

MIXTURE BLOCK CODING WITH PROGRESSIVE TRANSMISSION  
IN PACKET VIDEO

by

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**MIXTURE BLOCK CODING WITH PROGRESSIVE TRANSMISSION  
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Video transmission will become an important part of future multimedia communication because of dramatically increasing user demand for video, and rapid evolution of coding algorithm and VLSI technology. Video transmission will be a part of the broadband integrated services digital network (B-ISDN). Asynchronous transfer mode (ATM) is a viable candidate for implementation of B-ISDN due to its inherent flexibility, service independency, and high performance. According to the characteristics of ATM, the information has to be coded into discrete cells which travel independently in the packet-switching network.

In this thesis, a practical realization of an ATM video codec called Mixture Block Coding with Progressive Transmission (MBCPT) is presented. This variable bit rate coding algorithm shows how a constant quality performance can be obtained according to user demand. Interactions between codec and network are emphasized including packetization, service synchronization, flow control and error recovery. Finally, some simulation results based on MBCPT coding with error recovery are presented.

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**Mixture Block Coding with Progressive Transmission  
in Packet Video**

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## Chapter 1 Introduction

Communicating images has traditionally been the specialty of postal services, and of late, the air freight industry. Early electronic means of communicating photographs used wire services that were essentially forerunners of facsimile. Fax is now moving toward plain paper and eventually color. Fax networks are also becoming increasingly popular for timely distribution of routine communications. But fax is only the tip of an imaging communications iceberg. On the cusp of an explosion in integrated imaging, one effect will be a quantum leap in the demands on networks to move all these images. As color graphics and video become more prevalent, networking capabilities will have to increase further[1].

Due to the rapidly evolving field of image processing and networking, video information is promising to be an important part of tomorrow's telecommunication system. Up to now, telecommunication traffic has been mainly transported over circuit-switched networks. Since packet-switched networks are likely to dominate the communications world in the near future, it is necessary to develop techniques for video transmission over such networks.

The classic approach in circuit switching is to provide a "dedicated path", thus reserving a continuous bandwidth

capacity in advance. Any unused bandwidth capacity on the allocated circuit with circuit-switching is therefore wasted. Rapidly varying frequency signals, like video signals, require too much bandwidth to be accommodated by a standard circuit-switching channel. With a certain amount of capacity assigned to a given source, if the output rate of that source is larger than the channel capacity, quality will be degraded. If the generating rate is less than the limit, the excess channel capacity is wasted. Another point that strongly favors packet-switched networks is the possibility that the integration of services in a network will be facilitated if all of the signals are separated into packets with the same format.

Some coding schemes which support the packet video idea have been explored. Verbiest and Pinnoo proposed a DPCM-based system which consists of an intrafield / interframe predictor, a nonlinear quantizer, and a variable length coder[2]. Their codec obtains stable picture quality by switching between three different coding modes: intrafield DPCM, interframe DPCM, and no replenishment. Ghanbari has simulated a two-layer conditional replenishment codec with a first layer based on a hybrid DCT-DPCM and a second layer using DPCM[3]. This scheme generates two type of packets: "guaranteed packets" contains vital information and "enhancement packets" contains "add-on" information. Darragh and Baker presented a sub-band codec which attains user-prescribed fidelity by

allowing the encoder's compression rate to vary[4]. The codec's design is based on an algorithm that allocates distortion among the sub-bands to minimize channel entropy. Kishino et al. describe a layered coding technique using discrete cosine transform coding, which is suitable for packet loss compensation[5]. Karlsson and Vetterli presented a sub-band coder using DPCM with a nonuniform quantizer followed by run-length coding for baseband information and PCM with run-length coding for the remaining information[6]. In this thesis, a different coding scheme called MBCPT is investigated. Unlike the methods mentioned above, MBCPT doesn't use decimation and interpolation filters to separate the signals into sub-bands. However it retains the desirable aspects of sub-band coding by using variable blocksize transform coding. In Chapter 2, some of the important characteristics and requirements about packet video are discussed. In Chapter 3, some details of image data compression, scalar quantization, vector quantization and transform coding are introduced and the coding scheme, called Mixture Block Coding with Progressive Transmission, is discussed. In Chapter 4, a network simulator used in this thesis is introduced. In Chapter 5, the simulation result is discussed. Finally, in Chapter 6 a summary of this thesis is presented.

## Chapter 2 Packet Video

In this chapter some background for packet video is presented, and some characteristics and requirements of packet video are demonstrated.

### 2.1 Broadband Integrated Service Digital Network

The demand for various services, such as telemetry, terminal and computer connections, voice communications, and full-motion high-resolution video, and the wide range of bit rates and holding times they represent, provide an impetus for building a Broadband Integrated Service Digital Network(B-ISDN). B-ISDN is a projected worldwide public telecommunications network that will service a wide range of user needs. Furthermore, the continuing advances in the technology of optical fiber transmission and integrated circuit fabrication have been the driving forces to realize the B-ISDN.

The idea of B-ISDN is to build a complete end-to-end switched digital telecommunication network with broadband channels. Still to be precisely defined by CCITT(International Telegraph and Telephone Consultative Committee), with fiber transmission, H4 has an access rate of about 135 Mbps. A user gains access to the B-ISDN by means of a local interface to a "digital pipe" of a certain bit rate. At any given point in time, the pipe to the

user's premises has a fixed capacity, but the traffic on the pipe may be a variable mix up to the capacity limit. Thus a user may access circuit-switched and packet-switched services, as well as other services, in a dynamic mix of signal types and bit rates.

The principal benefits to the user can be expressed in terms of cost savings and flexibility. The integrated services means that the user does not have to buy multiple services to meet multiple needs. Further, the user needs to bear the expense of just a single access line to these multiple services.

The B-ISDN can offer a variety of services, including existing voice and data transmission as well as:

- \* Facsimile: services for the transmission and reproduction of graphics, handwritten, and printed material.
- \* Teletext: service that enables the subscriber terminals to exchange correspondence.
- \* Video: video conferencing, picturephone, DTV, HDTV.

## 2.2 Video Transmission over Packet-Switched Networks

Packet-switched networks have the unique characteristics of dynamic bandwidth allocation for transmission and switching resources and the elimination of

channel structure[7]. It acquires and releases bandwidth as it is needed. Because video signals vary greatly in bandwidth requirement, it is attractive to utilize a packet-switched network for video coded signals. Allowing the transmission rate to vary, video coding, based on packet transmission, permits the possibility of keeping the picture quality constant, implementing "bandwidth on demand". Summarizing the above, there are three main merits when transmitting video packets over a packet switching network:

- (1) Improved and consistent image quality: if video signals are transmitted over fixed-rate circuits, there is a need to keep the coded bit rate constant, resulting in image degradation when accompanying rapid motion.
- (2) Multimedia integration: as mentioned in section 2.1, integrated broadband services can be provided using unified protocols.
- (3) Improved transmission efficiency: using variable bit-rate coding and channel sharing among multiple video sources, scenes can be transmitted without distortion if other sources, at the same time, are without rapid motion.

But it has the following drawbacks:

- (1) The time taken to transmit a packet of data may change from time to time.

- (2) Packets of data may arrive very late or even get lost.
- (3) Headers of packets may be changed because of errors and delivered to the wrong receiver.

It has to be emphasized that the delay effect can reach very high levels if there are a lot of users accessing the network. Under many conditions, the loss of packet or erroneous receipt of other packets may seriously damage the quality of the image. Otherwise, because of the strong interaction between the coding algorithm and the network on which it is applied, a new video coding approach is required.

### **2.3 Interaction between Signal Processing and Networking**

Video transmission over a packet-switched network, or "packet video" for short, poses a general problem: a signal with high and greatly varying rate has to be transmitted in a constrained period. When the signals transmitted in the network are nonstationary and circuit-switching is applied, a buffer between the coder and the channel is needed to smooth out the varying rate. If the amount of data in the buffer exceeds a certain threshold, the encoder is instructed to switch into a coding mode that has a lower rate but worse quality to avoid buffer overflow.

In packet-switched networks, Asynchronous Time Division

Multiplexing (ATDM) can efficiently absorb temporal variations of the bit-rate of individual sources by smoothing out the aggregate of several independent streams in common network buffers.

It is a difficult resource allocation and control problem to deliver packets in a limited time and provide a real time service, especially when the source generates a high and greatly varying rate. In packet-switching networks, packet losses are inevitable but they yield a better utilization of channel capacity. The video coder will require different channel capacity over time but the network will provide a channel whose capacity changes depending on the traffic in the network.

There are some interactions between the coder and the network which we have to consider and which become a part of specifications when we design the coder:

- (1) Adaptability of the coding scheme: The video source we are dealing with has a varying information rate. So it is expected that the encoder can generate different bit rates by removing the redundancy. When the video is still, there is no need to transmit anything.
- (2) Insensitivity to error: The coding scheme has to be robust to the packet loss so that the quality of the image is never seriously damaged. Remember that retransmission is impossible because of the tight

timing requirement.

- (3) Resynchronization of the video: Because of the varying packet-generating rate and the lack of a common clock between the coder and the decoder, we have to find a way to reconstruct the received data synchronous to the display terminal.
- (4) Control of coding rate: Sensing the heavy traffic in the network, the coding scheme is required to adjust the coding rate by itself. In the case of a congested network, the coder is switched to another mode which generates fewer bits while degrading image quality.
- (5) Parallel architecture: The coder can be implemented in parallel. That means we can run the coding procedure at the lower rate in many parallel streams.

In the next chapter, we investigate a coding scheme to see if it satisfies the above requirements.

## **Chapter 3 Image Data Compression and Mixture Block Coding with Progressive Transmission**

In this chapter, we introduce the basic concepts of image data compression. We also investigate a coding algorithm called Mixture Block Coding with Progressive Transmission (MBCPT).

### **3.1 Image Data Compression**

Image data compression is a technique used to minimize the number of bits for representing an image. Typical television images have spatial resolution of approximately 512 x 512 pixels per frame. At 8 bits per pixel per color channel and 30 frames per second, this image raw data rate is about  $1.8 \times 10^8$  bits/s. The large channel capacity and memory requirement for digital image transmission makes image data compression desirable.

There are two categories for image data compression, one is lossless coding which can recover the original image without any loss. The need for perfect recovery limits the compression rate that can be achieved. For larger compression rates, a second kind of coding scheme called lossy coding is applied. Lossy coding relies on many-to-one mappings to get a desired rate which is less than the source entropy.

There are two main ways to do lossy image data compression also. The first method, which is called predictive coding, exploits the redundancy in the data. Because an image is a highly correlated source, there is a lot of predictability, called redundancy, in the image. Techniques such as delta modulation and differential pulse code modulation fall into this group. The second method, called transform coding, transforms the given image into another array such that a large amount of the information is packed into a small number of samples. A more detailed discussion is provided in Section 3.3.

The entropy of an image source with  $L$  possible independent symbols with probabilities  $p_i$ ,  $i=0, \dots, L-1$ , is defined as

$$H = - \sum p_i \log_2 p_i \quad \text{bits per symbol} \quad (1)$$

In the simulated image used in the thesis,  $L$  equals 256. According to Shannon's noiseless coding theorem, it is possible to losslessly code a source with an entropy of  $H$  bits per symbol using  $H+\epsilon$  bits per symbol, where  $\epsilon$  is an arbitrarily small positive quantity. In this case, the compression rate of lossless coding is defined by

$$\frac{\text{average bit rate of the original raw data (B)}}{\text{average bit rate of the encoded data (C)}} \quad (2)$$

In lossy coding, C can be much smaller than B.

### 3.2 Transform Coding and DCT

A variety of coding approaches have been developed for image compression. Some of the more promising involve segmenting the image into small subimages before coding. Specifically, the original image is divided into subimages which are usually of equal size. Then, each subimage is coded independently of the others. To reproduce the full image, the separate subimage blocks are reassembled by the decoder. The purpose of segmenting the image is to exploit the image's local characteristics and to simplify hardware implementation of the coding algorithm. Transform coding is a prime example of a coding technique involving image segmentation[8]. In this section, the characteristics of transform coding are introduced and we investigate one important transform called the discrete cosine transform used in MBCPT.

#### 3.2.1 Transform coding

Block coding, another name for transform coding, transforms a block of data into a set of transform coefficients and quantizes each coefficient independently. An image is divided into equal size blocks. The size of these blocks is limited by processing and storage ability. For an  $M \times N$  image, if an  $m \times n$  transform is applied, the image will be divided into  $MN/mn$  blocks. The main storage

space for doing the transform is reduced by a factor of  $MN/mn$ . Meanwhile, the number of operations will be reduced by a factor of  $\log_2(MN)/\log_2(mn)$ . That comes from two dimension transform with  $O(N\log_2 N)$  operations via an  $N$ -point FFT.

The aim of the transformation is to convert statistically dependent picture elements (pixels) into a set of essentially independent transform coefficients, preferably packing most of the signal energy (or information) into a minimum number of coefficients[9]. Bit allocation is another problem when designing a transform coder. If a coefficient contains a lot of energy, the absolute value is large, and more bits will be assigned to it. On the other hand, a coefficient with little energy will be represented with fewer bits, even none. There are two approaches used for bit allocation. In the first approach, only a predetermined set of transformed coefficients are transmitted. This approach is called zonal coding with the zone covering the set of coefficients with the largest variances. The second approach is threshold coding. In this approach those coefficients with amplitude greater than a predetermined threshold are coded. In MBCPT, zonal coding is used.

Asymptotically DPCM and Transform coding have the same performance. However, under practical constraints, transform coding is a much more powerful tool than

predictive coding. It can get the relatively higher compression rates and distributes the error coming from quantization or channel over the entire image. If predictive coding is used, the visual degradation because of error will appear locally.

### 3.2.2 Discrete Cosine Transform (DCT)

Most unitary transforms pack a large fraction of the average energy of the image into a relatively few components of the transform coefficients. Since the total energy is preserved, this means many of the transform coefficients will contain very little energy. In terms of energy compaction and decorrelation, the Karhunen Loeve transform is optimum. But the Karhunen Loeve transform depends on the statistics of the image and, in general, the basis vectors have to be recomputed for different images. After the transform matrix has been computed, the transform itself requires a large number of computations. The discrete cosine transform is a nice substitute in highly correlated image transformation because it has excellent energy compaction and fast implementations[10].

The discrete cosine transform consists of a set of basis vectors that are sampled cosine functions. The transform matrix  $C = \{c(k,n)\}$  may be written

$$\begin{aligned}
 c(k,n) &= \frac{1}{N^{\frac{1}{2}}} \quad , k = 0, 0 \leq n \leq N-1 \quad (3) \\
 &= \frac{2}{N^{\frac{1}{2}}} \cdot \cos \frac{\pi(2n+1)k}{2N}, 1 \leq k \leq N-1, 0 \leq n \leq N-1
 \end{aligned}$$

The two-dimensional DCT may be defined as

$$F(u,v) = C[f(x,y)]C' \quad (4)$$

and the inverse transform

$$f(x,y) = C'[F(u,v)]C \quad (5)$$

As mentioned above, DCT is a fast transform. By the fast algorithm developed by Chen et al. [11], an  $N \times N$  image DCT needs only  $2N^2 \log_2 N - 2N^2 + 8N$  real multiplications and  $3N^2 \log_2(N/2) + 4N$  real additions. Because zonal coding is used in MBCPT and only some of the coefficients need to be calculated, the operations can be reduced further and the real time processor can be practically implemented.

### 3.3 Quantization

Quantization is the next step after sampling in image digitization. A quantizer maps a continuous variable  $u$  into a discrete variable  $u'$ , which is a value from a finite set  $(r_1, r_2, \dots, r_n)$ . For most image transform, the dc coefficient is positive because the gray level is usually nonnegative. The ac coefficients have a zero mean and a

distribution very much like the Laplacian model. In the following, the two specific quantizers used in this thesis are discussed.

### 3.3.1 Scalar Quantizer

A scalar quantizer is an one-dimension quantizer which maps intervals of a line into points. The average distortion for a scalar quantizer is

$$d = \frac{1}{n} \cdot \sum_{i=1}^n \int_{a_i}^{a_{i+1}} p(x) \cdot d(x, y_i) dx \quad (6)$$

where  $n$  is the number of codebook elements and  $(a_i, a_{i+1})$  is the  $i$ -th interval containing element  $y_i$ .

An optimal Laplacian quantizer is used in this thesis which is developed with MAX's optimization theory for minimum distortion.

### 3.3.2 Vector Quantizer

Vector Quantization (VQ) has been widely used in low-bit-rate compression. It is a generalization of scalar quantization, and is one step closer to the optimum, as given by Shannon's rate distortion theory[7]. In the image coding area, VQ is a new but promising technique for video compression.

There are two steps involved in the type of Vector Quantization used in this study. First, a codebook is generated from a large set of training vectors which should be as large and as varied as possible in order to accurately predict future vectors. The size of the codebook determines the bit rate of the vector quantizer. Second, the codebook is downloaded to both the transmitter and receiver. When the vector comes in, the codebook is then searched for the codevector which is the closest match to it and an alphabet representing the codevector is transmitted. At the receiving end, it only needs to find the matched vector which is much easier than at the transmitter end.

During both the codebook generation and the coding phases of vector quantization, it is necessary to find a "best match" for each vector. This best match should be the codevector which most closely approximates the input vector, or in other words, yields the lowest distortion.

In this thesis, the LBG vector quantizer is used. This LBG algorithm is simple yet powerful, and it can be used for the generation of a codebook for any vector quantization application. The algorithm itself is an iterative one, refining the codebook until the distortion has reached an acceptable value.

The distortion is simply the square of the Euclidian distance between the two vectors. The overall distortion

measure is computed after all training vectors have been partitioned. If this distortion falls below the acceptable threshold, the iterative process stops, and the current codebook is saved. Otherwise, if the distortion is too high, each codevector is replaced by the centroid of all the training vectors assigned to it. Then the training sequence is re-partitioned and the process is repeated.

### 3.4 Mixture Block Coding with Progressive Transmission

Here we investigate the algorithm and property of MBCPT to see if it can properly fit into the packet-switching environment.

#### 3.4.1 Progressive Coding

The technique that allows an initial image to be transmitted at a lower bit rate and to be refined with an additional bit rate is called progressive coding[12]. Consider, for example, an image with size  $xyz = 256 \times 256 \times 8$  bits is transmitted. One way to send it is in the  $zxy$  order: transmit all the eight bits of the first pixel in the first row, then stepping along the row ( $x$ ) for all the pixels in that row, advancing down to the following row ( $y$ ) until all the pixels in that image are sent. This is probably the simplest and usual way to send an image. Another alternative is to go through the  $xyz$  order, where the most significant bit of every pixel is sent first, then

the second one and so on to the least significant bit. In this way, successive approximations converge to the target image with the first approximation carrying the "most" information and the following approximations enhancing it. The process is like focusing a lens, where the entire image is transformed from low-quality into high-quality[13].

In progressive coding, every pixel value or the information contained in it is possibly coded more than once and the total bit rate may increase depending on the coding schemes and quality desired. Because only the gross features of an image are being coded and transmitted in the first pass, the processing time is greatly reduced for the first pass and a coarse version of the image can be displayed without significant delay. It has been shown that it is very useful for perception to get a crude image in a short time, rather than waiting a long time to get a clear complete image[14].

With different stopping criterion, progressive coding is suitable for dynamic channel capacity allocation. If a predetermined distortion threshold is met, processing is stopped and no more refining action is continued. The threshold value can be adjusted according to the traffic condition in the channel. Successive approximations (or iterations) are sent through the channel in progressive coding converging to the desired image. If these successive approximations are marked with decreasing priority, then a sudden decrease in channel performance may only cause the

received image to suffer from quality degradation rather than total loss of parts of the images[13].

#### 3.4.2 Structure of MBCPT Coder

Mixture Block Coding (MBC) is a variable-blocksize transform coding algorithm which codes the image with different block sizes depending upon the complexity of that block area. Low-Complexity areas are coded with large blocksize transform coder while high-complexity regions are coded with a small blocksize one. The complexity of the specific block is determined by the distortion between the coded and original image. A more complex image block has higher distortion.

The advantage of using MBC is that it does not process different complex regions with the same blocksize. That means MBC has the ability to choose a finer or coarser coding scheme to deal with different complex parts of the same image. For the same coding rate, MBC is able to code an image with greater fidelity than a coding scheme which codes regions of varying complexity with the same blocksize coder.

When using MBC, the image is divided into maximum blocksize blocks. After coding, the distortion between the reconstructed and original block is calculated. The block being processed is subdivided into smaller blocksize blocks

if that distortion fails to meet the predetermined threshold. The coding-testing procedure continues until the distortion is small enough or the smallest blocksize is reached. In this scheme, every block is coded until the reconstructed image is satisfactory, then the next block is coded.

Mixture Block Coding with progressive transmission (MBCPT) is a coding scheme which combines MBC and progressive coding. MBCPT is a multipass scheme in which each pass deals with different block sizes. The first pass codes the image with a maximum block size and transmits it immediately. Only those blocks which fail to meet the distortion threshold go to the second pass. In the second pass the difference image block from the original and coded image obtained in the first pass is processed with smaller size blocks. The difference image coding scheme continues until the final pass which deals with the minimum size block. At the receiving end, a crude image is obtained from the first pass in a short time and the data from following passes serve to enhance it. Fig. 3.1.a shows the structure of pass 16x16 for MBCPT. Fig. 3.1.b shows the parallel structure of MBCPT. A coding structure like a quad tree is proposed by Dreizen[15], and Vaisey and Gersho[16] which subdivides those busy blocks into four pieces and will be used in this thesis. In the quad tree coding structure of this thesis, the 16x16 block is coded and the distortion of the block is calculated. If the distortion is greater than the predetermined threshold for 16x16 blocks, the block is

divided into four 8x8 blocks for additional coding. This coding-checking procedure is continued until the only image blocks not meeting the threshold are those of size 2x2. Figure 3.2 shows the algorithm.

### 3.4.3 Design Consideration

There are several features which have to be considered when designing a MBCPT coder.

They are:

- (1) the blocksize of the transform coder.
- (2) the bits allocation.
- (3) the quantizer.
- (4) the distortion measurement.
- (5) the threshold value.

The block size should be small enough for ease of processing and storage requirements, but large enough to limit the inter-block redundancy[17]. Larger block size results in higher image quality, but it is very difficult to build real-time hardware for block sizes larger than 16x16 because the number of calculations increase exponentially with block size for the DCT[13]. Besides, if the maximum blocksize is set too large, it is destined to be subdivided and decreases the efficiency of the coder. So, 16x16 is chosen to be the largest blocksize here.

The minimum blocksize determines the finest visual quality that is achievable in the busy area. If the minimum blocksize is too large, it is likely that the blockiness will be observed in the coded edge of spherical object because the coding block is square. In order to match the zonal transform coding used in this thesis, 2x2 is the smallest blocksize and there are four passes (16x16, 8x8, 4x4, 2x2) in this scheme. Fig. 3.3-6 show the images from 4 passes individually.

The monochrome images used in this thesis are represented with 8 bits of non-negative intensity ranging from 0 to 255. After a discrete cosine transformation, only four coefficients including the dc and three lowest order frequency coefficients are coded and the others are set to zero. The dc coefficient in the first pass is coded with an 8-bit uniform quantizer due to the fact that it closely reflects the average gray level for that image block and is hard to predict. It is easy to predict the dc coefficient in the following pass because it is a residual and has a distribution like a Laplacian model. Typically, a 5-bit optimal laplacian nonuniform quantizer is used. The three ac coefficients, as mentioned above, fit a Laplacian model with a variance greater than that of the dc coefficient. Because different variances are exhibited for different coefficients, the input samples are first normalized so that they have unit variance and therefore can be quantized with the same 5-bit Laplacian quantizer. As an alternative, a LBG vector quantizer with a 512 codebook size is used to

quantize the vector which comprises the three ac coefficients. Along with the blocksize determined above, the maximum and minimum bit rates for this coder ranges from 0.09 to 6.65 bits/pel for the scaler quantizer and 0.07 to 4.66 for the vector quantizer depending upon the complexity of the image.

Any distortion measure can be used in this MBCPT coder. It is possible to use different distortion measures for each different blocksize pass to adjust for the expected radial frequency coding sensitivity of the eye. Each different blocksize represents a different spatial frequency range that is to be coded, and details of distortion induced within each of these blocksizes will be seen differently by the eye. In this thesis, the maximum absolute difference is used:

$$d = \max_i |x_i - y_i| \quad (7)$$

where the range of  $i$  is taken over the entire block to be coded,  $u$  is the original image pixel while  $v$  is the coded image pixel. Because the visual performance mentioned above, a luminance to contrast model called logarithmic law as follows:

$$c = 50 \cdot \log_{10} f \quad , \quad 1 \leq f \leq 100 \quad (8)$$

is used to modify the maximum absolute difference law.

The threshold of each pass has to be selected before the coder is going to work. It is readjustable during the operation. If zero is assigned as the threshold for each pass, no block is going to satisfy that threshold and the maximum data rate is transmitted hoping for a perfect coded image. When using an infinite threshold, only the first pass data will be sent using the minimum bit rate. Any non-negative threshold will fall between these two extreme cases and can be adjusted according to the channel condition and quality required.

Because only partial blocks which fail to meet the distortion threshold need to be coded, there must be some side information to instruct the receiver how to reconstruct the original image back. One bit of overhead is needed for each block. If a block is to be divided, a 1 is assigned to be its overhead; if not, a 0 is assigned. A coding process in Fig. 3.7 has the following overhead: 1,1001,1001,1001,1001,1001.

#### 3.4.4 Distortion and Blocking Effect

When using MBCPT, there are some types of error that can appear in a decoded image. First, high-frequency errors, result from eliminating DCT coefficients, using zonal masking, and a large thresholds. High-frequency errors are characterized by a general blurring of sharp edges in the reconstructed image. Another type,

quantization error, occurs when DCT coefficients are assigned too few bits from the bit assignment map. Quantization error is characterized by sinusoidal rippling of intensity in the originally solid areas; edges remain fairly sharp, but are distorted[8].

In MBCPT, the input image is partitioned into a series of nonoverlapping rectangular blocks or subimages with equal size. Each subimage is a partial scene of the original image and is processed independently. In low bit-rate application, like the first pass, the block boundaries become highly visible and objectionable. Two approaches are used in this thesis to eliminate the blocking effect. First, because the location of these block edges are known exactly in MBCPT, it is reasonable to expect that low-pass filtering the image at or near the subimage boundaries could smooth the unwanted discontinuities. This is the basis of the filtering method[18]. A 3 x 3 Gaussian spatial domain filter (Fig. 3.8) is used. Second, instead of forcing the regions to be exclusive of each other, it is reasonable that a slight overlap around the perimeter of each region could reduce the blocking effect, this is called the overlap method (Fig. 3.9)[18]. The pixels at the perimeter would then be coded in two or more regions. In reconstructing the image, a pixel that was coded more than once would use an average of the coded values.

Both methods are successful in reducing the blocking effect. But the overlap method results in a 13% increase in bit rate while the filtering method, due to its low-pass nature, may degrade edge content in the image.

#### 3.4.5 Application in Packet-Switching Network

Because of the dynamic and adaptive characteristic in MBCPT, we can see some interesting features when applied to packet video:

- (1) The minimal quality is ensured. (i.e. that of the basic channel with higher priority)
- (2) Packet losses on the improvement channel do not impair the received signal below the quality offered by the basic channel.
- (3) Bandwidth on demand can be easily implemented.
- (4) The scheme is very simple since all complexity is in the basic channel codec which operates at low frequency.
- (5) An evolutionary transition from today's synchronous networks to tomorrow's asynchronous networks becomes possible, since the basic channel is implemented now and the improvement channel can be added in the future on the fast packet network[19].

In this chapter, the structure and basic features about MBCPT was investigated. From that, it can be seen why this algorithm is able to fit into packet-switching environment.

Details about the actual implementation in a packet network environment will be discussed in Chapter 5.

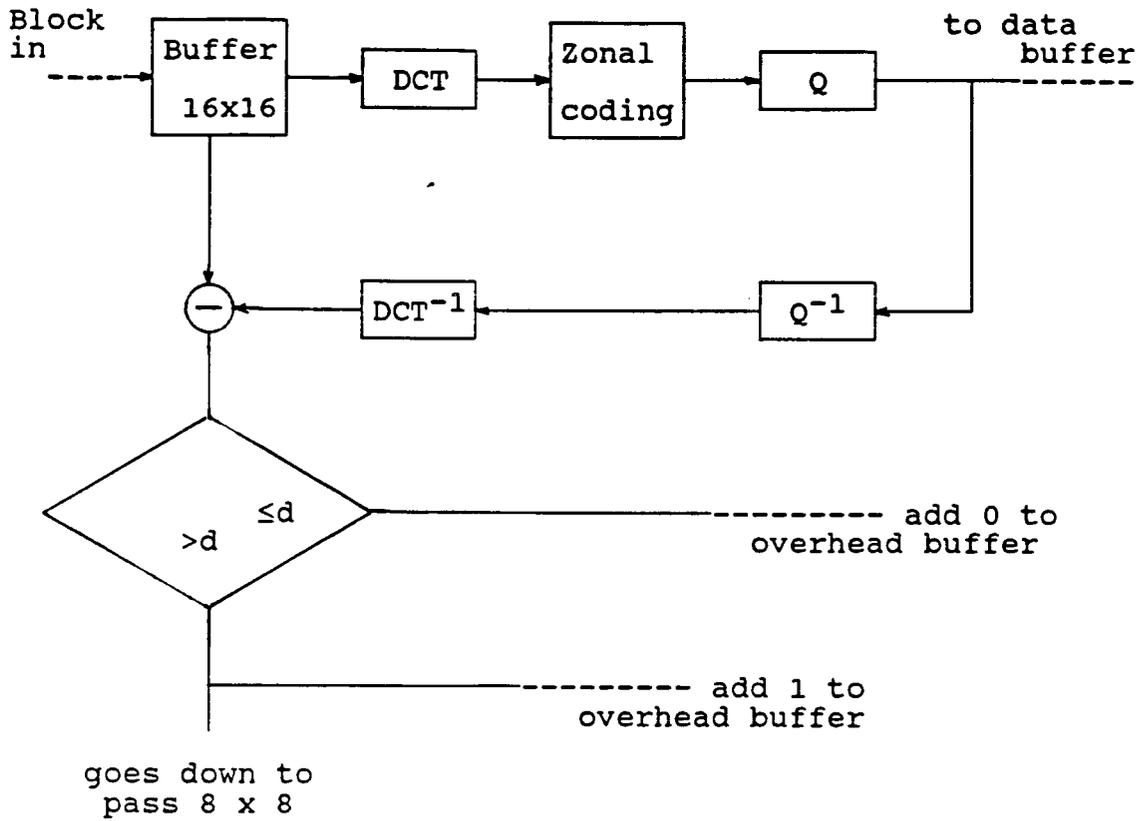
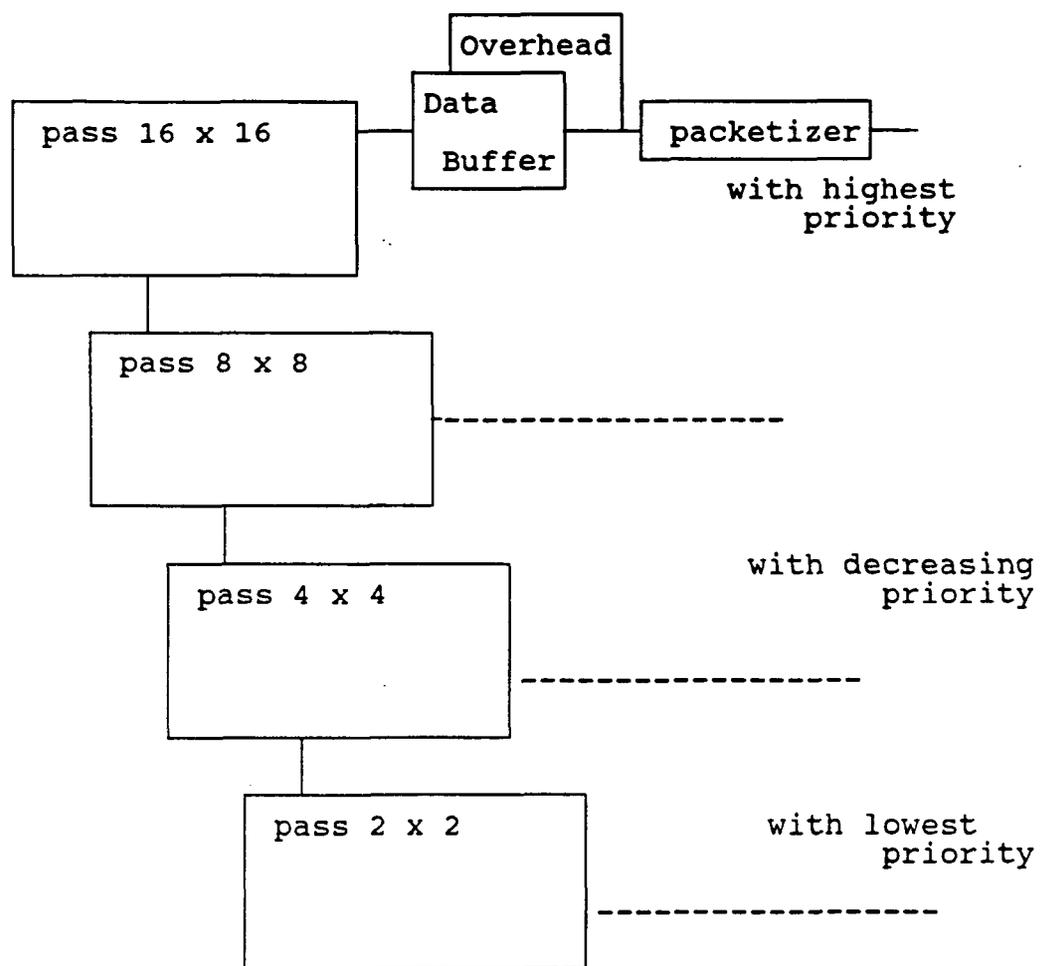


Figure 3.1.a Structure of pass 16 x 16 for MBCPT.  
 $d$  is distortion defined in Eqs.(7).



Figuer 3.1.b Parallel structure for MBCPT

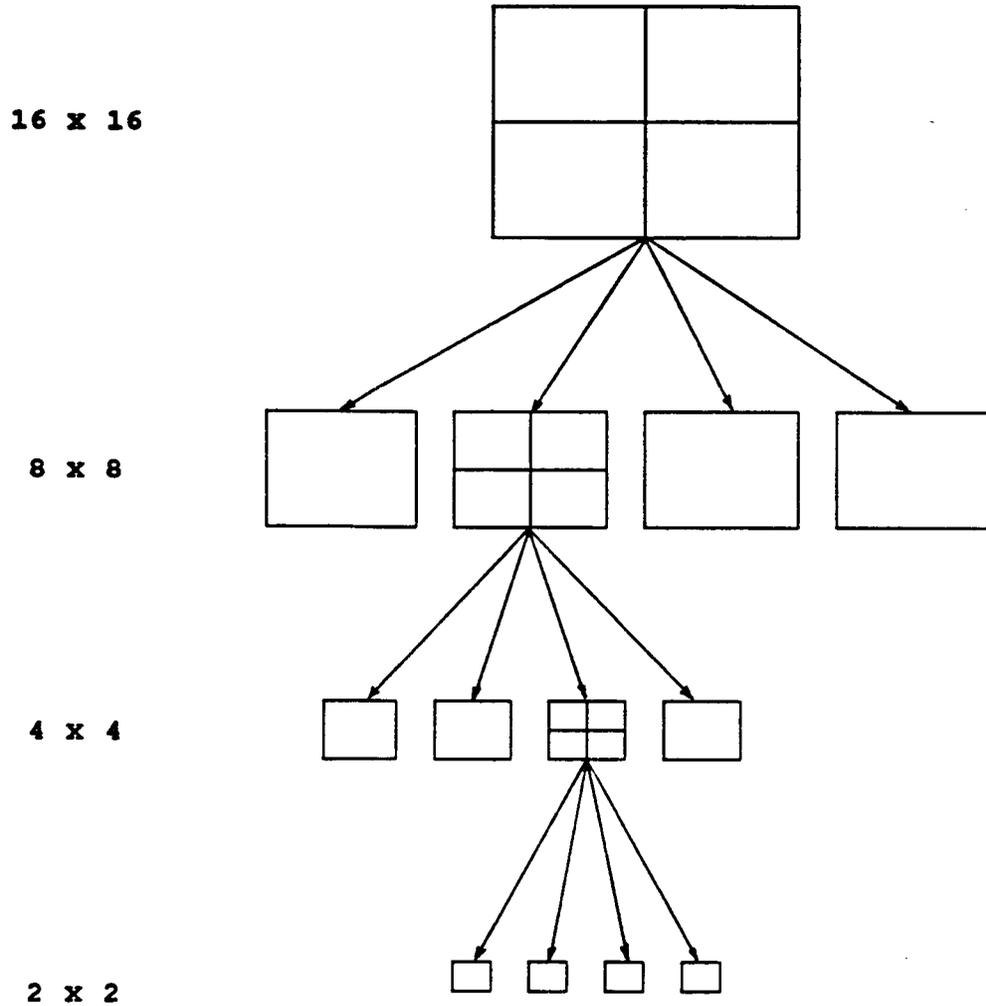


Figure 3.2 Example of 16x16 block quad tree

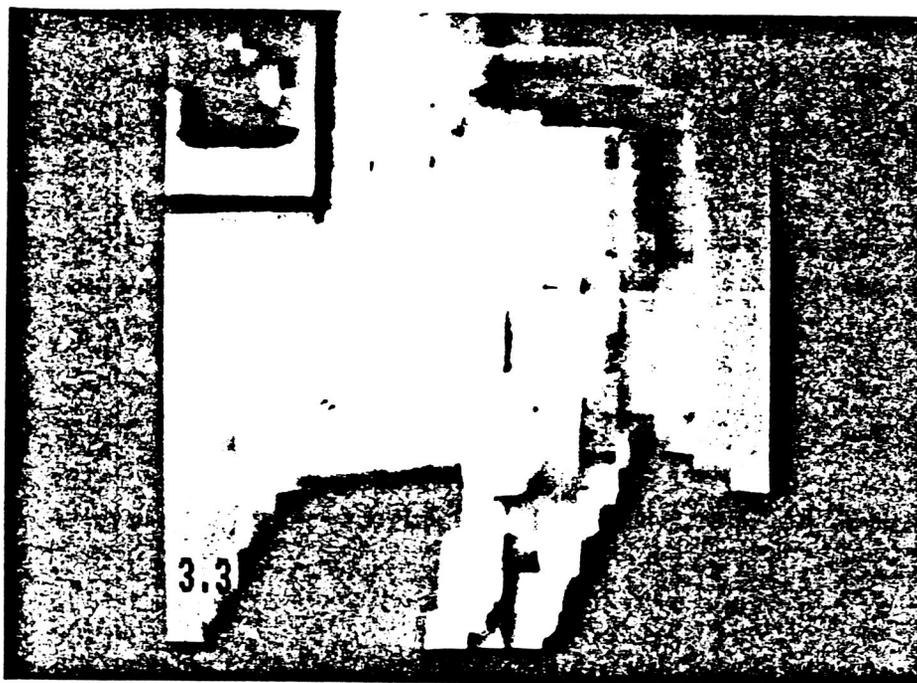


Figure 3.3 Image reconstructed from pass 16x16.



Figure 3.4 Image reconstructed from passes up to 8x8.

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BLACK AND WHITE PHOTOGRAPH

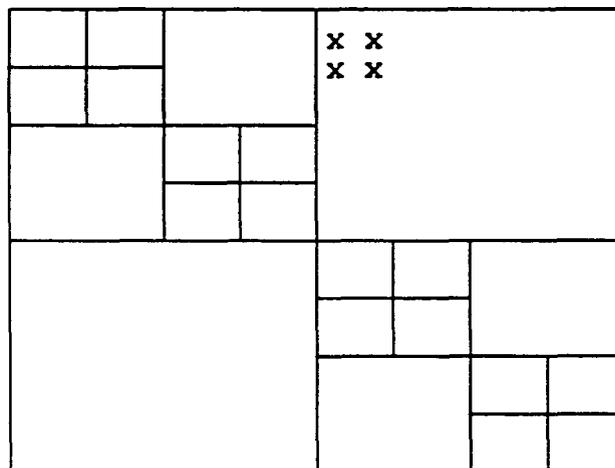


Figure 3.5 Image reconstructed from pass up to 4x4.



Figure 3.6 Image reconstructed from passes up to 2x2.

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16 x 16

overhead = 1,1001,1001,1001,1001,1001

Figure 3.7 Overhead assignment and zonal coding

.0751	.1239	.0751
.1239	.2042	.1239
.0751	.1239	.0751

Figure 3.8 3x3 Gaussian spatial filter coefficients

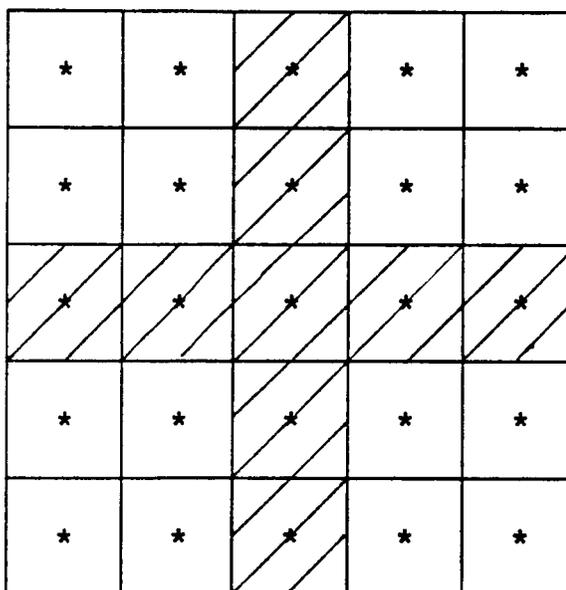


Figure 3.9 One-pixel overlap method. Shading indicates over-lap. Subimage size 3x3 pixels.

## Chapter 4 Network Simulator

The network simulator to be used for this thesis is a modification of an existing simulator developed by Nelson et al.[20]. A brief description of the simulator is provided here.

### 4.1 Introduction

As mentioned in Chapter 2, tomorrow's integrated telecommunication network will have a very complicated and dynamic structure. It's efficient use will require sophisticated monitoring and control algorithms. Communication between nodes will have to reflect the existing capacity and reliability of system components. The scheme for communicating information regarding the operating status is called the system protocols.

Since this communication of system information must flow through the channel, it reduces the overall capacity of the physical layers, but hopefully provides a more efficient system overall. Therefore, the optimal system efficiency depends a lot upon these protocols, in turn, upon the system topology, communication channel properties, nodal memory and component reliability. Most network protocols have been developed around high reliability in topological structures with reasonably high channel reliability.

The modifications made to this simulator for the purpose of this thesis, most are basically in those modules concerning network layers. This simulator is structured in modules which represent, to some degree, the ISO Model for packet switched networks. Therefore, a more detailed description about the network layer modules will be made in the next section. In this chapter, a whole picture for this simulator will be provided.

#### 4.1.1 Topology, Traffic and Preparation

The program Topology is used to generate a topological description of the network to be simulated. It contains the number of nodes, the definition( includes connectivity and propagation delay) of the links between nodes, and the initial bit error rate for each link.

The program Traffic is used to generate an initial statistical description of the network traffic to be simulated. It contains the average message length for each precedence, the percent of messages generated for each precedence level, the rate of message generation at each node and the distribution of those messages to the other nodes.

The program Simprep is used to generate a checkpoint file which contains all the data needed for the simulation

including the topology, traffic and network parameters for various network layers.

#### 4.1.2 Simulator Philosophy

The principle function of the simulator is to perform tasks at the appropriate time. A queue called SIM\_Q drives the simulator. The records in SIM\_Q contain:

1. The task to be performed.
2. The time at which the task will be completed.
3. Node 1 (sender).
4. Node 2 (receiver).
5. Line (channel line routed).
6. The message number and the packet number.
7. A pointer to a packet (if one is involved).
8. Queue pointers for a doubly linked list.

The main simulator program has the popping of SIM\_Q and the execution of routines which effect the completion of the scheduled task contained in the popped record. These completion routines simulate the completion of the task and may result in other completion tasks to be performed in the same layer or other layers. A new task will be queued in the appropriate queue. If it is for another layer, then if the processor for that layer is idle it will invoke the scheduler for that layer.

#### 4.1.3 Simulator Queue and Queue Processors

Central to the operations of the simulator are the various queues. There are two types of records which are entered into queues. One is the Sim\_Q\_Record which contains the information required to perform a task and the other is the Packet\_Record that contains the information regarding the contents and status of a packet. The main program SIMEX works directly from SIM\_Q, which is the queue of Sim\_Q\_Records. There is only one such queue for the entire simulator but there exists many packet queues. There are three kinds of packet queues which are referred as Memory\_Q, Packet\_Q and Cleanup\_Q in the simulator.

The Message\_Q contains all packets originating at this node and the Transfer\_Q contains all packets received from other nodes fall into the group of Memory\_Q. The Packet\_Q is used to simulate the nodal queues in which the packets reside as they progress through the various network layers. These queues are mutually exclusive in that a packet can only reside in one of these queues at any given time. The transport\_Q is for those packets waiting for packetization or reassembly in the transport layer. In the case of a packet waiting for routing, it is placed in the Input\_Q in the network layer. If a packet is heading for other nodes, it is placed in the Output\_Q waiting for transmission by datalink layer.

If piggy-back acknowledgement is allowed, then it is

possible that a packet's address from the sending node must be stored for a period of time before the opportunity exists to return the address in an acknowledgement. In the simulator, this is accomplished through the Cleanup\_Q.

## **4.2 The Network Layers**

Each layer of the simulator module contains a processor and one or more packet queues. The processor is idle before there is a packet coming into its associated queue. The packet and the task that must be performed are entered into SIM\_Q with a completion time. When the task is performed, that means the completion time has arrived, then the queue is checked. If there is another task to be performed, then its completion is scheduled. If the queue is empty the processor is marked idle again.

The layers in the simulator are quite close in operation to the ISO transport, network and datalink layers. A "partial" session layer exists principally as a reporting layer for end to end statistics.

### **4.2.1 The Session Layer**

In the OSI model, the session layer allows users on different machines to establish "sessions" between them. In the simulator, as mentioned above, it is a relatively simple model of the subscribers and an end to end statistics collector. At message arrival time, the session

layer generates the message with all of its randomly selected attributes and if flow control or node hold-down are not in effect, submits it to the transport layer and then builds up the next message arrival time.

During initialization, a task "SL\_Rcv\_Msg" for each node is queued in SIM\_Q for the arrival time of the first message at that node. When this task is executed by the simulator, a message packet is generated and placed in the transport queue. The arrival of the next message is then queued in SIM\_Q with the same task and an arrival time determined by the random number generator (Poisson distribution).

The only other task performed at the session layer is the SL\_Snd\_Msg task which simulates the delivery to the subscriber. In the simulator, this is principally a "bookkeeping task" that records message statistics and "cleans up" the queues containing packets with resolved references.

#### 4.2.2 The Transport Layer

The basic function of the transport layer is to receive the message from the session layer, separate it up to smaller units if necessary, pass these to the network layer and make sure these pieces will arrive sequentially at the other end. Furthermore, all this work is expected to

be done efficiently, and in a way that isolates the session layer from future progress in hardware technology.

In the simulator, the transport layer simulates packetization, reassembly, message acknowledgement and resubmittal in the case that a message acknowledgement is not received in time, transport-layer time-out. There are four tasks simulated by the transport layer. They are TL(Transport Layer)\_Packetize, TL\_Timeout, TL\_Reassemble, and TL\_Ack\_Send. It is recognized that in some networks, packetization takes place at the network level, leaving the transport layer responsible only for message level structures. Reassembly, depending upon the protocol can take place as low as the datalink level. These tasks were both placed in the transport layer for ease of coding, but are separate modules that could be quite easily extracted and placed elsewhere. Also, the system was originally designed for datagram operation and since the packets will not necessarily arrive in order, it is unlikely that assembly would take place at the datalink level.

#### 4.2.3 The Network Layer

The network layer is concerned with controlling the operation of the network. A key design issue is determining how packets are routed from source to destination. Another issue is how to avoid the congestion caused if too many packets are presented into the network at the same time. In the simulator, the network layer performs all of the

functions related to these two aspects with the exception of flow control which takes place at the session layer, and the recovery protocols which require some service from the datalink layer. It also activates new channels when needed and determines when packets originating at other nodes are to be discarded.

The network layer is currently the most dynamic with regard to the coding of modules. Five modules currently comprise the network layer. These include relatively static modules; one module for dialing up new lines when more line capacity is required and releasing them when not needed; one module for the network processor and queue handling and one module for the routines which are common to most routing algorithms. This leaves two modules for the dynamic parts of the routing and flow control algorithms.

#### 4.2.4 The Datalink Layer

The main task of the datalink layer is to take a raw transmission facility and transform it into a line that appears free of transmission errors to the network layer. It simulates the sending of the message over the channel and the delivery at the other end. When a packet is received, the datalink acknowledgement is initiated either by piggy-back acknowledgement or by generating a datalink acknowledgement packet.

As mentioned previously, the datalink level also simulates the physical layer on a statistical basis. If correct transmission was indicated (through a random number generator) then acknowledgement was also assumed. Current datalink layer simulation modules include generation of acknowledgement packets and simulation of the piggy-back acknowledgement as well. When a line is "brought up", health packets are used to establish initial connections. Also, when a line "goes down", an active node will immediately issue health check packets to ascertain when the channel is again available.

#### 4.3 Modifications

A major problem of using this system as a simulation tool for the study of packet video is that the system doesn't actually transmit the data from node to node. While a packet is transmitted, the data field is empty. Therefore modifications had to be made to the simulator to accommodate the video data.

In the sending node, a field called "Image" which contains real image data is attached to the record "Packet\_Ptr" allocated to the message generated in the session layer. There are three new modules in this layer. First, "Get\_Image" puts the image data into the image field of a message generated at a specific time and node. Second, "Image\_Available" checks if there is still any image data that needs to be transmitted. If that is true, the

following message generated at that specific node is still the image message and contains some image data. Third, "Receive\_Image" collects the image data in the session layer of the receiving node when the flag "Image\_Complete" is on. In module "Session\_Msg\_Arrive", different priority is assigned to different messages. In module "Session\_Msg\_Send", some statistics are calculated including the number of lost image packets and the transmission delay for image packets.

In the original version of the simulator, the transport layer simply duplicated the same packet with different assigned sequential packet numbers without actually packetizing the message. The module "Transport\_Packetize" was modified to really packetize the image data which resides in the message record queued in Transport\_Q when it is called. The module "Transport\_Reassemble" is called to reassemble these image packets according to their packet number when the flag "Image\_Content" defined in Packet\_Ptr is true.

The network layer is responsible for routing and flow-control. This module is already very well developed, so the modifications to be performed here were relatively minor.

In the datalink layer, in order to simulate the delivery of packets through the channel, a new packet will

be generated at the receiving node and the information including the image data from the transmitted packet (which will still be resident at the sending node) will be copied into it. With the bit-error-rate defined in the program Topology, transmission success rate will be set and bit errors can be inserted in both the data and control bits in the packet. Errors in the control bits are simulated separately as long as the error rates are consistent. If an error in the control bits occurs, the transmission fails and needs to be sent again depending on the threshold of the timeout number.

Besides the modifications made in those layer modules, we still have to arrange some new memory elements allocated for image messages and packets. In order to make sure the simulation is run in the steady state, image data is available after some simulation time.

In the next chapter, the interaction between this simulator and the coding scheme investigated in the previous chapter will be presented.

## Chapter 5 Simulation Results

In this chapter, an interframe coder based on MBCPT will be introduced and the simulation results will be discussed.

### 5.1 Differential Interframe Coding

Teleconferencing, picturephones, and broadcast videos are all transmitted as sequences of two dimensional images. An interframe coder is used to exploit the redundancy between the successive frames. The differences between frames basically come from object and camera motion.

During this work we examined two interframe coders, both of which are differential schemes based on MBCPT. Both coders processes the difference image coming from the current frame and a reconstruction of the previous frame. In the first case the reconstruction is locally decoded from the first three passes. This algorithm is shown in Fig. 5.1. Fig. 5.2 shows the second case in which the reconstruction is performed with all four passes. To select the preferred algorithm, we compare the simulation results from these two approaches. When there is no packet loss, the performances of both schemes are the same (from Fig. 5.3). But when congestion occurs in the network, given the priorities assigned to packets, packets from pass 4 are expected to be discarded first. In this case, the

performance (from Fig. 5.4) of scheme in Fig. 5.1 is much better than the one in Fig. 5.2. Based on this result, the coding scheme in Fig. 5.1 was selected in our simulation.

In this thesis, the Kronkite motion picture with 16 frames is used as the simulation source. Every image consists of 256x 256 pixels with gray levels ranging from 0 to 255. The test sequence is similar to a video conferencing type image sequence which has neither rapid motion nor scene changes. Due to this characteristic, advanced techniques like motion detection or motion compensation are not used here but could be implemented when dealing with broadcast video.

From the values listed in the Table 5.1, we can see that the data in pass 4 represents 30-40% of the entire data. Based on perceptual evaluation, pass 4 is deemed the least significant pass(LSP). This part of the data is going to increase the sharpness of the image and is usually labeled with the lowest priority in the network. With a substantial possibility of being discarded due to low priority, the packets from pass 4 will not be used to reconstruct the locally decoded image and will not be stored in the frame memory. This prevents the packet loss error due to loss of packets from pass 4 from propagating into the following frames. It is found through simulation that this approach increases the peak signal-to-noise ratio (PSNR) by 1-2 dB under conditions of packet loss.

## 5.2 Interaction of the Coder and the Network

When the video data is packed and sent into a nonideal network, some problems emerge. These are discussed in the following section.

### 5.2.1 Packetization

The task of the packetizer is to assemble video information, coding mode information if it exists, and synchronization information into transmission cells. In order to prevent the propagation of the error resulting from packet loss, packets are made independent of each other and data from the same block or the same frame is not separated into different packets. The segmentation process in the transport layer has no information regarding the video format. To avoid having the bit stream being cut randomly, the packetization process has to be integrated with the encoder which is in the presentation layer of user's premise. Otherwise, some overhead has to be added into the datastream to guide the transport layer in doing the correct packetization. In order to limit the delay of packetization, it is necessary to stuff the last cell of a packet video with dummy bits if the cell is not completely full.

Every packet must contain an absolute address which indicates the location of the first block it carries. Because every block in MBCPT has the same number of bits in

each pass, there is no need to indicate the relative address of the following blocks contained in the same packet. There always exists a tradeoff between packaging efficiency and error resilience. If error resilience is considered, each packet should contain a smaller number of blocks. However, since each channel access by a station contains an amount of overhead, the packet should be long for transmission efficiency. Fixed length packetization is used in this thesis for simplicity.

### 5.2.2 Error Recovery

There is no way to guarantee that packets will not get lost after being sent into the network. Packet loss can be attributed to two main problems. First, bit errors can occur in the address field, leading the packets astray in the network. Second, congestion can exceed the networks management ability and packets are discarded due to buffer overflow. Effects created by higher pass packet (like pass 4) loss in MBCPT coding will be masked by the basic passes and replaced with zeros. The distortion is almost invisible when viewing at video rates because the lost area is scattered spatially and over time. However, low pass packet (like pass 1) loss, though rare due to high priority, will create erasure effects due to packetization and be very objectionable.

Considering the tight time constraint, retransmission

is not feasible in packet video. It may also result in more severe congestion. Thus, error recovery has to be performed by the decoder alone. In our differential MBCPT scheme, the packets from pass 4 are labeled lowest priority and form a great part of the complete data. These packets can be discarded whenever network congestion occurs. That will relieve the network congestion and will not cause too much quality degradation. The erasures caused by basic pass loss is simply covered with the reconstructed values from the corresponding area in the previous frame. This remedy appears insufficient even when there is only a small amount of motion in that area. Motion detection and motion compensation could be used to find a best matched area in the previous frame for replacement.

Side information in the MBCPT decoding scheme is very important. So, this vital information is not allowed to get lost. Two methods can be used for protection. First, error control coding, like block codes or convolutional codes, can be applied in both directions along with and perpendicular to the packetization. The former is for bit error in the data field while the latter is for packet loss. Fig. 5.5 demonstrates the second case. The minimum distance that the error control coding should provide depends on the network's probability of packet loss, correlation of such loss and channel bit error rate. Second, from Table 5.1, we can see that the output rate of side information and pass 1 and even pass 2 is quite steady. It seems feasible to allocate an amount of channel

capacity to these outputs to ensure their timely arrival. That means circuit switching can be used for important and steady data.

### 5.2.3 Flow Control

In order to shield the viewer from severe network congestion, there are some flow control schemes which are considered useful. If there is an interaction between the encoder and the transport layer, then the encoder can be informed about the network condition. Depending on that, the encoder can adjust its coding scheme. In the MBCPT coding scheme, if the buffer is getting full, it means that the bit generating rate is overwhelming the packetization rate and the encoder will switch to a coarse quantizer with fewer steps or loosen the threshold to decrease its output rate. In this way, smooth quality degradation is obtainable. This will also complicate the encoder design.

It is possible to use the congestion control of the network protocols to prevent the drastic quality change by assigning different priorities to packets from different passes. Without identifying the importance of each packet and discarding packets blindly sometimes brings disaster and cause session shut down, for example if the side information gets lost. In the MBCPT coding scheme, side information and packets from pass 1 are assigned with highest priority and higher pass packets are assigned with

decreasing priority.

#### 5.2.4 Resynchronization

Because of the lack of a common clock between transmitter and receiver and the variable packet generating rate used in packet video, resynchronization is an inherent problem in packet transmission. Transmission delay is irrelevant for one-way sessions and resynchronization can be solved by buffering the received packets in the receiver for a duration equal to  $L$  units from the start of transmission before transferring to the decoder. That means there is a constant lag of  $L$  units between the encoder and decoder. A packet loss occurs when any packet can not arrive in the limited time.

Although transmission delay is tolerable in one-way transmission, it becomes critical in two-way sessions because long delays impede information exchange. There are three methods which can be employed to accomplish the resynchronization task. The first approach is to modify the phase between the sending and receiving clocks by skipping or repeating video frames. The second scheme is to approach the transmitting frequency by the time stamps carried in the packet. Noted that this scheme can not be adopted by a multidrop decoder because it receives signals from more than one source. The third method is to adjust the receiving clock with a phase-locked loop by observing the level of the input buffer at the receiving end.

### 5.2.5 Interaction with protocols

In the ISO model, physical, datalink and network layers comprise the lower layers which form a network node. The higher layers have transport, session, presentation and application layers and typically reside in the customer's premises.

The lower layers have nothing to do with signal processing and only work as a "packet pipe". The physical layer requires adequate capacity and low bit-error-rate which are determined only by the technology. The datalink layer can only deal with link-management because all the mechanics like requesting retransmission is not feasible in packet video transmission. The network layer has to maintain orderly transmission by deleting the delay jitter with input buffering. Otherwise, it can take care the network congestion by assigning transmission priority.

As the higher layers reside in the customer's premises, they perform all the functions of the packet video coder. The transport layer does the packetization and reassembly. The packet length can be fixed or variable. Fixed packet length simplifies segmentation and packet handling while a variable packet length can keep the packetization delay constant. The session layer supervises set-up and tear-down for sessions which have different

types and qualities. There is always a tradeoff between quality and cost. The quality of a set-up session can be determined by the threshold in the coding scheme and the priority assignment for transmission. Of course, the better the quality, the higher the cost. Fig. 5.6 shows the tradeoff between PSNR and video output rate by adjusting thresholds. The presentation layer does most of the signal processing, including separation and compression. Because it knows the video format exactly, if any error concealment is required, it will be performed here. The application layer works as a boundary between the user and the network and deals with all the analog-digital signal conversion.

### 5.3 Results from Packet Video Simulation

Results obtained in this packet video simulation show that a pretty high compression and associated image quality can be obtained using this differential MBCPT scheme.

The monochrome sequence used in this simulation contains 16 frames, each of size 256x256 pixels with 8 bits per pixel, corresponding to a bit rate of 15.3 Mbits/s, given a video rate of 30 frames/s. As Table 5.2 shows, the average data rates of our system is 1.539 Mbits/s. The compression rate is about 10 with a mean PSNR equals 38.74 dB as calculated from

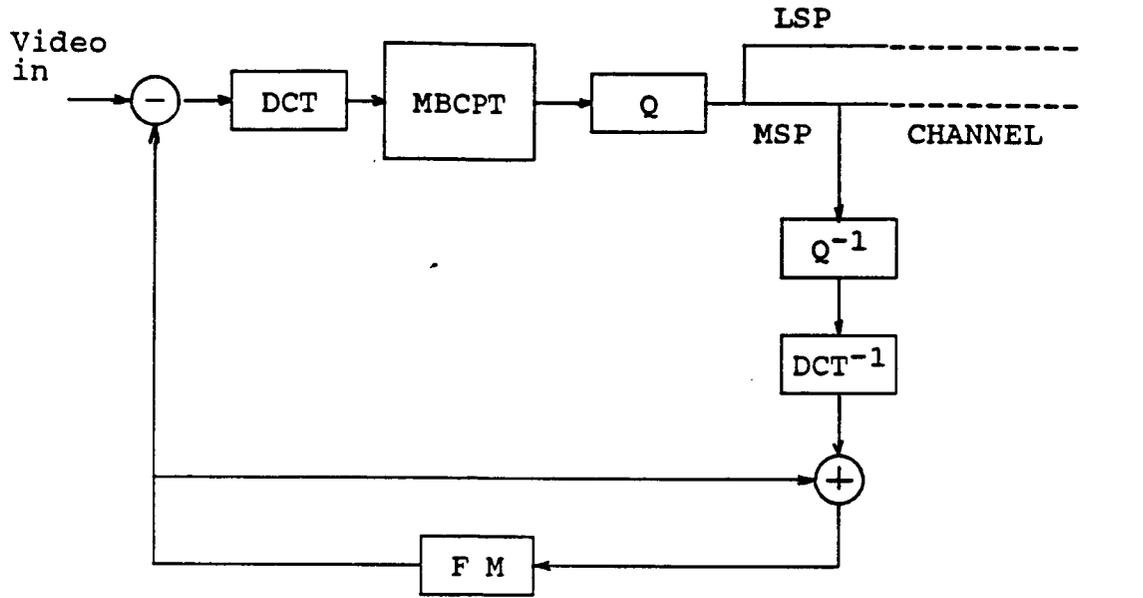
$$\text{PSNR} = 10 \cdot \log_{10} \left( \frac{256^2}{\sigma^2_{\text{diff}}} \right) \quad (9)$$

where 256 is the peak intensity of the image pixel and  $\sigma^2_{diff}$  is the variance of the difference between original and reconstructed frames. Fig. 5.7 shows the data rate of the sequence frames with side information, 4 passes and the total rate. It is clear that the data rate of pass 1 is constant as long as the quantization mode remains the same.

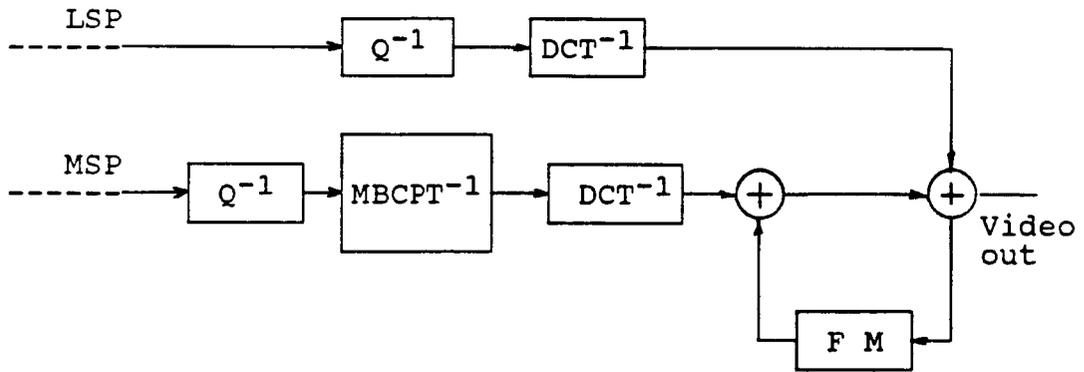
Side information and data from pass 2, and even pass 3, is quite steady and is referred as Most Significant Pass (MSP). The data rate of pass 4 is bursty, highly-uncorrelated and is called Least Significant Pass (LSP). Fig. 5.8 shows the PSNR for each frame in the sequence. The standard deviation is only 0.2 dB. In the simulation, the same threshold is used throughout the sequence. If constant visual quality is desired, a varying threshold can be used for different frames. That will generate a much more varying bit rate, and of course motion detection would be required. Comparing these two figures, it seems true that a varying bit rate can support constant quality video.

From the difference images of this sequence, frames 1-8 (Fig. 5.9-11) seem quite motionless while frames 9-13 (Fig. 5.12-14) contain substantial motion. We adjust the traffic condition of the network to force some of the packets to get lost in order to check the robustness of the coding scheme.

Transmission delay is not considered in this simulation because it is not the main interest. Heavy traffic is set up in the motionless and motion period separately. The average packet loss percentage is 3.3% which is considered high for most networks. Fig. 5.15-16 show the images which suffer the packet loss from pass 4. As can be seen, the effect of lost packets is not at all severe, even if the lost packet rate is unrealistically high. This is because the performance from the first three pass is relatively good. Fig. 5.17-18 show the case when packet loss occurs in pass 1. Clearly there are visible defects in the motion period. What's worse is that the error will propagate to the following frames. Apparently, the replenishing scheme used here is not sufficient in areas with motion. It is believed that this inconsistency can be eliminated with a motion compensation algorithm, which would find the appropriate area for replenishment, and with error concealment, which limits the propagation of error.



Coder



Decoder

Figure 5.1 Differential MBCPT coding scheme(1)

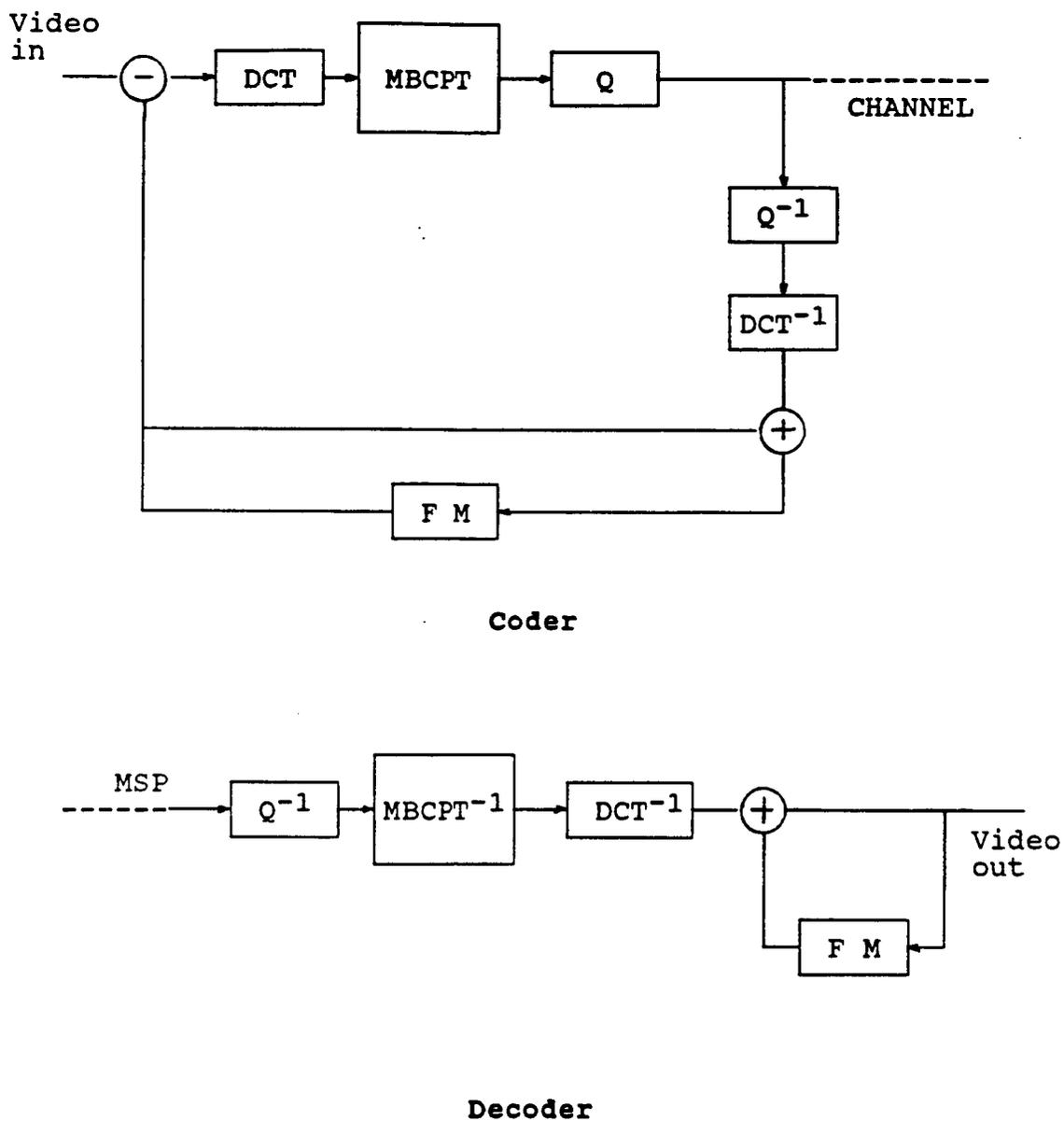


Figure 5.1 Differential MBCPT coding scheme(2)

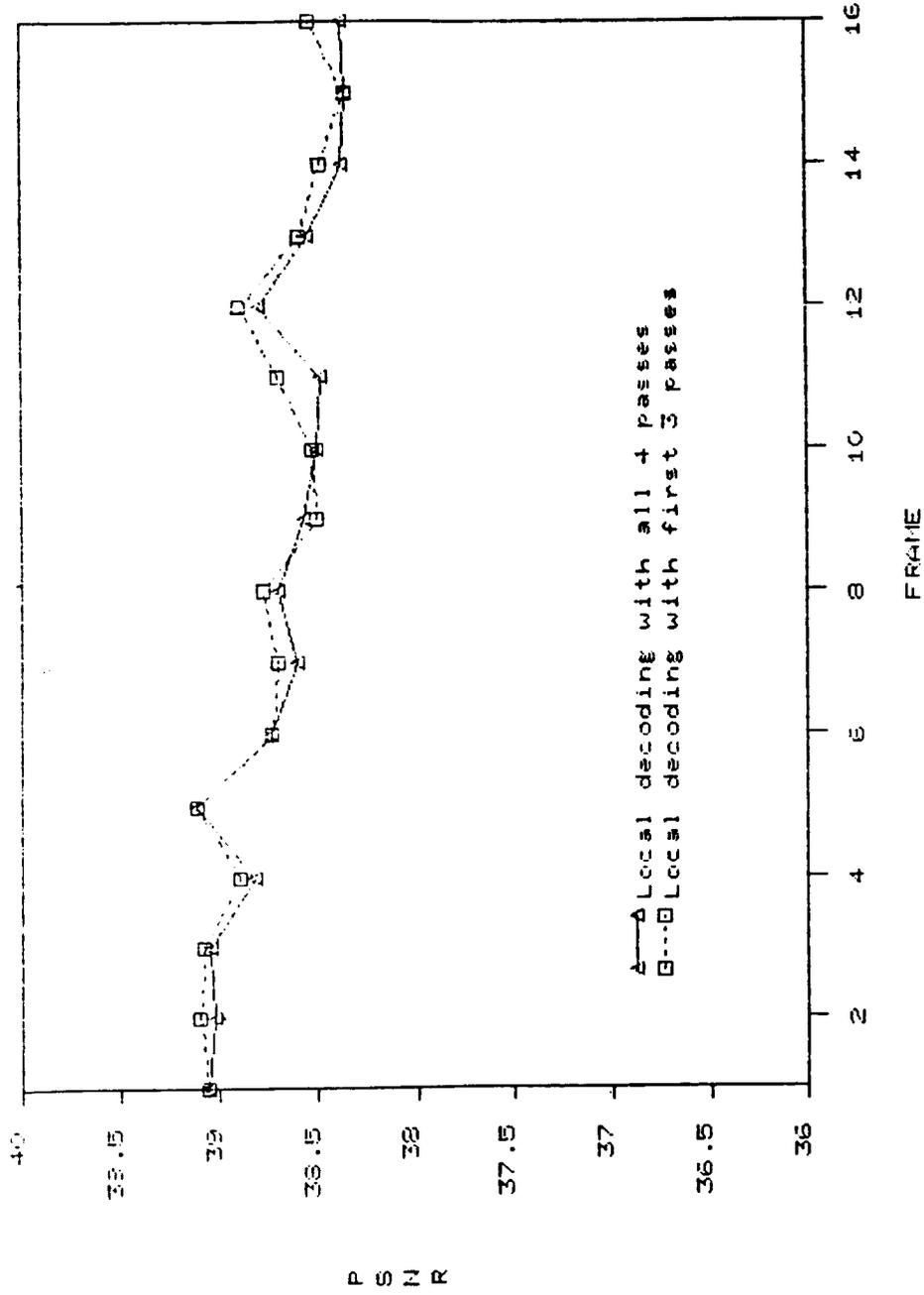


Figure 5.3 Performances without packet loss.

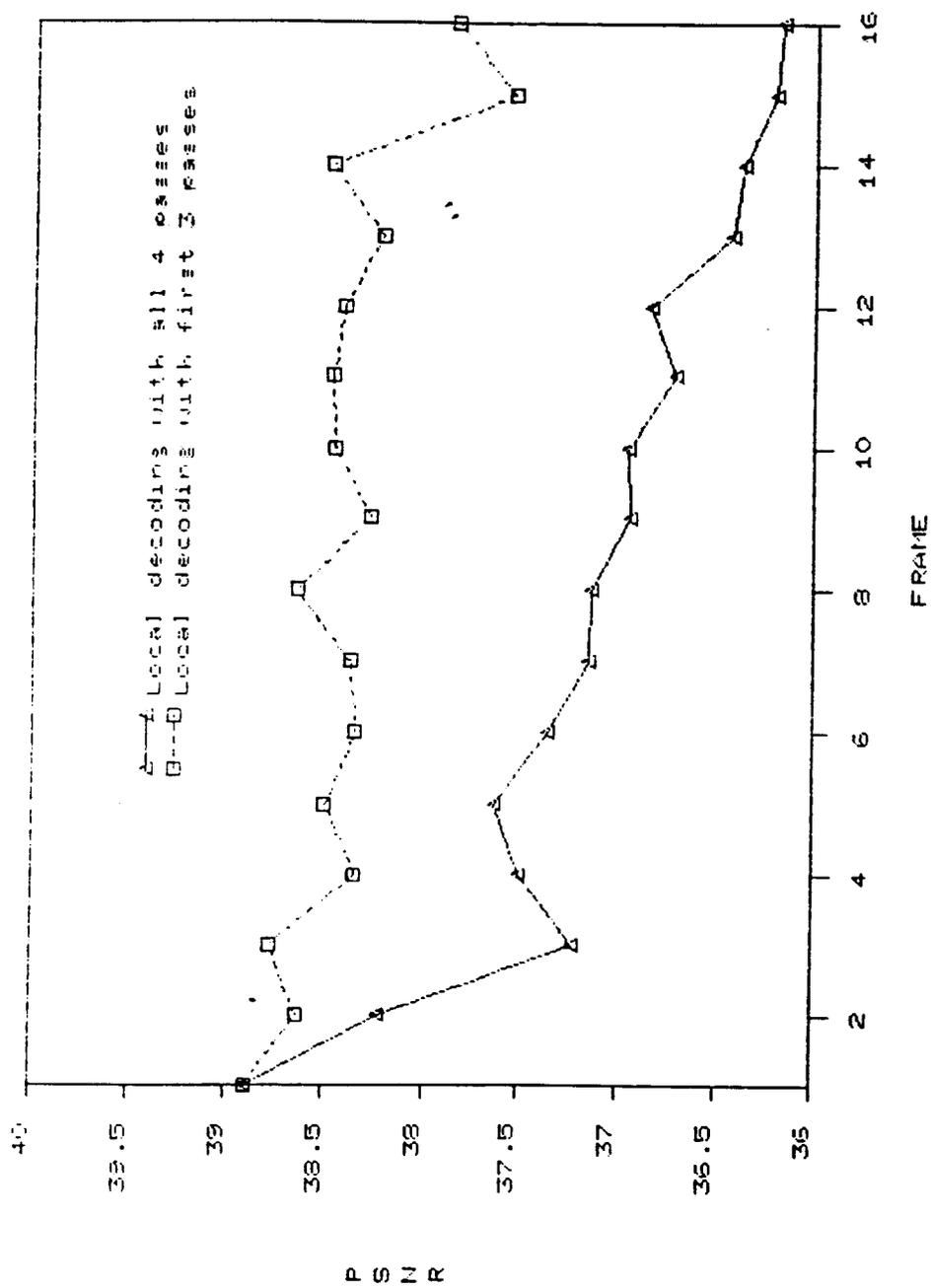


Figure 5.4 Performances with packet losses from pass 4.

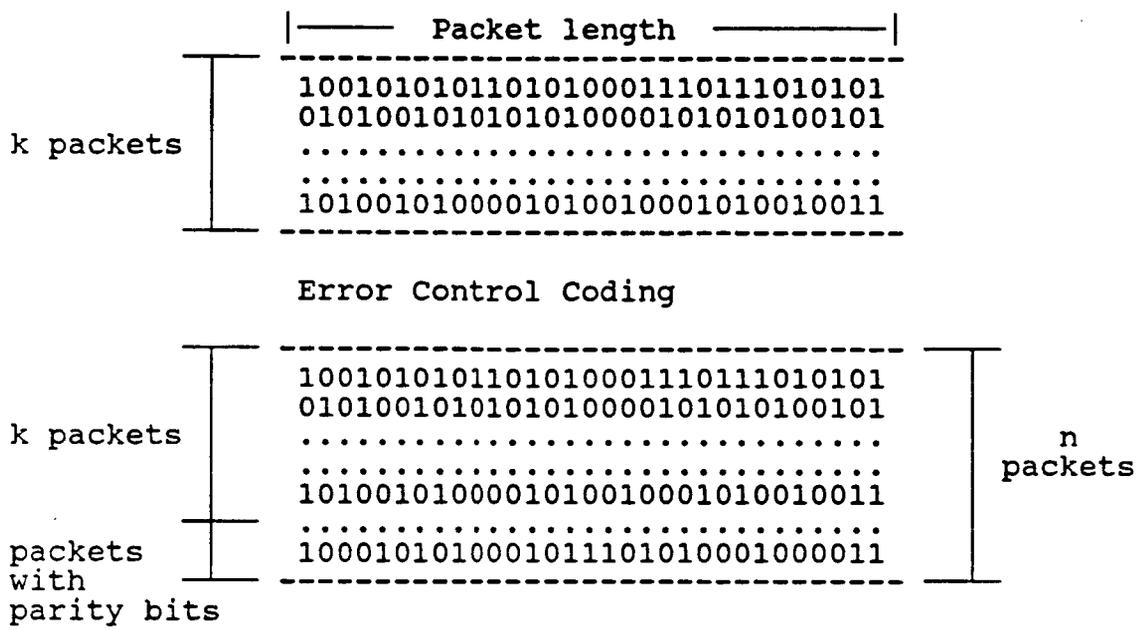


Figure 5.5 Error control coding applied perpendicular to the direction of packetization.

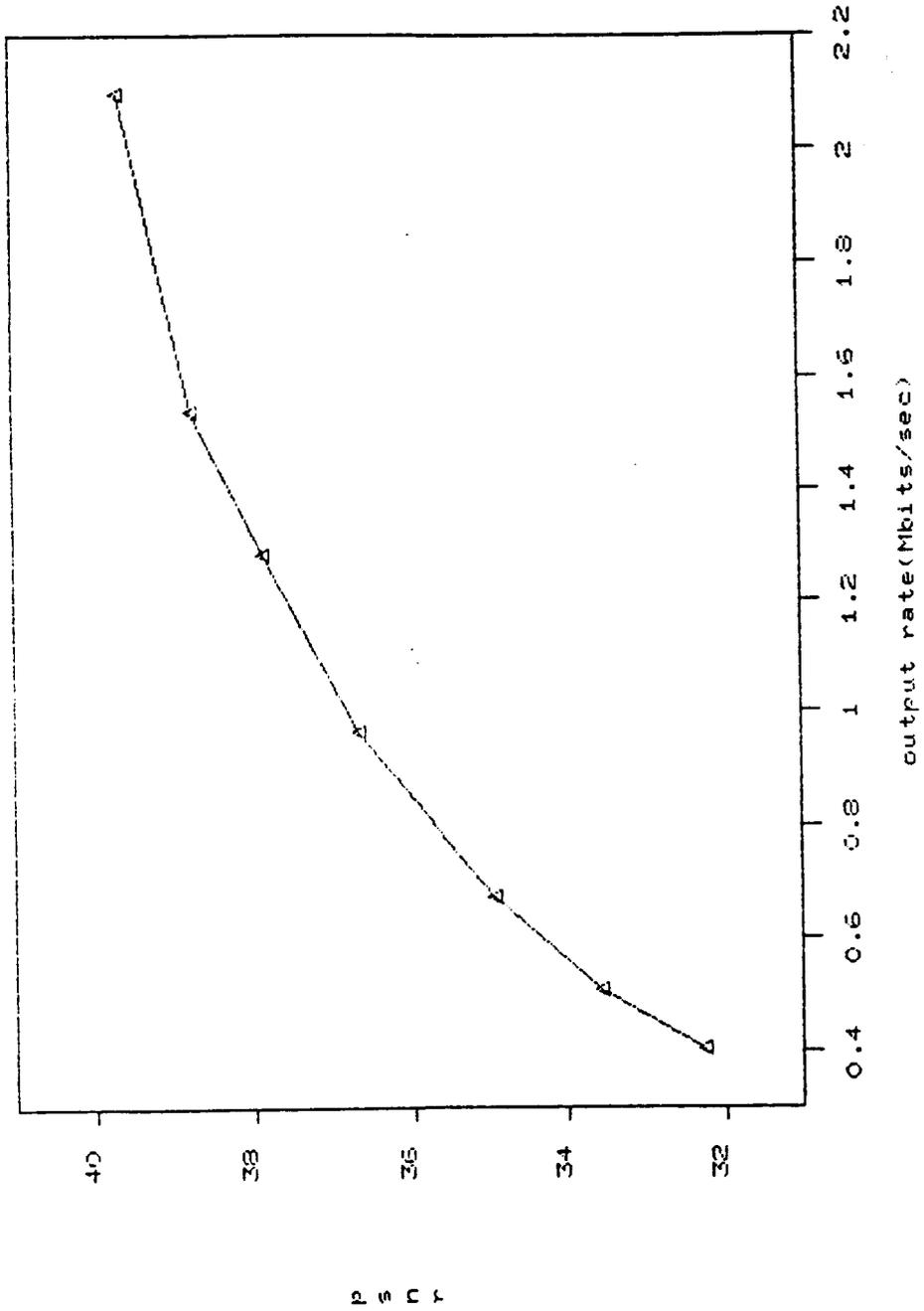


Figure 5.6 PSNR versus video output rate with 30 frames per second.

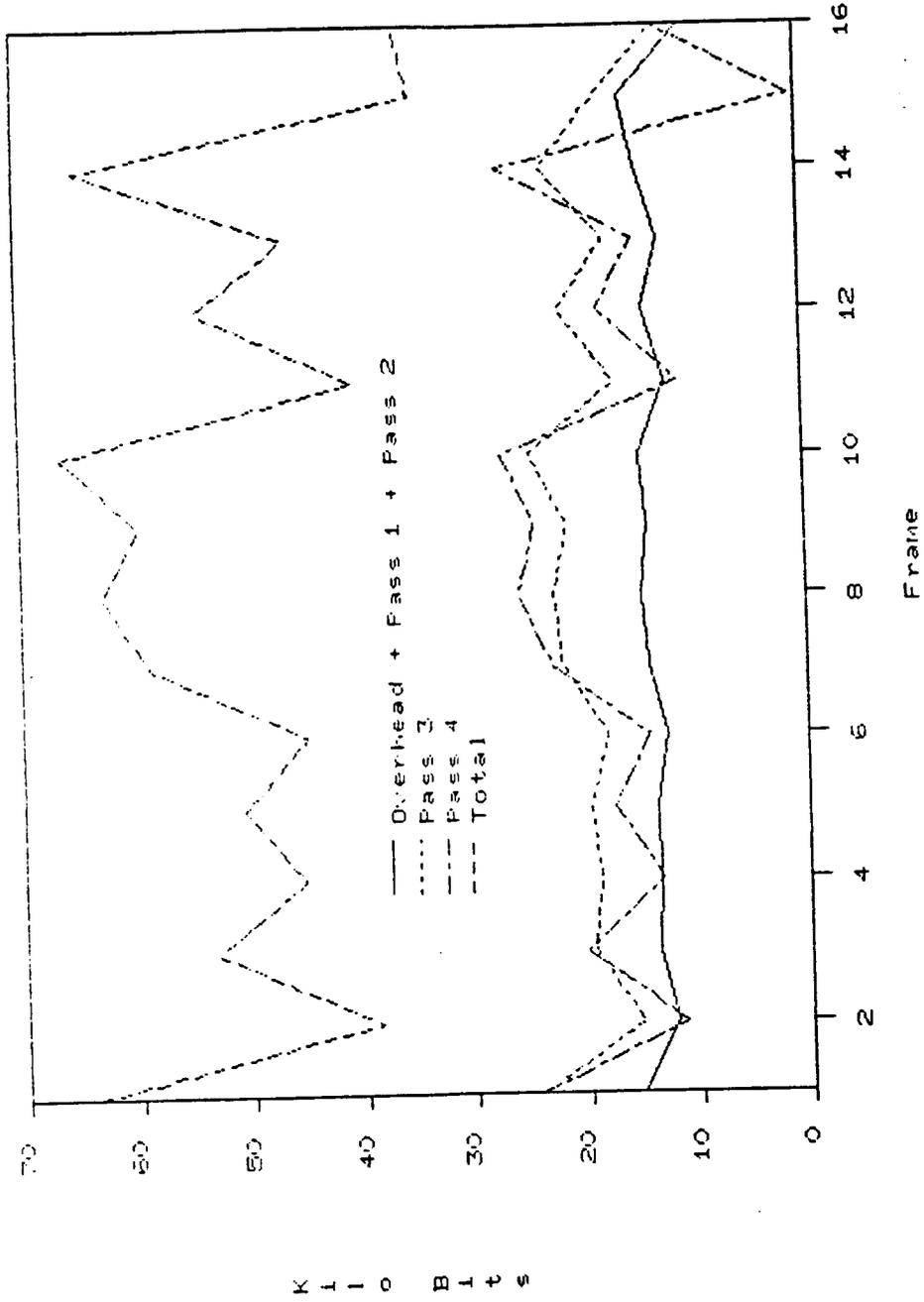


Figure 5.7 Data rate of simulation sequence frames.

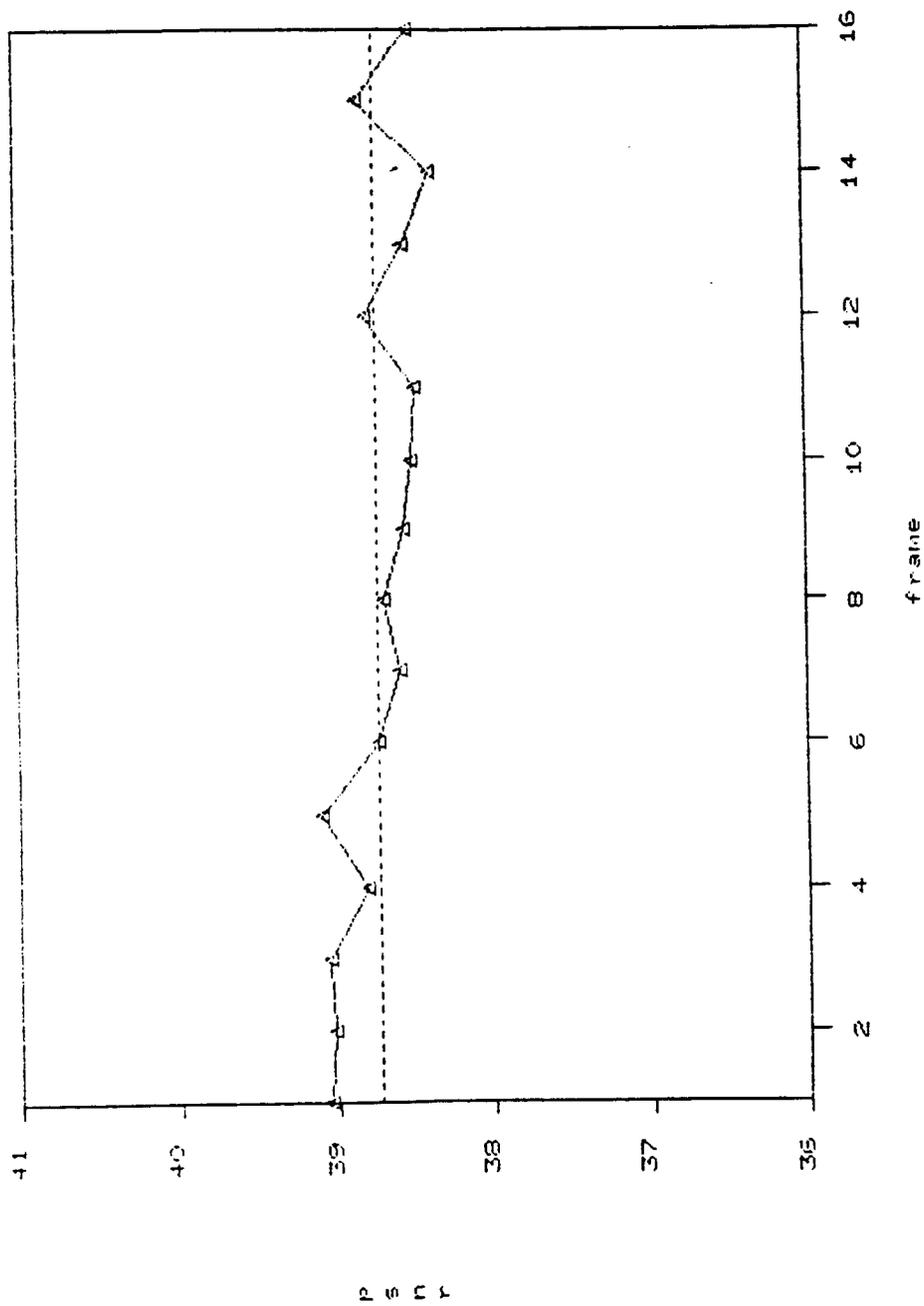


Figure 5.8 PSNR of simulation sequence frames.

FRAME	OVER- HEAD	PASS1	PASS2	PASS3	PASS4	TOTAL
1	2588	4352	8400	24248	24416	64004
2	1772	4352	5992	15232	11312	38660
3	2156	4352	7168	19432	20104	53212
4	2088	4352	6888	18760	13216	45304
5	2164	4352	7112	19600	17416	50644
6	1988	4352	6328	17920	14336	44924
7	2352	4352	7448	21896	22736	58784
8	2432	4352	7952	22512	25704	62952
9	2316	4352	7504	21336	24136	59644
10	2568	4352	7840	24528	26992	66360
11	1892	4352	6048	16856	11144	40292
12	2352	4352	7616	21728	18200	54248
13	1968	4352	6384	17584	15008	46296
14	2468	4352	7840	23128	26936	64734
15	2216	4352	9352	18088	728	34736
16	1496	4352	4536	12824	12936	36164
TOTAL	34816	69632	114408	315672	287392	820992
MEAN	2176	4352	7150	19729	17962	51312
DEVIATION	290	0	1094	3179	7000	10395

Table 5.1 Output bit rate for each and total pass.  
The unit is bits.

	OVER- HEAD	PASS1	PASS2	PASS3	PASS4	TOTAL
MEAN	65.28	130.56	214.50	591.87	538.86	1539.36
DEVIATION	8.70	0.00	32.82	95.37	210.00	311.85
MAXIMUM	77.04	130.56	280.56	735.84	821.52	1990.80
MINIMUM	44.88	130.56	136.08	384.72	21.84	1042.08

Table 5.2 Output bit rate for each and total pass calculated with 30 frames/sec video rate. The maximum and minimum values are the instantaneous rates, which correspond to the respective maximum and minimum number of bits needed to encode a particular frame in the sequence. The unit is kilobits.



Figure 5.9 Frame 3 of simulation sequence.



Figure 5.10 Frame 4 of simulation sequence.

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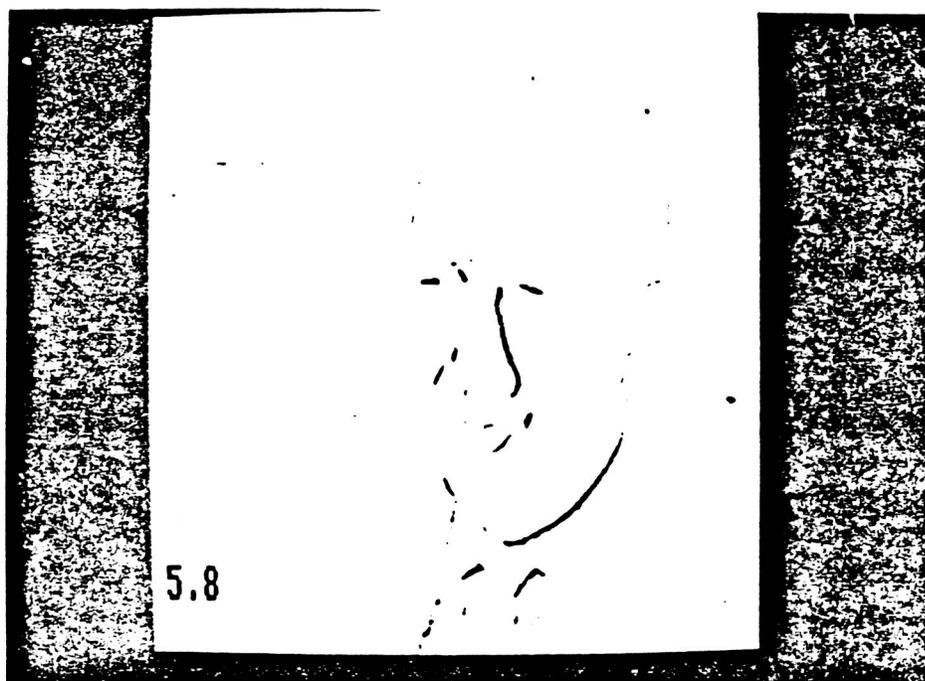


Figure 5.11 Difference image of frame 3 and 4.

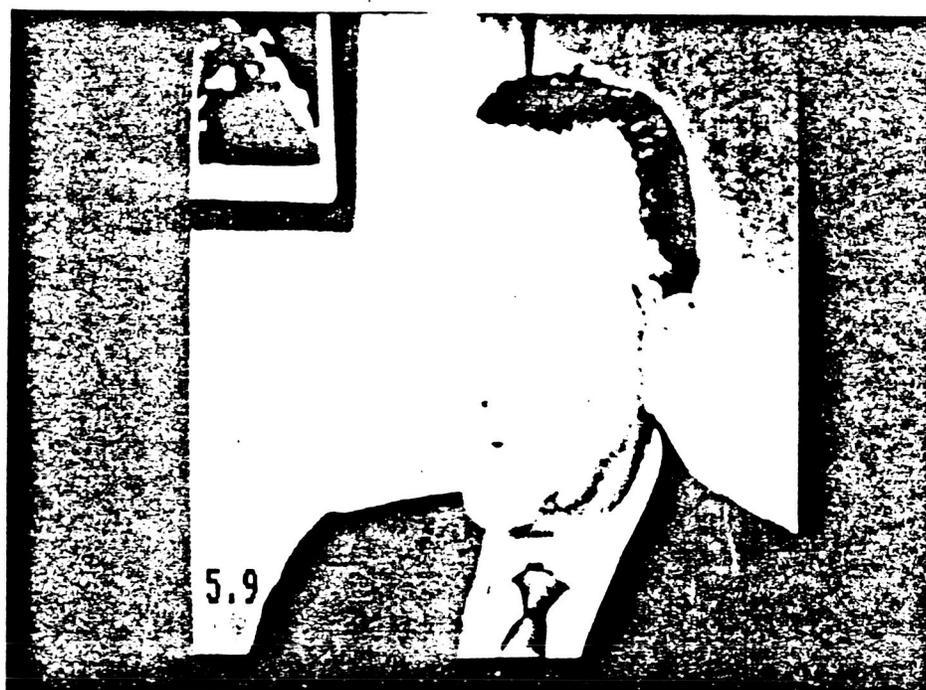


Figure 5.12 Frame 9 of simulation sequence.



Figure 5.13 Frame 10 of simulation sequence.



Figure 5.14 Difference image of frame 9 and 10.



Figure 5.15 The effect of pass 4 packet loss for frame 4.



Figure 5.16 The effect of pass 4 packet loss for frame 10.



Figure 5.17 The effect of pass 1 packet loss for frame 3.



Figure 5.18 The effect of pass 1 packet loss for frame 9.

## Chapter 6 Conclusions

In Chapter 1 and 2 the environment of the future's telecommunications is described and some specifications for integrating signal processing into this environment are proposed. In Chapter 3 the basic materials of data compression were introduced and the characteristics of MBCPT were investigated. In Chapter 4 a view of the network simulator used for these tests was provided and the modifications required were discussed. Finally, in Chapter 5 the differential scheme of MBCPT as a packet video coder was proposed and its performance was examined.

The network simulator was used only as a channel in this simulation. In fact, before the real-time processor is built, a lot of statistics can be collected from the network simulator to improve upon the coding scheme. These include transmission delays and losses from various passes under different network loads. For resynchronization, the delay jitter between received packets can also be estimated from this simulation.

The environment for tomorrow's telecommunications has been described and requires a flexibility which is not possible in circuit switching network. MBCPT has several appealing properties such as high compression rate with good visual performance, robustness to packet lost, tractable integration with network mechanics and simplicity

in parallel implementation. Some more considerations have been proposed for the whole packet video system like designing protocols, packetization, error recovery and resynchronization. For fast moving scenes, the differential MBCPT scheme seems insufficient. Motion compensation, error concealment or even attaching function commands into the coding scheme are believed to be useful tools for increasing the performance and will be the direction of future research.

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