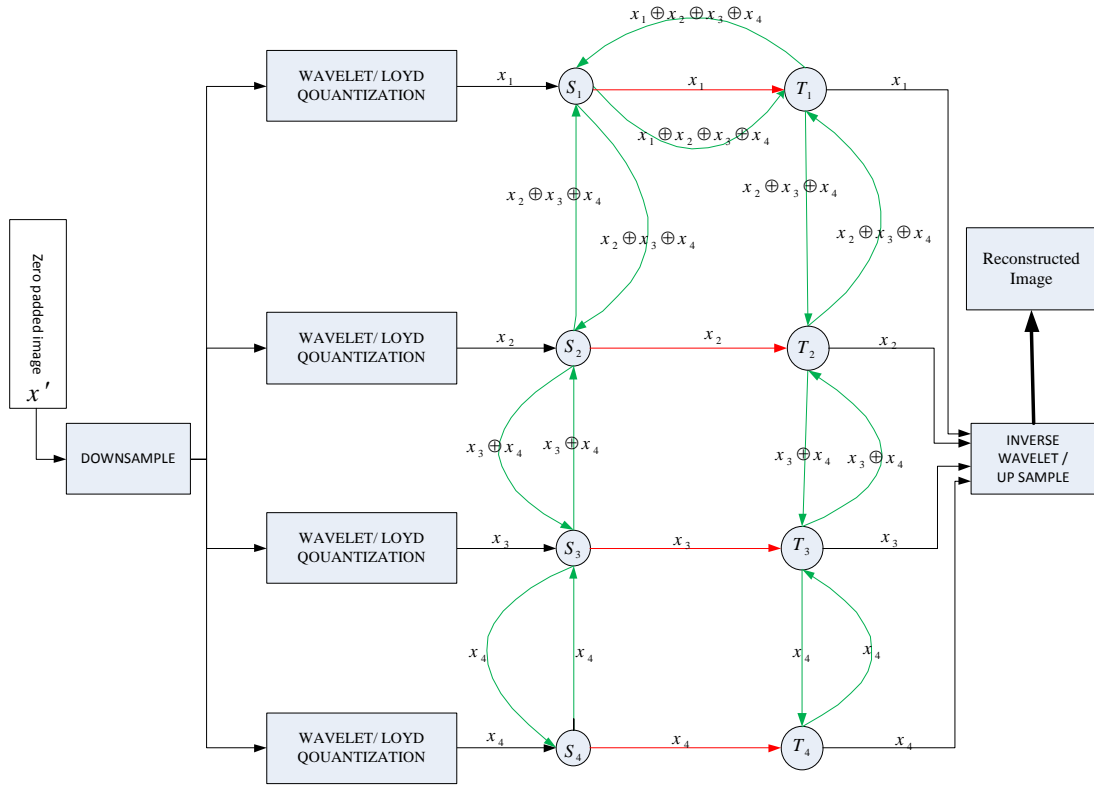


Fig. 4. Block diagram of proposed method for single lost description.

### 3.2 Proposed Method for Multiple Lost Descriptions.

Consider coded descriptions  $(x_1, x_2, x_3$  and  $x_4)$  are transmitted through the network. Fig. 5 shows the block diagram of the proposed method. In this method, we can recover of 2, 3 or 4 lost descriptions. We supposed that number and name of missing links are unknown. As an example, it could be two lost descriptions but which pairs? It can be  $(x_1, x_2)$ ,  $(x_1, x_3)$ ,  $(x_1, x_4)$ ,  $(x_2, x_3)$ ,  $(x_2, x_4)$ ,  $(x_3, x_4)$ . So there could be 6 states for two lost descriptions. Also if we have three lost descriptions, then it can be  $(x_1, x_2, x_3)$ ,  $(x_1, x_2, x_4)$ ,  $(x_1, x_3, x_4)$ ,  $(x_2, x_3, x_4)$ . As can be seen 4 states are available for three lost descriptions. So our p-cycle links should be designed to protect all these situations. In Fig. 6, there are four pairs of protecting p-cycle, which are plotted with different color and font line. Below these p-cycle links with both clockwise and counter clockwise circulation are explained in Fig. 5.

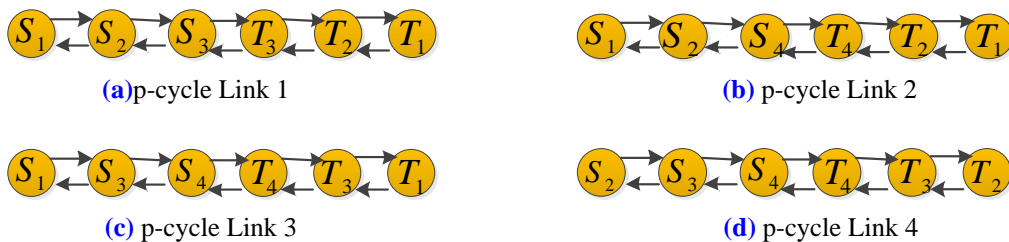


Fig. 5. Four different p-cycle links in block diagram of Fig.6.



Examples:

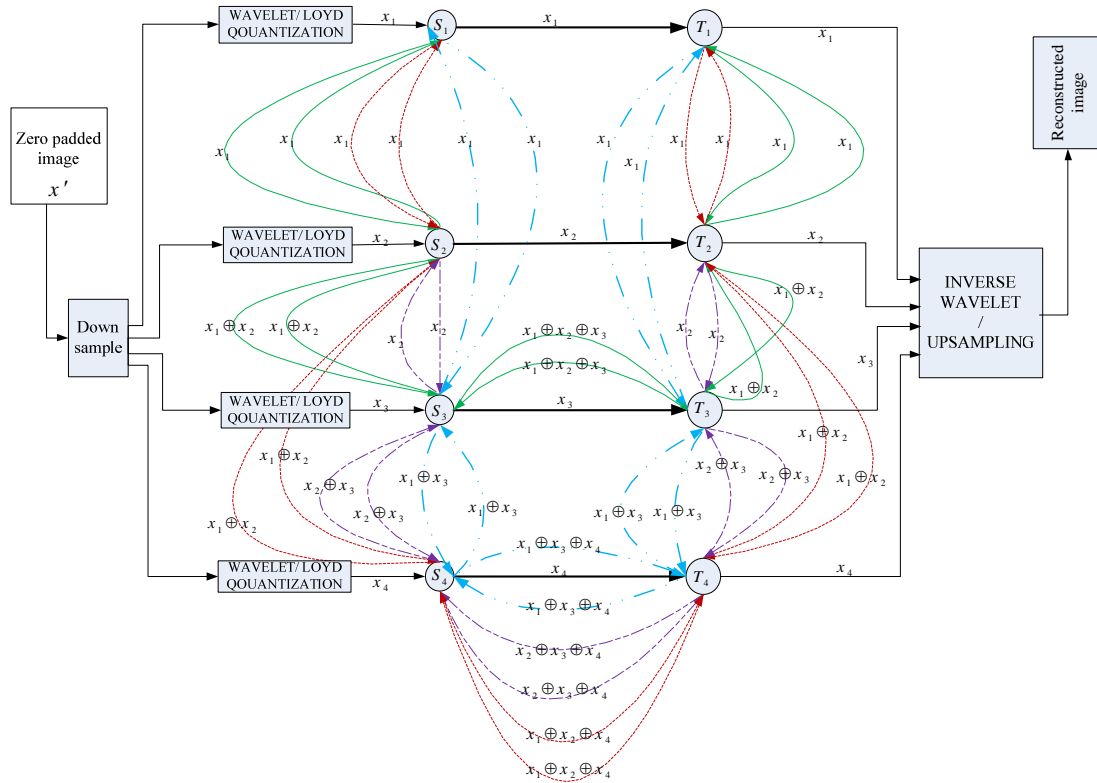
There are 2 lost descriptions and those are supposed to be  $x_1$  and  $x_3$ . From link 4 in node  $T_3$  there is one entering clock wise  $x_2$  and one counter clockwise entering  $x_2 \oplus x_3$ . Node  $T_3$  by taking xor of  $x_2$  and  $x_2 \oplus x_3$  can reconstruct the lost  $x_3$ . Also by using link 1 on node  $T_1$ , the lost  $x_1$  can be recovered.

Suppose if there are three lost descriptions, which are  $x_1$ ,  $x_2$  and  $x_3$ . Then in node  $T_4$  the outgoing counter clockwise protection links are:  $x_1 \oplus x_3$ ,  $x_2 \oplus x_3$  and  $x_1 \oplus x_2$ . In node  $T_3$  by using the incoming counter clockwise link  $x_1 \oplus x_2 \oplus x_3$  from p-cycle link 1 and xoring it with  $x_1 \oplus x_3$ , the  $x_2$  is created and transmitted to node  $T_2$  and if again xor  $x_1 \oplus x_2 \oplus x_3$  with  $x_2 \oplus x_3$  the  $x_1$  is recovered and transmitted on counter clockwise direction to node  $T_1$ . Later, node  $T_1$  transmits the  $x_1$  on the clock wise direction to node  $T_3$  then by xor  $x_1$  with  $x_1 \oplus x_3$  the coded  $x_3$  is obtained. So all 3 lost descriptions are created by using these links.

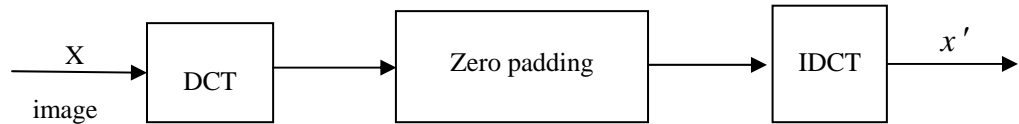
#### 4. Simulation Results

In this work, the input  $512 \times 512$  grayscale image is zero padded. The zero padding process is presented in **Fig. 7**. Zero padding is pre-processing method. In this process, some zeros are added to the image until high quality reconstruction of the image is achieved although losing descriptions in the transmission channel [20]. At first, DCT is applied to whole grey scale  $512 \times 512$  image. Then 108 lines zeros are added to rows and columns. Inverse DCT is later used to map the data to spatial domain  $\hat{x}$ . Hence, the correlation of pixels of image is increased in this method. If there are losses in the channel, by using received descriptions, lost descriptions can be constructed in high quality.

Zero padded data are applied to the block diagram of **Fig.4** and **Fig. 6**. Data are downsampled to four subimages. Second level of type bi-orthogonal wavelet is taken from each subimage then Lloyd – max quantization is used to quantize and code subimages. More details on Lloyd-max quantization are described in [17]. Descriptions are sent to the network and p-cycle NC applied to them. In the receiver side if any lost descriptions happen, by using p-cycle as mentioned in the above examples, lost data are recovered. Later on inverse wavelet is taken from all obtained descriptions. Then all descriptions are upsampled and created a reconstructed image.



**Fig. 6.** Block diagram of proposed method for multiple lost descriptions.



**Fig. 7.** Zero padding.

**Table 1** show average PSNR (peak signal to noise ratio) of lost descriptions in different bit rates and number of lost descriptions from [17]. **Table 2** presents PSNR of proposed method with different lost descriptions and bit rates for various input images.

PSNR formula for 8 bit image is:

$$\text{PSNR} = 20 \log_{10} \left( \frac{255}{\sqrt{\text{MSE}}} \right) \quad (4)$$

Mean Square Error (MSE) for two  $q \times n$  monochrome images  $I$  and  $J$  that one of the images is considered a noisy approximation of the other is defined as:

$$\text{MSE} = \frac{1}{qn} \sum_{i=0}^{q-1} \sum_{j=0}^{n-1} [I(i, j) - J(i, j)]^2 \quad (5)$$

By comparing two tables, we can observe that in the proposed method (**Table 2**), values of PSNR are higher than **Table 1** in terms of fixed bit per pixel (bpp). Since all lost

descriptions are exactly reconstructed in proposed method by p-cycle NC, so there could be no changes in the PSNR by losing different descriptions. In [17] average of received descriptions are used instead of lost data to recover. But in proposed method instead of averaging, p-cycle NC is used for recovering lost descriptions. In this method during the transmitting descriptions on primary links ( data links) there is no overhead information is sent. The only redundancy of this process is usage of protection links (p-cycle links) which are disjoint from primary links. This is the penalty we should pay in order to have high throughput and better quality of reconstructed image.

**Table 1.** Average PSNR (dB) values for different images from [17].

input image	n=number of lost description	bit rate= 2 bpp	bit rate= 1 bpp	bit rate= 0.5 bpp
<i>lena</i>	n=0	29.91	28.05	26.39
	n=1	29.77	27.99	26.36
	n=2	29.19	27.66	26.23
	n=3	29.10	27.64	26.21
<i>dark-hair woman</i>	n=0	35.13	33.02	31.55
	n=1	34.95	32.92	31.50
	n=2	34.04	32.44	31.24
	n=3	33.82	32.28	31.12
<i>house</i>	n=0	33.73	30.55	28.35
	n=1	33.50	30.47	28.31
	n=2	32.40	30.03	28.10
	n=3	31.99	29.80	28.01
<i>camera man</i>	n=0	27.49	24.58	23.76
	n=1	27.39	24.55	23.74
	n=2	26.88	24.41	23.66
	n=3	26.70	24.35	23.62
<i>f16</i>	n=0	27.24	24.78	23.54
	n=1	27.14	24.74	23.49
	n=2	26.61	24.58	23.40
	n=3	26.42	24.48	23.35
<i>peppers</i>	n=0	28.96	26.79	25.85
	n=1	28.79	26.72	25.80
	n=2	28.21	26.49	25.66
	n=3	28.09	26.40	25.62

**Table 2.** PSNR (dB) for one to four lost descriptions from proposed method.

input image	bit rate= 2 bpp	bit rate= 1 bpp	bit rate= 0.5 bpp
<i>lena</i>	33.13	30.13	29.33
<i>dark hair woman</i>	37.15	34.61	33.04
<i>house</i>	36.22	33.08	30.55
<i>camera man</i>	31.42	27.68	26.69
<i>f16</i>	30.81	28.05	26.60
<i>peppers</i>	31.91	29.73	28.60

In order to compare these two tables better, in Fig. 8 rate distortion plot for *lena* photo is shown. It is obvious that in the fixed bpp, the MSE of proposed method is lower than [17], which means having lower distortion. Since in proposed method for any number of lost description system can recover completely, so results of PNSR are same. However, 4 different p-cycle links according to 0-4 number of lost descriptions are presented. In Fig. 9 also for subjective evaluation, *lena* reconstructed image with 0.5 bpp from proposed method is shown. In Fig.10 same image is reconstructed from [17] with one lost descriptions in 0.5 bpp. By comparing Fig.9 and Fig.10 it is clear that Fig. 9 has less blur than Fig.10 which means the edge of the image features are sharper and more obvious. In Fig. 11 rate distortion figure for

the *dark hair woman* is plotted. Again, it is clear that in the fixed bpp the MSE of the proposed method is lower than the [17]. Reconstructed image is shown in Fig. 12 with the proposed method in 0.5 bpp for *the dark hair woman*. Fig. 13 illustrates the received image from 0.5 bpp and one lost description from [17]. By comparing Fig. 12 and 13, it is clear that by using NC lost data can be recovered clearly in terms of subjective evaluation that leads to have less blur and sharp edges of the image features. Furthermore, Fig. 14 illustrates the subjective evaluation of the Table 2 for the rest of the input images. It is obvious that in the low bpp still quality of the reconstructed data is acceptable and features of the images are clear enough. Finally, in Fig.15 rate distortion plot for the rest the photos of the Table 1 and 2 are illustrated. It is clear that in the fixed bpp the proposed method has lower MSE compared to the results of [17].

## 5. Conclusion

We introduced a proposed method called MDC p-cycle based NC. MDC is used for removing redundant data and creating iid descriptions for data transmission over the communication channel. On the other hand, p-cycle NC is used for adding several links on the protection path in order to combat packet loss and recover any lost descriptions that happen in the network. Results have shown that PSNR of proposed method is higher than previous work in terms of the fixed bpp. Moreover, subjective evaluation illustrates that our reconstructed image is clearer and less blur which means; the edges of the image features are obvious. Furthermore, since NC is to recover the lost data, the number of mislaid descriptions does not affect results in terms of distortion. Finally, because the p-cycle links are disjoint from the primary path, the throughput of the system is maintained.

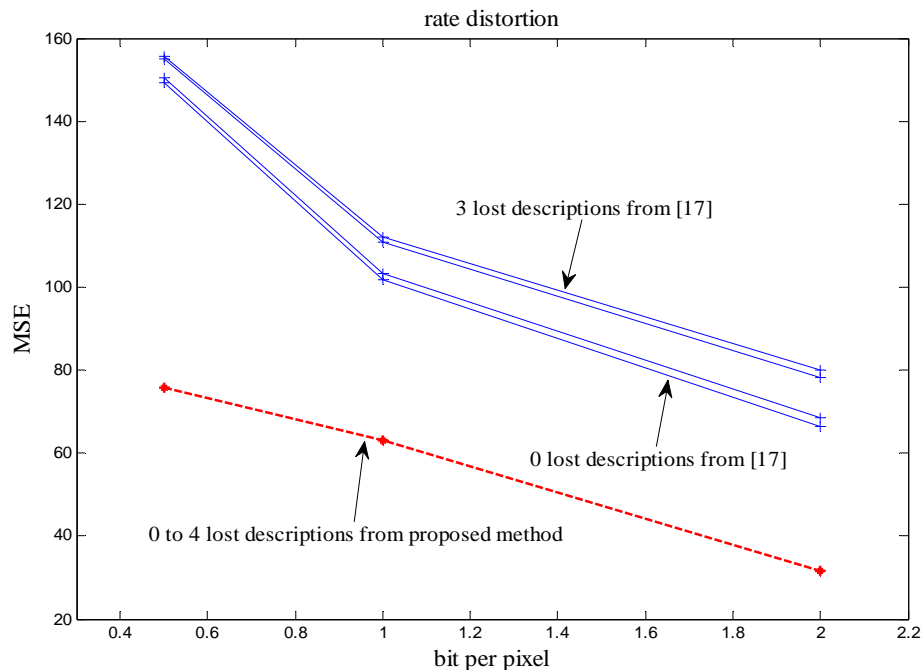


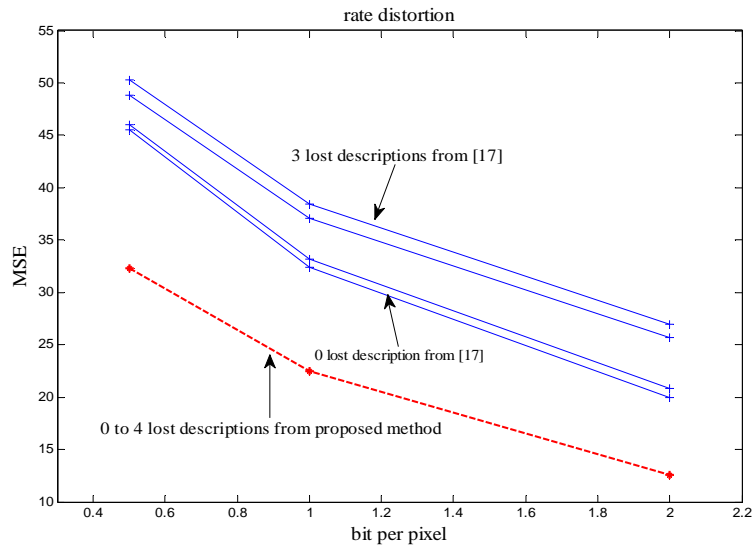
Fig. 8. Rate – distortion plot of proposed method and method of [17] for *Lena*.



**Fig. 9.** Reconstructed *lena* from proposed method with 0.5 bpp, PSNR=29.33.



**Fig. 10.** Reconstructed image in 0.5 bpp with one lost description, PSNR=26.36 [17].



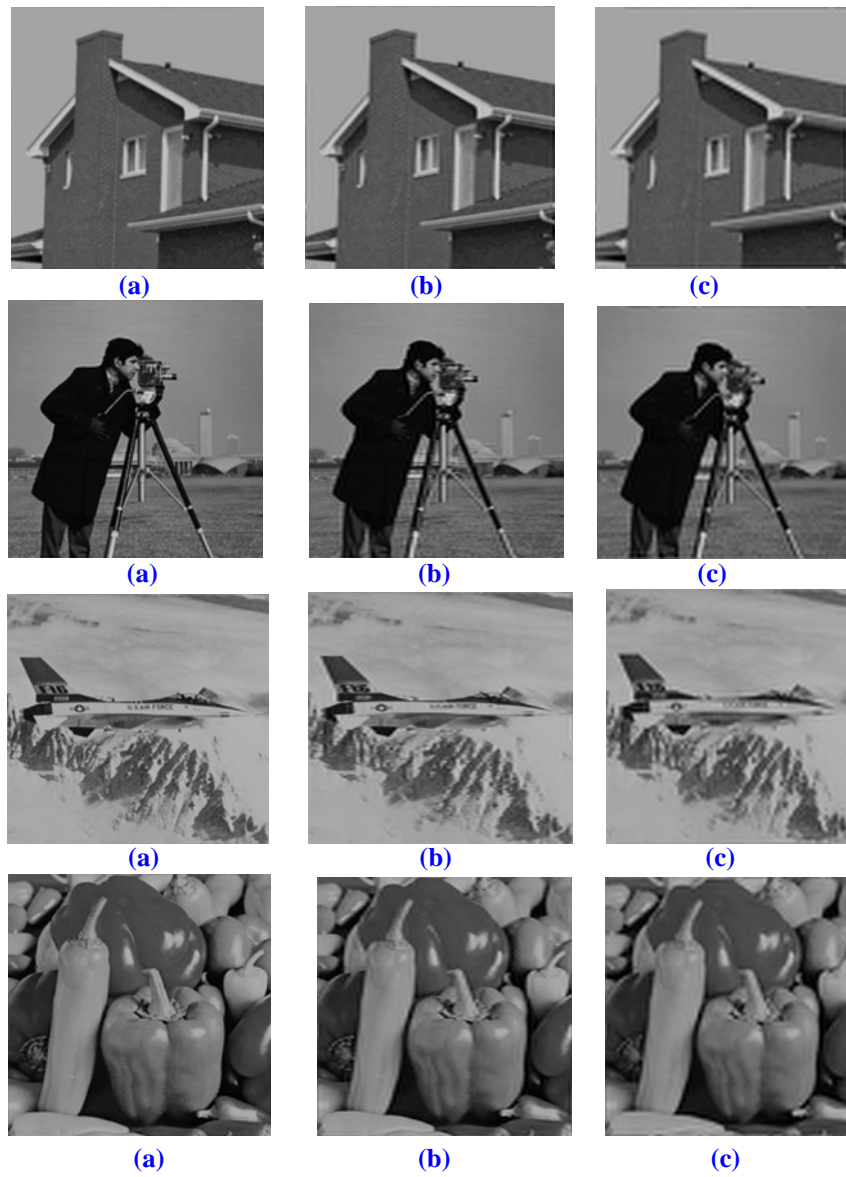
**Fig. 11.** Rate – distortion plot of proposed method and method of [17] for *dark hair woman*.



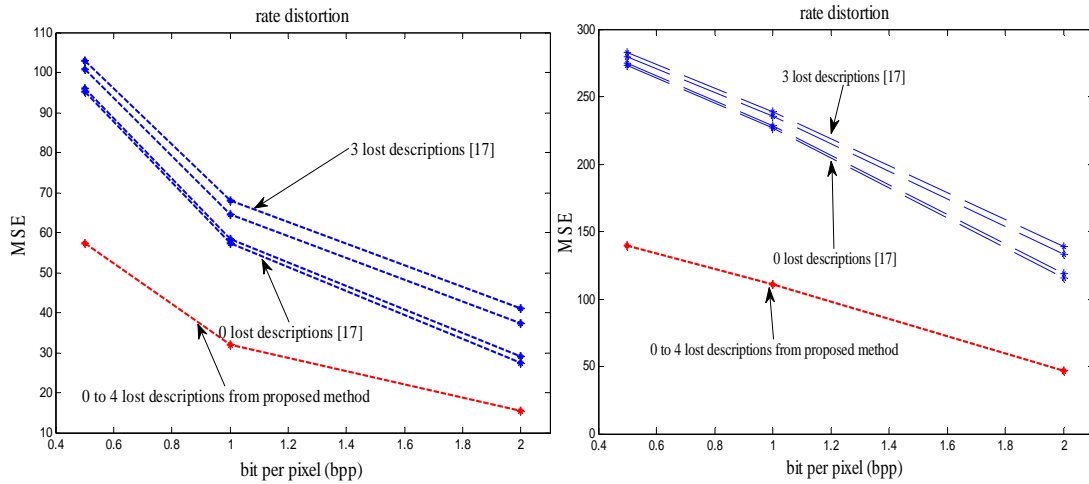
**Fig. 12.** Reconstructed *dark hair woman* from proposed method with 0.5 bpp, PSNR=33.04.



**Fig. 13.** Reconstructed image in 0.5 bpp with one lost description [17], PSNR=31.50.

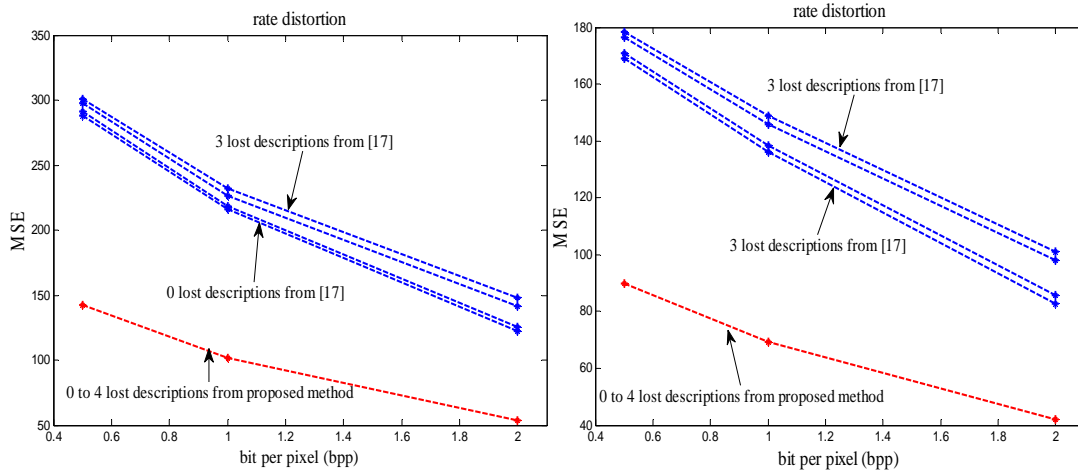


**Fig. 14.** The reconstructed image for *house*, *cameraman*, *f16*, and *peppers* from proposed method. (a) , (b) and (c) are recovered lost descriptions in 2 bpp, 1 bpp and 0.5 bpp respectively.



(a) Rate – distortion plot for *house*.

(b) Rate – distortion plot for *cameraman*.



(c) Rate – distortion plot for *f16*.

(d) Rate – distortion plot for *peppers*.

**Fig. 15.** Rate – distortion plot of proposed method and method of [17] for *house*, *cameraman*, *f16* and *peppers*.

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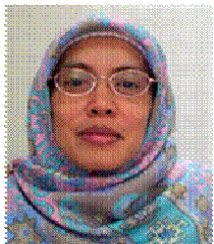




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