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Study and Implementation of Intra Prediction in the latest video compression standard VVC/H.266

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Thanks

First of all, we would like to thank God Almighty for enabling us to accomplish this thesis.

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Dedication

With the help of Almighty God, I was able to complete this modest work that I dedicate:

- To my dear mother who is no longer in this world, may the Almighty God grant her his holy mercy
- To my dear father may God keep him for me, who never stopped supporting me, encouraging me during all my studies

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- To all the members family: of my paternal family IRES and maternal family MAZARI.
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Abstract

The intra prediction modes in VVC (Versatile Video Coding), are techniques used for encoding video frames by predicting pixel values with in a block based on neighboring pixels. These prediction modes aim to reduce spatial redundancy in the video and improve compression efficiency.VVC supports various intra prediction modes, including planar, DC (ComposanteDirecte), angular, and CCLM (Cross-Component Linear Model) modes. The choice of mode depends on the characteristics of the content being encoded, and the encoder determines the best mode for each block to achieve optimal compression performance. The main goal of this project is the implementation software and hardware on (FPGA) platform of the four intra prediction modes in VVC, implementation thise modes on Matlab and ISE show its good performance and the similarity of the obtained simulation codes.

Key words: Angular, CCLM ,DC, FPGA, HEVC, intra predictiion, ISE, Matlab, Planar, Video compression, VVC.

Résumé

Les modes de prédiction intra dans le VVC (Versatile VideoCoding), sont des techniques utilisées pour coder les images vidéo en prédisant les valeurs des pixels à l'intérieur d'un bloc sur la base des pixels voisins. Ces modes de prédiction visent à réduire la redondance spatiale dans la vidéo et à améliorer l'efficacité de la compression. Le VVC prend en charge différents modes de prédiction intra, notamment les modes planaire, DC (ComposanteDirecte), angulaire, et CCLM(Cross-Component Linear Model) modes.Le choix du mode dépend des caractéristiques du contenu encodé, et l'encodeur détermine le meilleur mode pour chaque bloc afin d'obtenir des performances de compression optimales.L'objectif principal de ce projet est l'implémentation logicielle et matérielle sur plateforme FPGA des quatre modes de prédiction intra dans VVC, l'implémentation de ces modes sur Matlab et ISE montre sa bonne performance et la similarité des codes de simulation obtenus.

Mots clés : Angular, CCLM, DC, FPGA, HEVC, prédiction intra, ISE, Matlab, Planar, Compression vidéo, VVC.

خلاصة

أوضاعالتنبؤالداخليفيترميزالفيديومتعددالاستخدامات (VVC)
هيتقنياتتستخدملتشفيرإطاراتالفيديوعنطريقالتنبؤبقيمالبكسلفيكتلةبناءعلىوحداتالبكسلالمجاورة.
تهدفأوضاعالتنبؤهذهإلىتقليلالتكرارالمكانيفيالفيديووتحسينكفاءةالضغط.
يدعمVVCأوضاعالتنبؤالداخليةالمختلفة،بمافيذلكالأوضاعالمستويةو(DCمكونمباشر)والزاويو(CCLMالنموذجا لخطيعبرالمكونات).يعتمداختيارالوضععلىخصائصالمحتوىالذييتمترميزه،ويحددبرنامجالتشفيرأفضلوضعلكلكتلةلتحقيقأداءضغطمثالي.الهدفالرئيسيمنهذاالمشروعهوتنفيذالبرامجوالأجهزةعلىمنصةFPGAلأوضاعالتنبؤالداخليةالأربعةفيVVC،ويظهرتنفيذأوضاعهذاعلىMatlabوISEأدائهاالجيدوتشابهرموزالمحاكاةالتيتمالحصولعليها.

الكلماتالمفتاحية: التنبؤالبيني،الزاوي، المستوي,، ضغط الفيديو، CCLM, DC, FPGA, HEVC, Matlab, VVC.

List of acronyms

A

ALF : Adaptive Loop Filter
AMT : adaptive multiple transform
ASIC : Application Specified Integrated Circuits

B

B : Bidirectional frame
BAC: Binary Arithmetic Coding
Bsz : block sizes
BT : binary tree
BT_H : Binary Tree_Horizontal Binary
BT_V : Binary Tree_Vertical Ternary

C

CABAC: Context Adavptive Binary Arithmetic Coding
CAVLC: Context Adaptive Variable Length Coding
CCLM : Cross-Component Linear Model
CoDecs : Compression Decompressio
CSM : Context Selection Modling
CSM : Context Selection Modling
CTU: Coding Tree Unit
CU : Coding Unit

D

DC: ComposanteDirecte
DCT :DiscreteCosineTransform
DMVR : Decoder-side MV refinement
DST: Discrete Sine Transfor

F

FPGA : Field Programmable Gate Arra

G

GB : Gigabyte
GIF : Graphics Interchange Forma

H

HD: High Definition
HEVC: High Efficiency Video Coding
HM : Hectometer

I

I : Intra frame
IDE : Integrated Development Environment
IEC: International Electrotechnical Commission
IMAX : Image Maximum
ISE: Integrated Software Environment
ISO: International Organization for Standardization

ISP : intra sub-partition
ITU-T : International Union of Telecommunication

J

JCT-VC : Joint Collaborative Team on Video Coding
JPEG : Joint Photographic Experts Group

L

LMCS: Luma Mapping with Chroma Scaling

M

ME: Motion Estimation
MPEG : Moving Picture Experts Gro
MPM : Most Probable Mode
MRL : multiple reference line
MSGDN : multi-scale grouped dense network
MSGDNGAN : generative adversarial network
MTS: Multiple Transform Selection
MTT: Multi-Type Tre
MV: Motion Vectors
MVs : Several Motion Vectors

P

P : Predicted frame
PCM : Pulse Code Modulation
PDPC : Position Dependent Prediction Combination
PNG : Portable Network Graphics
PSNR : Peak signal-to-noise ratio
PU : Prediction Unit

Q

QP : Quantization Parameter

Qstep: No Quantize

QT: Quadratic Tree

QTMT : quad tree with nested Multi-Type Tree

R

RD : rate-distortion
RDO : Rate Distortion Optimization
RGB : Red Green Blue
RLE : Run Length Encoding
RMD : rough mode decision
RTL : Register Transfer Level

S

SAO: Sample Adaptive Offset
SATD : Sum of Absolute Transformed Differences

T

TT : ternary tree
TT_H : Ternary Tree_Hertical
TT_V :Tree_Vertical

U

UHD: ultra high definition

V

ValDC :DC value
VCEG : Video Coding Experts Group
VHDL: Hardware Description Language
VR: virtual reality
VVC: Versatile Video Coding

W

WAIP : Wide-Angle Intra Prediction

Y

YCrCb :luminance (Y), chrominance (red yellow), chrominance (blue-yellow)

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General Introduction

General Introduction

With the advanced communication technologies including 5G and fast initiation of realistic video such as 360-degree, VR (virtual reality), andUHD (ultra high definition) videos, video demands of different consumers for specific purposes are exponentially increasing since the last few years. To efficiently improve the compatibility of the encoding technology for the current demands of realistic videos, JVET (the Joint Video Exploration Team) has started an initial step to release the newest video coding standard, called H.266/VVC, After exploring and adopting several advanced coding tools [1].

One of the basic tools used in video compression standards VVCis the Intra prediction. which we are interested in this work. It plays a crucial role in reducing the redundancy within video frames, resulting in efficient video compression and improved coding efficiency.

Intra prediction operates on a pixel level within a video frame, predicting the values of pixels based on the neighboring pixels within the same frame. It exploits the spatial redundancy present in natural video content by using previously encoded samples to estimate the values of pixels in the current block being encoded.

Almost all intra prediction features of VVC either contain substantial modifications in comparison with its predecessor H.265/HEVC or were newly added. The key aspects of these tools are the following: 65 angular intra prediction modes [2]. Also uses the same planar and DC interfacial prediction modes used in the previous benchmark, to estimate pixel values within blocks. While the basic principles of these patterns remain the same between the two standards. It is important to note that VVC adopted an new intra prediction technique are: CCLM (The Cross-Component Linear Model), a linear correlation between the luma and chroma components in a coding block which [3], is not available in HEVC or other previous video coding standards. The mode takes advantage of cross-linking to improve internal prediction, especially for color channels, which contributes to improved compression efficiency and visual quality in VVC-encoded videos

This thesis is organised into four chapters:

The first chapter provides a general overview of video compression standards. In the first step, video compression techniques are given. The second step is to

describe the video compression standards. Then, we detail the H.266/VVC standard and we emphasize the importance of intra prediction.

The second chapter presents the different papers that studied intra prediction technique in HEVC and VVC. Next we explained how the intra prediction in VVC done, Then we went deeper into explaining the four intra prediction modes, and the improvements introduced by the new standard.

The third chapter contains a presentation of the software tools used in our work, followed by the representation of the proposed flowcharts of the four intra prediction modes with their simulations in Matlab.

The fourth chapter is reserved for the proposed hardwar architectures of the intra prediction modes in the VVC standard with their descriptions in VHDLlanguage. Then, a synthesis, emulation and evaluation of the power consumption of the energy consumption on the ISE and ModelSim followed by comments on the results obtain. A comparison is made between the results obtained in Matlab and those obtained by ModelSim, in order to validate the proposed desiges.

finally, we summarize the conclusions and future work.

Chapter I

General information about video compression

I.1 Introduction

The applications of video processing are multiple and are involved in many aspects of everyday and professional life. Data compression is often referred to as encoding,where encoding is a very general term encompassing any special representation of data that satisfies a given need. Like file compression, The objective of media compression is to reduce file size and save disk space. However, media compression algorithms are specific to certain types of media, such as image, audio, and video files.In this chapter, we first start with the basics of video and we will detail the H.266/VVC standard.

I.2 General information of the video

I.2.1 Definition of digital video

Digital video is audio/visual content in binary format, with information presented as a sequence of digital data rather than a continuous signal like analog information.

Information in the natural world, received through the five senses, is similar. This means that it is infinitely variable. On the other hand, digital picture and sound information consists of discrete units of data placed so close to each other that human senses perceive them as a continuous stream.

Analog data, such as video recorded on tape, is transmitted as electronic signals with variable frequency or amplitude that are added to carriers of a specific frequency. For exemple when you shoot video on your phone, it is converted from analog media to digital as we show in the figure (I.1) below, and stored in memory, and when you play it, it is converted from digital to analog. This allows you to stream your video over the network, store it on your hard drive, and edit and compress it [4].



Figure II.1: How an analog-to-digital conversion work.

I.2.1.1 What a digital video is made of ?

Video consists of a sequence of dynamic pictures, that as they change rapidly make it appear as if objects are moving on the screen.

I.2.1.2 What is Frame Rate ?

Frames on the screen change at a certain rate. The number of frames per second is the frame rate or framerate. The standard for television is 24 frames per second, and 50 frames per second for IMAX (Image Maximum) in movie theaters.

I.2.1.3 What is pixel ?

Pixel is refers to the smallest unit of information in an image or on a display screen. All displays on televisions, tablets, phones and other devices are made up of little glowing lampscalledpixelsas we show in the figure(III.2). Let's say that each pixel can display one color (technically different manufacturers implement this differently). In order to display an image on a screen, it is necessary for each pixel on the screen to glow a certain color. In digital video each frame is a set of coloredpixels.



Figure I.2: Schematic screen structure.

I.2.1.4 What are color spaces ?

There are different ways of representing the color of a pixel digitally, and these ways are called color spaces. Color spaces are set up so that any color is represented by a point that has certain coordinates in that space.

The classic representation of a digital image is based on a so-called RGB (Red Green Blue) color space Figure (I.3).

color space is a three dimensional color space where each color is described by a set of three coordinates each of them is responsible for red, green and blue colors. Any color in this space is represented as a combination of red, green, and blue.

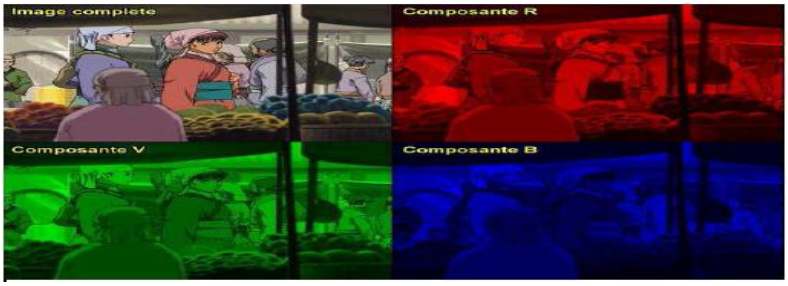


Figure I.3 : Decomposition of the image into RGB components..

Video CoDecs (Compression Decompression) use a more appropriate colour space. The most commonly used colour space in display systems is YCrCb. This is made up of three components: the first represents luminance (or luma), while the other two, Cr and Cb, represent chroma. This space is the most widely used because it offers the advantage of separating luminous intensity and colour information in the image see Figure (I.4).



Figure I.4 : Decomposition of the image into YCrCb components.

The formulae for moving from RGB space to Y'CrCb space equation (I.1), and vice versa equation (I.2), are fairly simple, and correspond to matrix products. These formulae are specified by the CCIR 601 (Consultative Committee for International Radio)standards.area is the most frequently used.see Figure (I.4) [5].

$$\begin{bmatrix} Y \\ Cr \\ Cb \end{bmatrix} = \begin{bmatrix} 0.229 & 0.587 & 0.114 \\ -0.169 & -0.331 & 0.500 \\ 0.500 & -0.419 & -0.081 \end{bmatrix} \times \begin{bmatrix} R \\ G \\ B \end{bmatrix} \text{(I.1)}$$

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 1.000 & 0.000 & 1.402 \\ 1.000 & -0.344 & -0.714 \\ 1.000 & 1.772 & 0.000 \end{bmatrix} \times \begin{bmatrix} Y \\ Cr \\ Cb \end{bmatrix} \quad \text{(I.2)}$$

I.2.1.5Video file size

Video file sizes have exploded over the past decade, and that growth is slowing down downloads and file transfers, smooth online streaming, and so on. In fact, new capture technologies and better camera resolutions (4K, 8K, 12K, etc.) are expected to accelerate file size growth and consume more bandwidth. This creates storage space.for example simple 1080 HD (High Definition) video can take up approximately 11 GB (Gigabyte)of space per minute of video. That's more space than anyone can handle for a one-minute video. This cost makes video compression important [6].

The solution is to use video compression techniques to improve storage demand as well as file transfer and transfer speed. This facilitates video uploading and sharing, allowing viewers to have enjoy.

I.3 Compression

I.3.1 Definition of compression

In generaldata compression consists of taking a stream of symbols and transforming them into codes. Compression is performed by a program that uses a formula or algorithm to figure out how to reduce the size of data to save storage space, and band width in transmission case.

Data compression is also known as source coding or Reduce the flow rate , It is the process of modifying, encoding or converting the binary structure of data so as to consume less disk space [7].

I.3.2 Compression concepts

There are two important compression concepts are lossless and lossy compression.The first category is lossless compression, every bit of data originally in a file remains after it is uncompressed, and all the information is restored. Lossy compression reduces a file by permanently eliminating certain information, especially redundant information [8].The main difference, compared to the first category, is that no one longer looking for a similar reconstruction of the source. The challenge of this lossy compression is to find the best compromise between the quality of the reconstructed image and the compression rate achieved.

I.3.3 Image compression

Image compression is a data compression application that encodes the original image with few bits. The three most common compression formats include JPEG(Joint Photography Experts Group), GIF (Graphics Interchange Format) and PNG (Portable Network Graphics).

a) JPEG compression, used for digital photos, incorporates a lossy compression algorithm that approximates close colors and removes color variations that are imperceptible to the human eye.
b) GIF compression, reduces the color palette of an image to 256 colors or less, which provides an efficient way to represent each color in the image.
c) PNG compression, uses a lossless compression algorithm that filters image data and predicts pixel colors based on other neighboring pixels.

Although each of these algorithms works in different ways, they can be used to reduce the size of an uncompressed image.

I.3.4 Video compression

Video compression technologies are reducing and removing repleated video data so that a digital video file can be sent efficiently over a network and stored on computer disks. With effective compression techniques, a significant reduction in file size can be achieved with little or no adverse effect on visual quality. Video quality, however, may be affected if the file size is further lowered by increasing the compression level for a given compression technique.The goal of compressing digital video is to take up less storage space and transmission bandwidth.

I.3.4.1 Principles of video compression

- Video compression aims to eliminate spatial and/or temporal repeated that may arise.
- In addition, the spatial redundancy is presents in each image, otherwise temporal redundancy is often present between successive images.
- Frames are classified as 1 of 3 basic frame types (I (Intra frame) , P (Predicted frame), B (Bidirectional frame)) and encoded differently.

I.3.4.2 RecentVideo compression codecs

Video codecs, are the compressing elements in video compression tools. Codec stands for video codec (Compression-Decompression). The different algorithms as per chosen codec format, encode for compression (code and compress.) They can also decompress videos for playback by decoding them (decode and decompress) [5]. The following are the most used video codec formats in recent years:

- H.264 /AVC (Advanced Vidéo Coding) .
- H.265/HEVC (High Efficiency Video Coding) .
- H.266/VVC .

I.3.4.2.1 H.264/AVC

Developed in 2003, H.264 or MPEG-4 AVC is a video coding format for recording and distributing full HD video and audio. It was developedand maintained by the ITU-T(International Union of Telecommunication), VCEG (Video Coding Experts Group) with ISO (the International Organization for Standardization) and IEC (the International Electrotechnical Commission), and MPEG (Moving Picture Experts Group).

Commonly used for the recording, compression, and distribution of video content, the H.264 format is a network-friendly video transmission method that delivers high-quality images without being a bandwidth hog.

I.3.4.2.2 H.265/HEVC

Developed in 2013, HEVC is developed video compression standard pioneered by the Joint Collaborative Team on Video Coding (JCT-VC).

This HEVC compression standard was developed to double the compression efficiency of the previous standard, H.264/AVC, and at typical consumer video distribution bitrates, HEVC has been largely successful in doing so and is the supported coded for the emerging Ultra HD format. However, compression efficiency results will always vary according to the type of content and the encoder settings [9] .

I.3.4.2.3 H.266 /VVC

Developed in 2020, H.266/VVC is the brainchild of the Fraunhofer Heinrich Hertz Institute, the same group that developed the famous MP3 audio format, as well as AVC and HEVC. VVC can reduce the bandwidth needed for a given video by a further 50% over HEVC as an example by using HEVC, you'd need 10GB of data to

transmit a 90-minute 4K video. But with VVC, only 5GB of data are required to achieve the same quality [10].In addition ,H.266 may seem like an efficient and flexible standard, but it will take years to replace current standards such as H.265[11].

To better understand the encoding process, get the basic ideas first: Video compression has two main parts : inter compression and intracompression.Intra is to remove spatial redundancy, while inter is to remove temporal redundancy. The following table represents the difference betweenH.264 and H.255 and H.266

TableI.1 : Comparison of H.264, H.265 and H.266 standards

		H.264/AVC	H.265/HEVC	H.266/VVC
Publishing date		2003	2013	2020
Entropycoding		CABAC or CAVLC	CABAC	CABAC with parallelloperations
intra-frame prediction		9 modes	35 modes	81 modes: 65 angular + planar + DC + Sub
Inter-frame prediction	**ME**	16×16, 8×8, 16×8,8×16,8×16,4×4	Max 64×64	1/16 Pixel
	MV	16×16,8×8,16×8,8×16, 8×16,4×4	Half pixel:8 or 7 tap filter quad pixel:8 tap filter	DMVR (Decoder-side MV refinement) 2 interpolationfilters
Coding unit		16 x 16 mocroblock	8x8 to 64x64	4x4 to 128x128
Transform		8×8, or 4×4 integer DCT transfom	square DCT-based transforms • 1 DST4x4-based transform	DCT2 (up to 64x64) + MTS (<=32x32, DST7, DCT8, independent(horizontal / vertical))
In-loopfiltering		Adaptive deblockingfilter	Adaptive deblocking filter, sample adaptive offset filter	Deblocking • SAO • ALF • LMCS

In our work we are interested to the study, design and implementation of one technique of the compression chain in the new h.266/VVC standard.

I.4 Overview of Codec H.266

VVC is the latest video coding standard, which uses aMTT (Multi-Type Tree) coding structure. Compared with existing video coding standards, this structure can flexibly split coding blocks according to the complex texture features of the image. As MTT structure introduces BT(binary tree)and TT(ternary tree) splitting, it will lead to

a sharp increase in computational complexity , so a fast CU(Coding Unit) size decision method for intra prediction of VVC is proposed, which can significantly reduce the calculation in the intra encoding of VVC.

I.4.1 Partitioning in VVC

VVC adopts QTMT (quad tree with nested Multi-Type Tree)partition structure compared to the basic QT(quadtree) structure in HEVC. QTMT supports additional vertical and horizontal binary and ternary splitting (BT_Ver, BT_Hor, TT_Ver, TT_Hor) in CTUs (coding tree units), as shown in Figure (I.5).



Figure I.5 :CU partition modes in H.266/VVC.

The division process is as follows: For a 128×128 Coding CTU (Coding Tree Unit), firstly theCTU is divided into a quad-tree to obtain four 64×64 CUs; secondly for the64 ×64 CU as shown in Figure (I.6).there are two options: quad-tree split and non-split; next, to divide the 32×32 CU, thereare four options: binary-tree, trinomial-tree, quad-tree split and non-split; and so on, until itis divided into a 4×4 CU [12] .

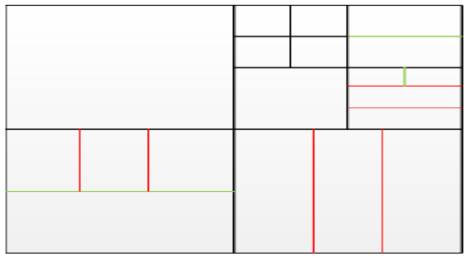


Figure I.6 :CTU partitioning in VVC, Take a 64 ×64 CU as an example.

Inclusion of more partitioning shapes vitally improves the accuracy of intra prediction and inter prediction. Furthermore, 67 intra modes including two non-directional modes (DC mode and Planar mode) and 65 directional modes can be chosen instead of 35 intra modes in H.265/HEVC. VVC also incorporates the affine motion model to enhance motion estimation. Despite the improved RD (rate-

distortion) performance, the plural of the above mechanisms significantly increases the encoding time [13].

I.4.2 VVC diagram

The VVC design follows the diagramevideo codec, as shown below in Figure (I.7). Here, a video frame is subdivided into blocks. For each block, a prediction is performed and a transform, which may be the identity mapping. This is followed by entropy coding of the prediction mode information and the transform coefficients. The prediction is generated by inter prediction or by intra prediction. While the former makes use of temporal redundancies, the latter exploits spatial correlations to generate the prediction signal for a given block out of previously reconstructed samples of the same frame that are located close to the current samples.

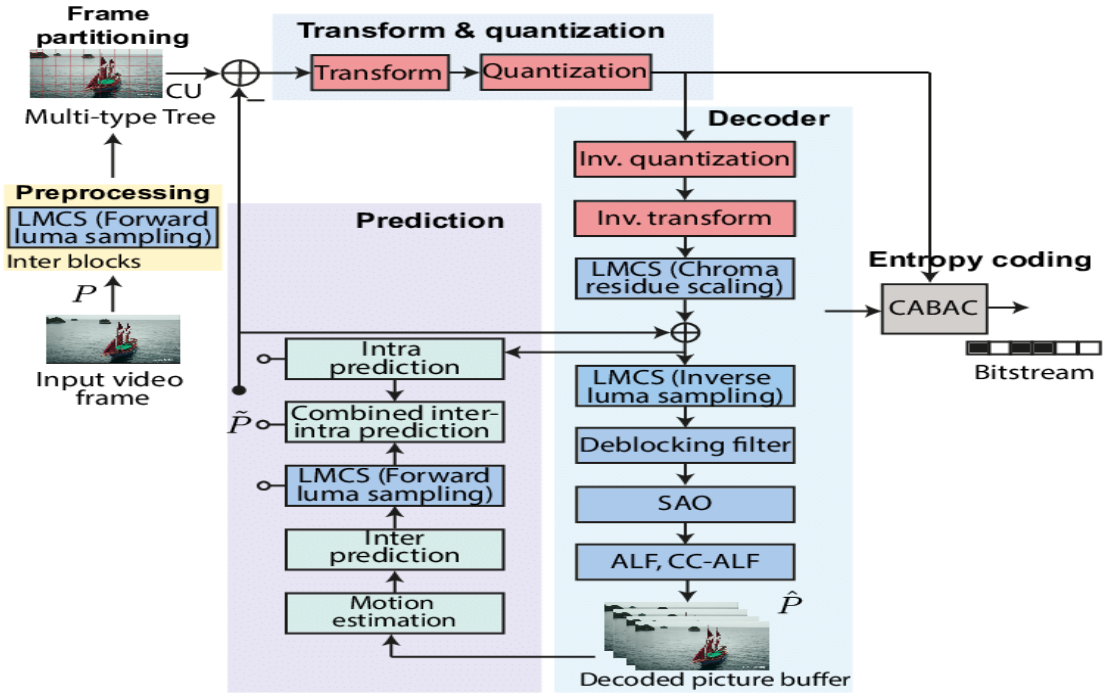


Figure I.7 : Block diagram of the VVC codec

I.4.2.1Transformation

H.266/VVC release has been accompanied with various new contributions to improve the coding efficiency beyond HEVC, particularly in the transformation process.

The discrete cosine/sine transform proves to be a basic algorithm for compression owing to its signal decorrelation and energy concentration properties. The DCT and DST transforms are widely used in video compression applications. In the VVC.There are multiple core transforms, namely, DCT-II, DCT-V, DCT-VIII, DST-I, and DST-VII,The DCT-II has a fast computing algorithm. while the DST-VII relies on a complex matrix multiplication, The coefficients of the transform matrices are scaled and rounded into integer numbers while maintaining the important transform properties [14].

I.4.2.2 Quantization

The main purpose of quantization is to reduce the dynamic range of the image data after the transformation step by removing insignificant high frequency values or coefficients[15].

VVC uses essentially the same quantization procedure, controlled by a QP (quantization parameter)as in the HEVC standard. The range of QP values is defined between (51 to 63), and a 6-fold increase in quantization step size. In addition, the QP has a direct influence on the visual quality and compression ratio of the images or video. Therefore, if the QP is low or equal to 1, the reconstruction is perfect and the compression ratio is very low and vice versa, Moreover, quantization consists of dividing the coefficients by the Qstep (No Quantize), while inverse quantization consists of a multiplication by the Qstep.Indeed, the Qstep given by equation (1.1) allows the encoder the possibility of an exact and flexible control to improve the compromise between bit rate and visual quality [16].

QStep=2(QP-4)/6(I.3)

I.4.2.3 CABAC

The new version of CABAC used in the latest VVC technology is state-of-the-art in the field of entropy. It provides an even more accurate estimation of the probabilities of coded data symbols CABAC is applied in three steps:

1. It converts all non-binary symbols to binary symbols (bins).

2. Each bit, a most suitable probability model is selected by the CSM (context selection modling) based on the neighborhood data to optimize the estimation of this probability.
3. BAC (Binary arithmetic coding) is applied to compress the binary symbols according to the coding, regular mode, bypass mode and terminate mode .

I.4.2.4 Loop filtering

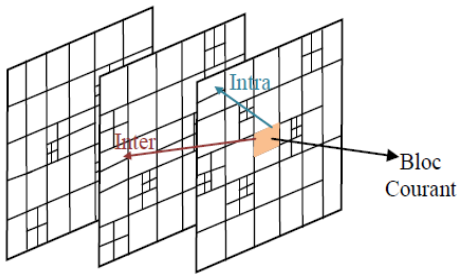
Loop filtering, in the context of the Versatile Video Coding, refers to a set of techniques used to reduce artifacts and enhance the visual quality of video content.

The Adaptive Loop Filter in the VVC standard has the following features: a 7×7 diamond filter (13 different coefficients) is used for luma components and a 5x5 diamond filter (7 different coefficients) for chroma components each 4x4 luma block is categorized into one of 25 different classes using vertical, horizontal, and two diagonal gradients based on the calculated gradients, the filter coefficients can undergo one of three transformsdiagonal reflections, vertical reflection, or rotation before they are applied [17].

I.4.2.5 Prediction

Prediction modes are basically subdivided into two main types:

- Intra: when pixels are predicted by other pixels of the current frame,intra prediction is used to eliminate spatial redundancies between blocks of the same image.
- Inter: when other frames predict the current frame, so inter prediction is used to eliminate temporal redundancies between successive images as show inFigure (I.8).



FigureI.8 : Intra and inter prediction of a PU (Prediction Unit) block in a video sequence.

I.4.2.5.1 Inter-prediction

H.266 has made some modifications, including the length of the Merge motion vector candidate list, the construction process, and the range of neighboring blocks.At the same time, some new prediction technologies are added, such as affine transformation technology and adaptive motion vector accuracy technology.

Inter prediction exploits temporal redundancy in the video sequence. It predicts the samples of a CU from samples of previously coded reference pictures. The process of finding the most similar block in the reference pictures is called ME (Motion estimation). The ME relies on block matching and is one of most computationally complex operations in the encoding process. It outputs one or several Motion Vectors (MVs), each composed of a vertical and an horizontal component, representing the translation of the CU from the reference frame to current frame [18].

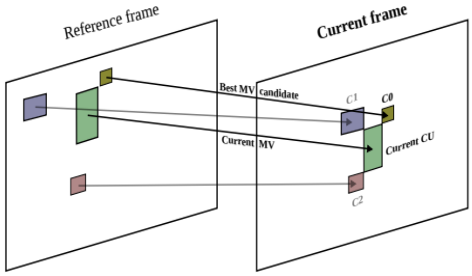


Figure I.9 : Simplified example of Advanced Motion Vector Prediction.

I.4.2.5.2 Intra prediction

Intra prediction stage computes intra prediction for a decoded block the existing Planar, DC, PCM (Pulse Code Modulation), and Angular Prediction modes are still available. The number of directions for Angular Prediction has been increased from 33 (in HEVC) to 65.

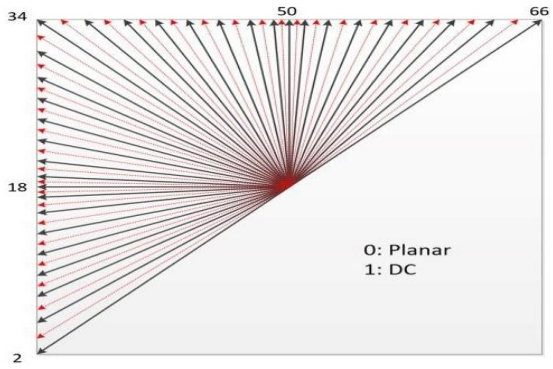


Figure I.10 :VVC intra angular prediction modes.

Since prediction blocks may be non-square in VVC, traditional modes are adaptively replaced by wide-angle directions, So this widens the prediction direction angles to values that exceed the normal 45° and –135°.

Furthermore, in many cases, the luma and chroma components carry very similar information, therefore a new prediction mode called Cross-component Prediction was added for those cases. In this mode, a method is used that directly predicts chroma components from a reconstructed luma block using a linear combination of reconstructed pixels with two parameters, a factor, and an offset, where the factors are calculated from the intra reference pixels. The block is also scaled if necessary.

I.5 conclusion

In this chapter, the basics of digital video and its compression are introduced. Then modern video compression standards were introduced and we focused on the latest H.266/VVC standard and the technologies associated with this standard are presented, namely discrete cosine transform, quantization and prediction, and loop filters. Finally, a detailed study of intra prediction will be the subject of the next chapter.

Chapter II

Intra prediction in VVC
(Versatile Video Coding)

II.1 Introduction

Versatile video coding, is an emerging video coding standard. H.266/VVC supports up to 16K resolution and panoramic videos. The improvement of VVC in coding efficiency derives mainly from the more flexible encoding structure, both for intra-picture prediction and inter-picture prediction, which in turn requires more computations. In this chapter, we focus on intra prediction technique and its modes.

II.2 Stateof the art

II.2.1 Proposed works of HEVC/H.265 Intra prediction

II.2.1.1 On the analysis of HEVC Intra Prediction Mode Decision Variants

In this workPreethi S. Naira &Madhu S. Nairbpresents a comparative analysis of some major HEVC intra prediction mode decision methods reported in the literature. Then they provide an extensive and up-to-date discussion of the research proposals regarding a variety of HEVC intra predictionmode decision strategies. Moreover, some most significant research contributions on fast intra mode decision methods in HEVC to improvise the encoder efficiency are reviewed in detail along with a comparative performance analysis of the reviewed proposals in terms of some standard evaluation metrics such as bit rate, PSNR (Peak signal-to-noise ratio) and time savings. In addition, this paper point out some research directions towards further developments in the intra prediction for the betterment of the encoder efficacy.

Researches are still going on to predict the intra modes by reducing the total number of modes in the HEVC reference software, introducing new methods to predict the candidate modes and so on. The paper gives an insight to the intra prediction in HEVC and the different methods that can be adopted to HEVC codec to improving its efficiency in addition to complexity reduction [19].

II.2.1.2 Review on Intra-prediction in HEVCStandard

In this work Dhruti Patel & Tarun Lad &DharamShahprovide a review of the intra prediction part in recently developed HEVC standard. It follows the same basic design principles as already established by the state-of-the-art video coding standard profile, with generalizations for more flexibility in terms of prediction. The new features of the proposals for HEVC inra-prediction design included the partition of

prediction blocks which use quad-tree structure for splitting , the interpolation scheme, directional interpolation filters, angular prediction, planar coding. Many compression improvements were made by increasing adaptability. From this survey confirm that the goal of developing a high-efficiency video coding standard, which delivers significantly improved compression performance relative to that of the H.264/AVC [20].

II.2.1.3 Analysis of the Intra Predictions in H.265/HEVC

Roman I. Chernyak obtained the results in this research research were collected within the current HEVC encoding logics. It means that when deciding on which method to use to code the next block, the encoder considered various costs of such encoding based on the calculated array of the most probable modes for the given block. Thus, the obtained statistic data are probably not the objective characteristics of the test video sequences, but only the illustration of the current intra coding practice. It is of interest to obtain objective statistical data which might contribute to the improvement of the existing approach [21].

II.2.1.4 Iterative Intra Prediction Search for H.265/HEVC

In this paper Maxim P. Sharabayko& Nikolay G. Markov propose iterative intra prediction search for H.265/HEVC encoder to reduce the number of prediction modes for estimation. They based of computational complexity and usage frequency of H.265/HEVC intra prediction. On JCT-VC test sequences, they got about 40% encoding time reduction for HM (Hectometer) 10.1 intra-only coding with negligible bitrate increase and PSNR quality degradation. They also offer some additional speed-up techniques, including fast prediction error estimation[22].

II.2.2 Proposed workS of VVC/H.266 Intra prediction

II.2.2.1 Intra Prediction and Mode Coding in VVC

This work Jonathan Pfaff &Alexey Filippov & Shan Liu, are presents the intra prediction and mode coding of VVC standard. It follows the traditional architecture of a hybrid block-based codec that was also the basis of previous standards HEVC and AVC. Almost all intra prediction features of VVC either contain substantial modifications in comparison with its predecessor H.265/HEVC .

The key aspects of these tools are the following: 65 angular intra prediction modes with block shape-adaptive directions and 4-tap interpolation filters are supported as well as the DC and Planar mode, . Finally, the intra prediction mode in VVC is coded separately for luma and chroma. Here, a Most Probable Mode list containing six modes is applied for luma. The individual compression performance of tools is reported in this paper. For the full VVC intra codec, a bitrate saving of 25% on average is reported over H.265/HEVC using an objective metric.

In the end it was concluded thatthe intra prediction tools of VVC provide a substantial compression benefit over HEVC both in an objective and in a subjective evaluation framework. Since a variety of intra prediction modes are possible for each block, compression gains are obtained throughout a large set of different types of content. On the other hand, each individual intra predictionmethod supported in VVC is of moderate computational complexity. Thus, the sequential dependencies that exist betweenintra-predicted blocks can be handled in real-time decoding applications [23].

II.2.2.2 Multi-scale Grouped Dense Network for VVC Intra Coding

In this paper Xin Li &SimengSun&Zhizheng Zhang &Zhibo Chen, They design theMSGDN(multi-scale grouped dense network)to further reduce the compression artifacts by combining the multi-scale and grouped dense block, which are integrated as the post-process network of VVC intra coding. Besides, to improve the subjective quality of compressed image, They also present a generative adversarial network (MSGDNGAN) by utilizing our MSGDN as generator. Across the extensive experiments on validation set [24].

II.2.2.3 Low complexity mode selection for H.266/VVC intra coding

In this paper, EiEiTun&SupavadeeAramvith& Takao Onoye present the original strategy of VVC intra mode decision and analyze the correlation among the SATD (Sum of Absolute Transformed Differences) costs of the RMD (rough mode decision) and RD (rate distortion) costs of RDO(rate distortion optimization) processes. They based on the useful correlations with an effective threshold formulation, we propose a fast intra prediction mode selection for the most time-consuming RDO process by selecting a small candidate set based on the SATD costs and calculating the time-consuming RD costs for only intra prediction modes of the small candidate set without a significant overhead [25].

II.3 Intra prediction of VVC standard

II.3.1 Intra prediction definition

Intra prediction indicate prediction which generates prediction samples for a current block based on reference samples in a picture to which the current block belongs (referred to as a current picture).

Intra prediction is used to reduce spatial redundancies by exploiting the principle of the correlation between the blocks in the same video image. This correlation spatial is applied to neighboring blocks already coded, which are of the same type and which are located above and to the left of the block of interest.

II.3.2 Main new intra prediction tools

VVC uses advanced new tools for intra prediction. Where Once the block shape has become diversified, the wide-angle intra prediction mode with 65 directional prediction modes is available. Therefore, there are 87 intra prediction modes including DC and planar modes. In addition, the multiple reference line (MRL) has been added which uses two non-adjacent reference lines. A new ISP (intra sub-partition) mode is included in VVC, where the prediction block is divided into smaller blocks of the same size to perform prediction and transform on these small blocks.

It splits 4 × 8 and 8 × 4 blocks into two small blocks and the remaining blocks into four small blocks, where the blocks are partitioned horizontally or vertically.
Reference sample filtering is also performed to generate more accurate prediction values from reference samples of adjacent blocks of the current block.When the intra prediction mode has integer-slope modes, reference sample smoothing is applied to the integer reference samples. For fractional-slope modes, an interpolation filter is applied to integer reference samples to create fractional positioned reference samples.

In PDPC (Position Dependent Prediction Combination), unfiltered or filtered reference samples are used according to the intra prediction mode and position-dependent weighting is applied to correct the prediction value of the current CU. MPM (The Most Probable Mode) list increased from the three (3) intra prediction modes in HEVC to the six (6) intra prediction modes in VVC. [26]

II.3.3 Intra prediction modes

In order to adapt to more prediction directions, the intra-angle prediction modes of VVC are increased to 65, plus DC mode and planar mode, there are 67 intra prediction modes of VVC [27].

Meanwhile, the intra prediction mode include CCLMmode for chroma samples in addition to the above-described intra prediction modes. The CCLM mode may be split into L_CCLM, T_CCLM, LT_CCLM according to whether left samples, upper samples or both thereof and may apply only to a chroma component [28]. For example, the intra prediction mode be indexed as shown in Table 1 below.

Tableau II.1: the intra prediction mode.

Intra prediction mode	Associated name
0	INTRA_PLANAR
1	INTRA_DC
2..66	INTRA_ANGULAR2..INTRA_ANGULAR66
81..83	INTRA_LT_CCLM INTRA_L_CCLM INTRA_T_CCLM

Note :The intra prediction modes INTRA_LT_CCLM, INTRA_L_CCLM and INTRA_T_CCLM are only applicable to chroma [29].

II.3.3.1 Planar Intra Prediction Mode

The Planar intra prediction mode specified in HEVC is also enabled in VVC. In the Planar modethe predicted sample values are obtained as a weighted average of 4 reference sample values. Here, the reference samples in the same row or column as the current sample and the reference samples on the bottom-left and on the top-right position with respect to the block are used. In VVC, the reference sample smoothing filter is also applied for the Planar mode in the luma component depending on the block size.

All prediction blocks sizes are processed with planar mode. This prediction mode is perfect and used for the picture that does not contain an edge model and does not result any discontinuities [30].

Equation (II.1) shows the predicted procedure applied in the planar mode which is based on the horizontal PredH[X][Y]and vertical PredV[X][Y] components. In thisprediction the X and Y are ranging from 0 to (nTbH×nTbW-1) (blocksize minus 1).

predV[x][y] = ((nTbH − 1 − y)×p[x][−1] + (y + 1)×p[−1][nTbH]) << Log2 (nTbW)

predH[x][y] = ((nTbW − 1 − x) × p[−1][y] + (x + 1) × p[nTbW][−1]) << Log2 (nTbH)

predSamples[x][y] = (predV[x][y] + predH[x][y] + nTbW * nTbH) >> (Log2 (nTbW) + Log2 (nTbH) + 1)(II.2)

II.3.3.2 DC IntraPrediction Mode

A DC intra prediction mode is supported in VVC as in AVC and HEVC . The DC intra prediction mode of HEVC and AVC uses the mean sample value of the reference samples to the left and above the block for prediction generation. Here, since only square blocks with side lengths that are an integral power of 2 are supported, the division needed in the mean value calculation can be implemented by a bit shift. VVC uses the reference samples only along the longer side of a rectangular block to calculate the mean value, while for square blocks the reference samples from both sides are used.in the Figure(II.1) below we show The calculation of the DC mode prediction

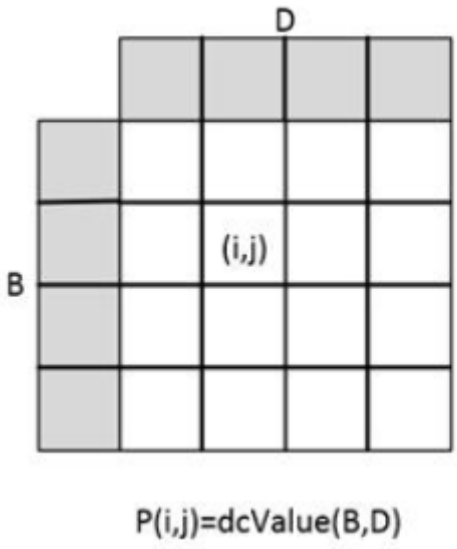


Figure II.1 : The calculation of the DC mode prediction[31].

The predicted block in this mode is obtained according to the following equations and depends on the original block size and the position of the samples in this block. As reported below, the predicted Bsz (block sizes) is equal to 4 x 4, 8 x 8, 16 x 16, and 32 x 32 and 64 x 64. Three prediction equations are used in this mode, which are applied depending on the position of the samples in the block and obtained

with the ValDC (DC value) presented in equations (II.3) (II.4) (II.5) respectively with x = 0..nTbW − 1, y = 0..nTbH − 1.

$$\text{ValDC} = \left(\sum_{x'}^{nTbW-1} p[x'][-1 - refIdx] + \sum_{y'}^{nTbH-1} p[-1 - refIdx][y'] + nTbW \right) >> \left(Log2(nTbW) + 1 \right) \quad \text{(II.3)}$$

$$\text{ValDC} = \left(\sum_{x'}^{nTbW-1} p[x'][-1 - refIdx] + \left(nTbW >> 1 \right) \right) >> Log2(nTbW) \quad \text{(II.4)}$$

$$\text{ValDC} = \sum_{y'}^{nTbH-1} p[-1 - refIdx][y'] + \left(nTbH >> 1 \right) >> Log2(nTbH) \quad \text{(II.5)}$$

II.3.3.3 Angular Intra Prediction

In VVC, the number of directional modes available for a given block is increased to 65 directions from the 33 HEVC directions. The angular modes of VVC are depicted in Figure(II.2) The directions having even indices between 2 and 66 are equivalent to the directions of the angular modes supported in HEVC.

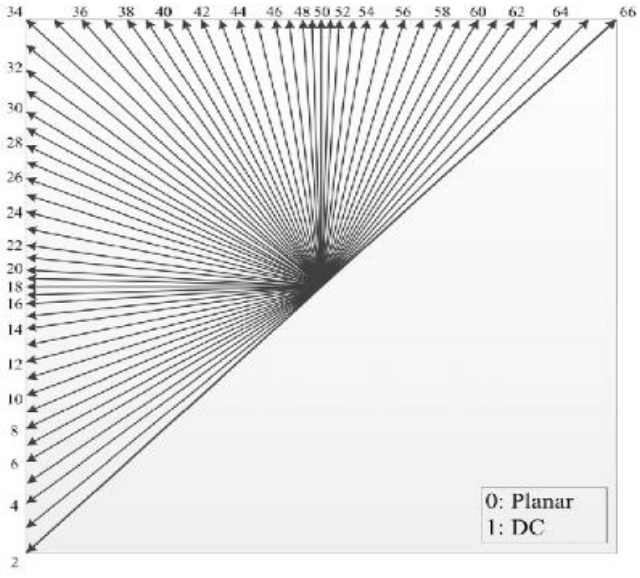


Figure II.2 : Angular intra prediction modes in VVC.

For intra blocks of rectangular shape, which are not present in HEVC, but which are a central part of VVC's partitioning scheme, more intra prediction directions are assigned to the longer side of a block. The additional modes allocated along a longer side are called WAIP (Wide-Angle Intra Prediction) modes , since they correspond to prediction directions with angles greater than 45◦ relative to the horizontal or vertical mode.

II.3.3.4 Cross-Component Linear Model Prediction (CCLM)

To improve coding efficiency by exploiting the local inter-component redundancy between the luma and chroma components, CCLM is included in VVC standard. Chroma samples predicted using corresponding reconstructed luma samples. The cross-component linear model is assumed that the chromaticity pixel of the same coding block is linear with the corresponding brightness pixel value[32].

So the CCLM creates a corresponding chromaticity prediction from the reconstruction brightness pixel value. In Figure(II.3) we show Pixel values that need to be used in the calculation process,This prediction is carried out using a linear model in the form equation (II.6):

$$P(i,j)=a\times rec\acute{}_L(I,j) \quad \text{(II.6)}$$

Here,P(i; j) : the predicted chroma samples in a CU.

$rec\acute{}_L$: the reconstructed luma samples of the same CU which are downsampled for the case of non- 4:4:4 color format. The model parameters a and b are derived based on reconstructed neighboring luma and chroma samples at both encoder and decoder side without explicit signaling.

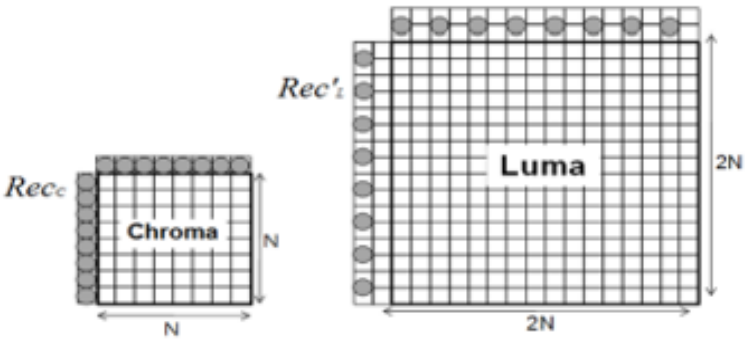


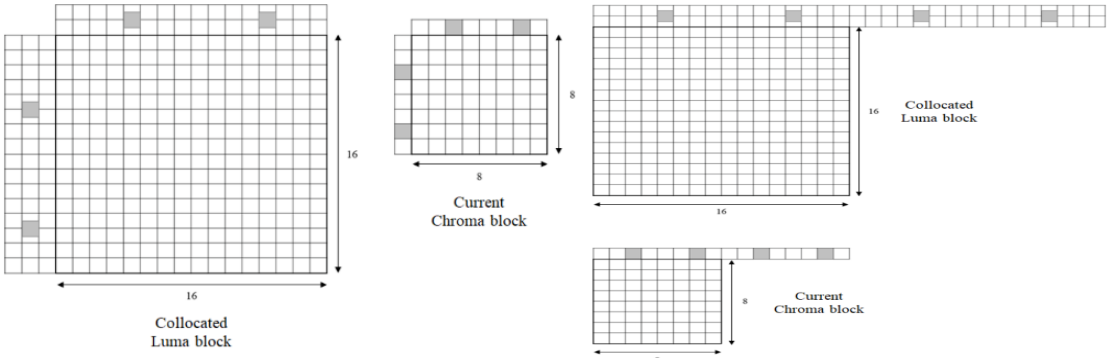
Figure II.3 : Pixel values that need to be used in the calculation process.

Three CCLM modes CCLM LT, CCLM L and CCLM T, are specified in VVC.These three modes differ with respect to the locations of the reference samples that are used for model parameter derivation.

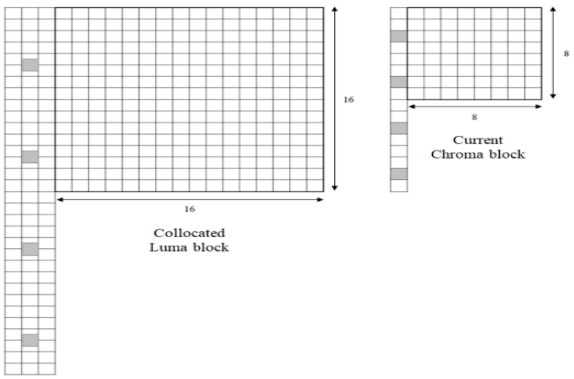
- CCLM_T mode : Samples from the top boundary are involved .
- CCLM_ L mode: Samples from the left boundary are involved .

- CCLM L_T mode: Samples from both the top boundary and the left boundary are used.

Figure(II.4) illustrates examples of the subsampled neighboring chroma sample positions and the corresponding subsampled neighboring luma sample positions for the LT_CCLM, T_CCLM, and L_CCLM modes, when the chroma subsampling ratio is 4:2:0. In figure, the square boxes indicate the sample positions, the shaded boxes represent the subsampled sample positions for the neighboring samples of the current 8 × 8 chroma block and the neighboring samples of the corresponding 16 × 16 luma block, and the sample positions outside the blocks are the available neighboring sample positions [33].



(a) (b)



(c)

Figure II.4 : Subsampled sample positions for the neighboring chroma samples and their corresponding neighboring luma samples for a given 8 × 8 chroma block:
(a) LT_CCLM mode; (b) T_CCLM mode; (c) L_CCLM mode.

Moreover the prediction of CCLM modes process the follow steps:

1. Downsampling of the luma block and its neighboring reconstructed samples to match the size of corresponding chroma block.
2. Model parameter derivation based on reconstructed neighboring samples.
3. Application of the model equation (II.6) to generate the chroma intra prediction samples.

II.4 Conclusion

In this chapter we present the different papers that studied intra prediction technique in HEVC and VVC. Next we focused on detailed stady of all the intra prediction modes used in VVC standard. In the next chapter, we focesed on the software implementation of the VVC.

Chapter III

Implementation of Intra Prediction Modes in VVC under MATLAB

III.1 Introduction

The VVC standard defines four modes of intra prediction: INTRA_PLANAR, INTRA_DC, INTRA_ANGULAR and INTRA_CCLM Mode, We will start this chapter with the tools used in our work. Then, we will present the proposed flowcharts of intra prediction modes with their simulations under Matlab.

III.2Used tools

It is essential to present the different hardware and software tools and their versions used in this work because each tool has its specific characteristics and functions. We have chosen the hardware description language VHDL (Hardware Description Language) for the hardware description of the Intra Prediction modesinthe latest VVC video compression standard on the FPGA (Field Programmable Gate Array) platform.

We used the ISE (Integrated Software Environment) platform for the hardware description of our algorithm, the Model-Sim for the simulation and the Matlab for the validation results of the our proposed architecture.



FigureIII.1 : Hardware and software tools used in our project.

III.2.1 Model-Sim (PE Student Edition 6.3)

Model-Sim is a Graphics Mentor tool that provides a comprehensive simulation and debugging environment for complex ASIC (Application Specified Integrated Circuits) and FPGA designs.

III.2.2 MATLAB

Matlab is a numerical calculation software marketed by the Math Works company to allow students to work from a high-level programming tool. It stands for Matrix laboratory. Moreover, it is a language for scientific computing of data analysis visualization and algorithm development. Its interface offers, on the one hand, an interactive console-type window for executing commands, and on the other hand, IDE (integrated development environment).

III.2.3 Xilinx ISE 14.5

ISE is an integrated development environment,usedforthe synthesis and analysis of electronic system designs. It allows the developer to synthesize their designs, perform timing analysis, examine RTL (Register Transfer Level) diagrams, simulate the reaction of a design, and configure the target device with the scheduler. Thus, it makes it possible to carry out all the phases of the application design flow on reconfigurable FPGA components. It is used for the description of multi-level systems, the RTL level synthesis, the simulation by component, a design aid tool and also it ensures the extensibility of systems [5].TheFigure (III..2) illustrates the entity and the top level scheme of an AND port has one input bit.

```
19  ----------------------------------------------------------------------------------
20  library IEEE;
21  use IEEE.STD_LOGIC_1164.ALL;
22
23  -- Uncomment the following library declaration if using
24  -- arithmetic functions with Signed or Unsigned values
25  --use IEEE.NUMERIC_STD.ALL;
26
27  -- Uncomment the following library declaration if instantiating
28  -- any Xilinx primitives in this code.
29  --library UNISIM;
30  --use UNISIM.VComponents.all;
31
32  entity my_and is
33      Port ( a : in  STD_LOGIC;
34             b : in  STD_LOGIC;
35             c : in  STD_LOGIC;
36             s : out  STD_LOGIC);
37  end my_and;
38
39  architecture Behavioral of my_and is
40
41  begin
42  s <= a AND b AND c;
43
44  end Behavioral;
45
46
```

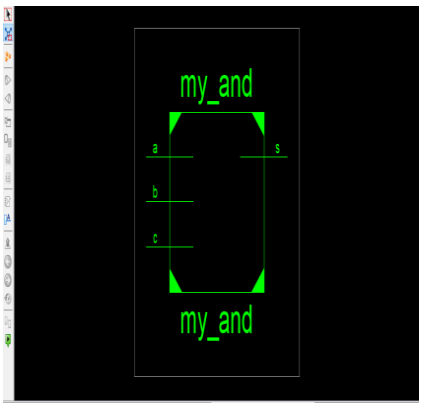


Figure III.2 : Entity and the top level scheme of an AND port has one input bit.

III.3 Intra prediction modes algorithm

In this section, we give the proposed flowchart, and its simulation on MATLAB software for each Intra predictionmode in VVC standard.

III.3.1 Planar intra prediction mode

Inputs to this process are: the variables nTbW, nTbH,theneighbouring samples p[x][y], with x = −1, y = −1..nTbH and x = 0..nTbW, y = −1. The outputs of this process are: the predicted samples predSamples[x][y], with x = 0..nTbW − 1, y = 0..nTbH – 1.

III.3.1.1 Flowchart of Planar intra prediction mode

The prediction intra planar mode shown in Figure (III.3) is calculated by using the three equations below:

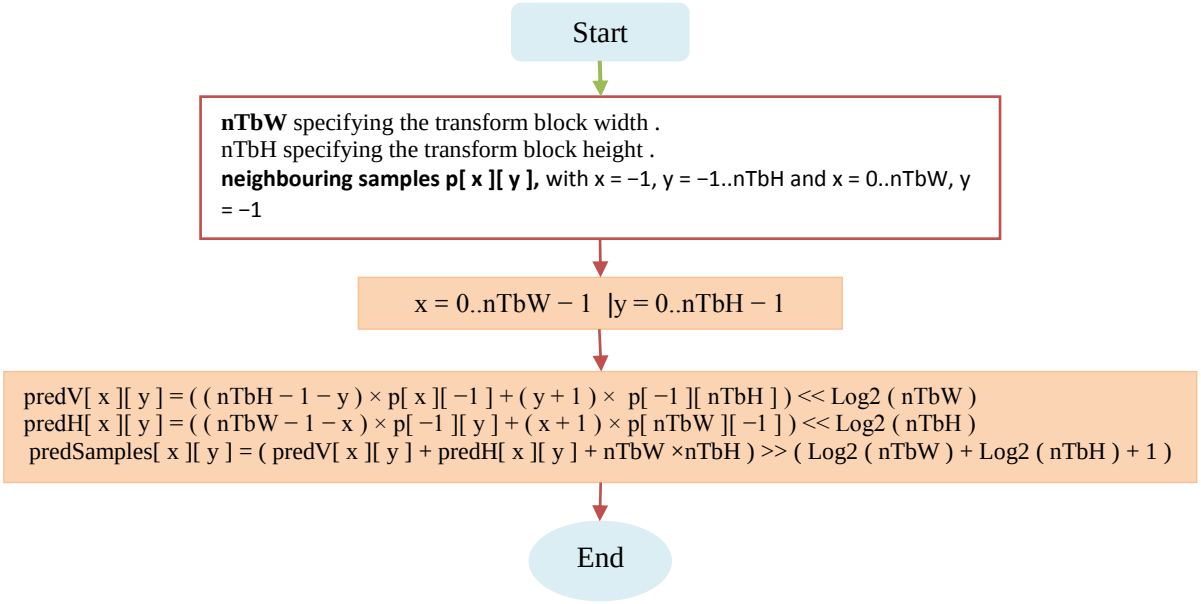


Figure III.3: Flowchart of Planar intra prediction mode.

III.3.1.2 Matlab implementation and Simulation result of Planar

Matlab implementation and simulation result ofpredsamples in Planar intra prediction mode are giver in Figure (III.4) and Figure(III.5) respectively

```
clc;
clear all ;
close all;
% Inputs:
%   nTbW: transform block width
%   nTbH: transform block height
%   p: neighbouring samples
% Outputs:
%   predSamples: predicted samples
% Define input parameters

nTbW = 4;       % transform block width
nTbH = 4;       % transform block height
p = [1 2 4 8; 9 7 6 2; 3 4 8 6;5 1 7 3];%neighbouring samples

for x = 1:nTbW-1;
   for y = 1:nTbH-1;

       predV(x,y) = bitshift(((nTbH-1-y)*p(x,1) + (y+1)*p(1,nTbH)),(log2(nTbH)))

       predH(x,y) = bitshift((nTbW-1-x)*p(1,y) + (x+1)*p(nTbW,1) ,(log2(nTbW)))

        predSamples(x,y) = ((predV(x,y) + predH(x,y) + nTbW*nTbH ))
   end
end
```

Figure III.4: Part of MATLAB code for Planar intra prediction mode.

```
predV =

    72   100   128
   136   132   128
    88   108   128


predH =

    48    56    72
    64    68    76
    80    80    80


predSamples =

   136   172   216
   216   216   220
   184   204   224
```

Figure III.5: Simulation under MATLAB for Planar intra prediction mode.

III.3.2 DC intra prediction mode

Inputs to this process are: the variables nTbW, nTbH, refIdx, the neighbouring samples p[x][y], with x = −1 − refIdx, y = 0..nTbH − 1 and x =

0..nTbW − 1, y = −1 − refIdx. The outputs of this process are the predicted samples predSamples[x][y], with x = 0..nTbW − 1, y = 0..nTbH − 1.

III.3.2.1 Flowchart of DC intra prediction mode

The proposed flowchart of DC Intra Prediction Mode is shown in Figure (III.6).

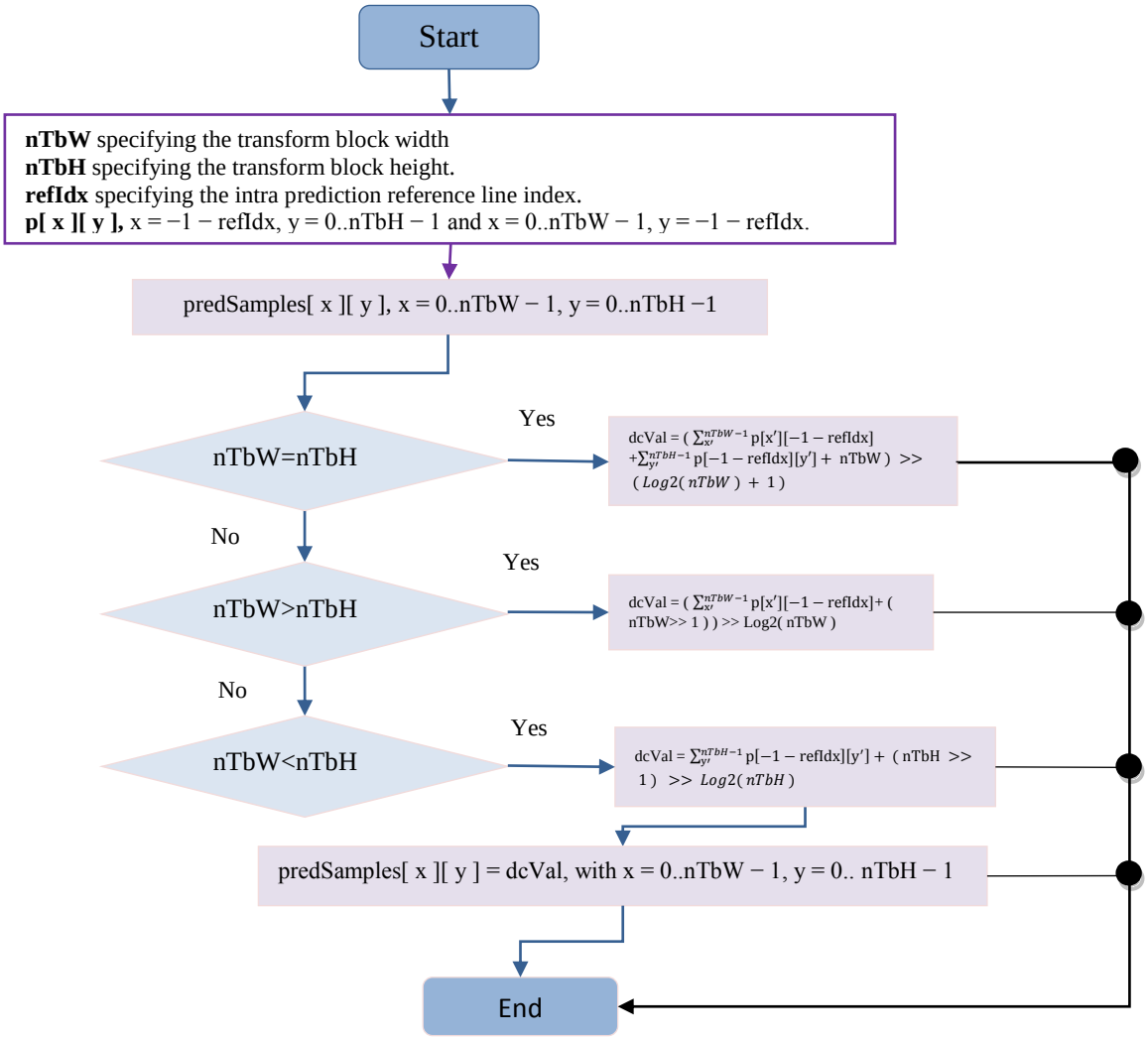


Figure III.6: Flowchart of DC intra prediction mode.

III.3.2.2 MATLAB implementation and Simulation of DC intra prediction mode

Matlab implementation and Simulation result ofpredsamples in DC Intra prediction mode are giver in Figure (III.7) and Figure(III.8) respectively .

```
clear all ;
close all;
nTbW = 4;
nTbH= 3;
refIdx=2;

p =[1 2 4 8;9 7 6 2;3 4 8 6;5 1 7 3];  % neighbouring samples
% Compute dcVal
for x=1: nTbW;
    for y=1:nTbH;


if nTbW == nTbH

   dcVal =  ((sum(p(x, abs(-1-refIdx))) + sum(p(abs(-1-refIdx), y) )+ nTbW))

elseif nTbW > nTbH

   dcVal =  ((sum(p (x,abs( -1-refIdx)))+bitshift (nTbW,-(1))))

else  nTbW < nTbH

   dcVal =bitshift ( (sum(p(-1-refIdx, y)) + bitshift (nTbH,(1))),(log2(nTbH)))
end
% Compute predSamples

predSamples_DC(x,y) = dcVal

    end
end
```

FigureIII.7: Part of MATLABcode for DC intra prediction mode.

```
predSamples_DC =

     6     6     6
     8     8     8
    10    10    10
     9     9     9
```

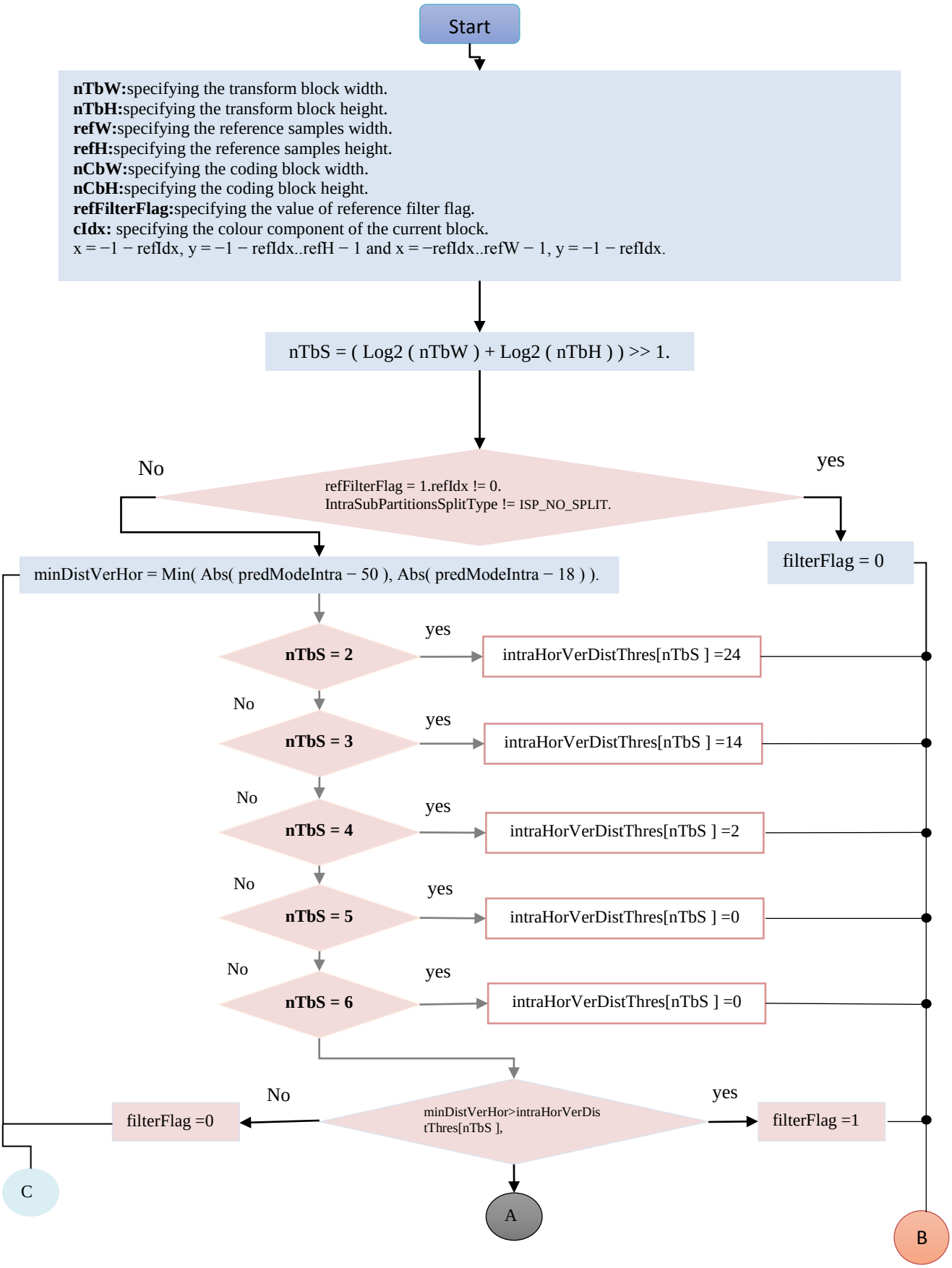
Figure III.8 : Simulationunder MATLAB for DC intra prediction mode.

III.3.3 Angularintraprediction mode

Inputs to this process are the variables: intra prediction mode predModeIntra, refIdx, nTbW, nTbH, refW, refH, nCbW,nCbH, refFilterFlag, cIdx, the neighbouringsamples p[x][y], with x = −1 –refIdx, y = −1 − refIdx..refH − 1 and x = −refIdx..refW − 1, y = −1 − refIdx. The outputs of this process are the predicted samples predSamples[x][y], with x = 0..nTbW − 1, y =0..nTbH − 1. The variable nTbS is set equal to (Log2 (nTbW) + Log2 (nTbH)) >>1.

III.3.3.1 Flowchart of Angular intra predictionmodes

The proposed flowchart for this angular is based on (16) sixteen conditions like is presented in Figure (III.9).


Start
nTbW:specifying the transform block width.
nTbH:specifying the transform block height.
refW:specifying the reference samples width.
refH:specifying the reference samples height.
nCbW:specifying the coding block width.
nCbH:specifying the coding block height.
refFilterFlag:specifying the value of reference filter flag.
cIdx: specifying the colour component of the current block.
x = −1 − refIdx, y = −1 − refIdx..refH − 1 and x = −refIdx..refW − 1, y = −1 − refIdx.
nTbS = (Log2 (nTbW) + Log2 (nTbH)) >> 1.
refFilterFlag = 1.refIdx != 0.
IntraSubPartitionsSplitType != ISP_NO_SPLIT.
No
yes
filterFlag = 0
minDistVerHor = Min(Abs(predModeIntra − 50), Abs(predModeIntra − 18)).
nTbS = 2
yes
intraHorVerDistThres[nTbS] =24
No
nTbS = 3
yes
intraHorVerDistThres[nTbS] =14
No
nTbS = 4
yes
intraHorVerDistThres[nTbS] =2
No
nTbS = 5
yes
intraHorVerDistThres[nTbS] =0
No
nTbS = 6
yes
intraHorVerDistThres[nTbS] =0
No
minDistVerHor>intraHorVerDistThres[nTbS],
yes
filterFlag =0
filterFlag =1
C
A
B

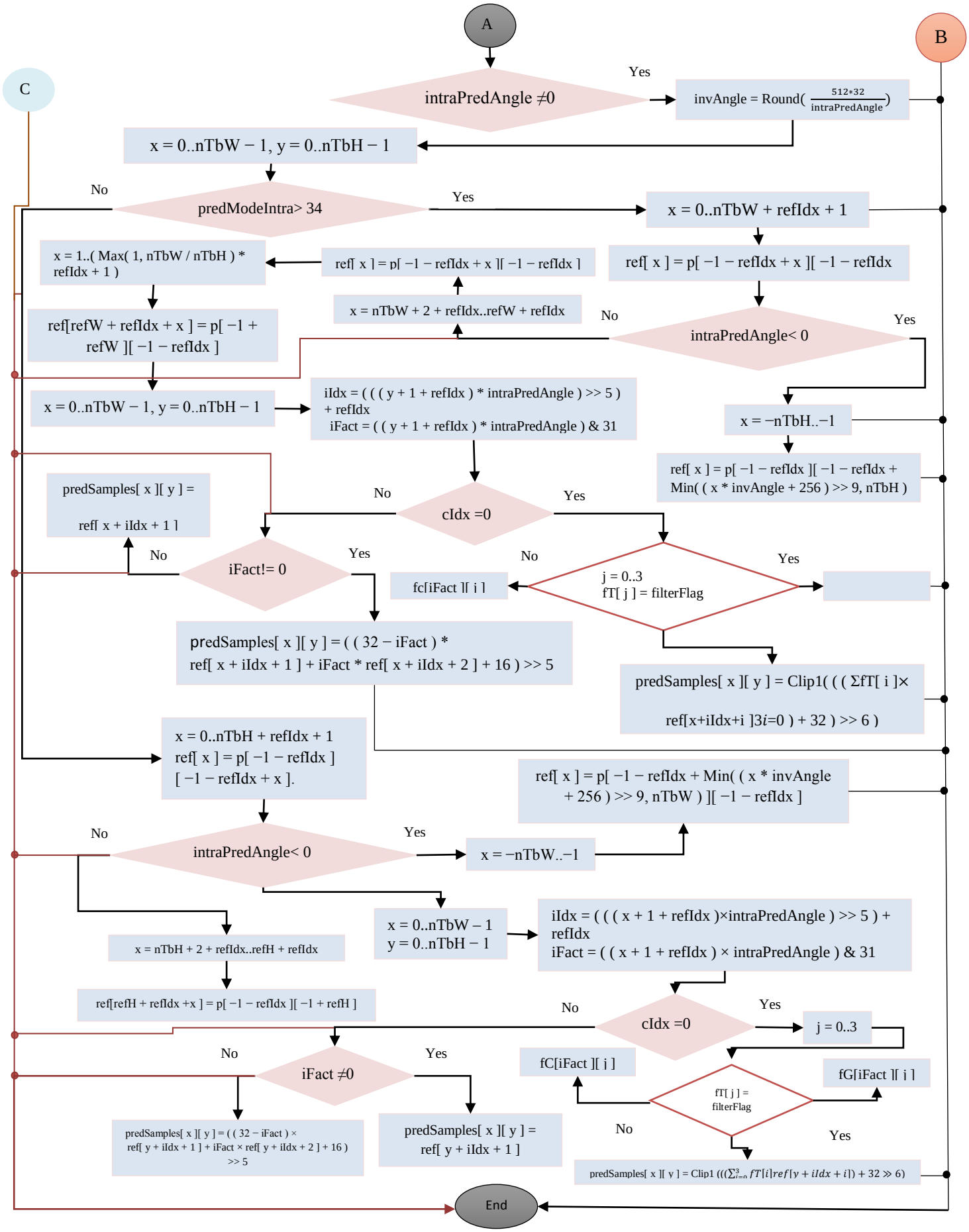

A
B
C
intraPredAngle ≠0
Yes
invAngle = Round(512*32 / intraPredAngle)
x = 0..nTbW − 1, y = 0..nTbH − 1
No
predModeIntra> 34
Yes
x = 0..nTbW + refIdx + 1
ref[x] = p[−1 − refIdx + x][−1 − refIdx
x = 1..(Max(1, nTbW / nTbH) * refIdx + 1)
ref[x] = p[−1 − refIdx + x][−1 − refIdx]
ref[refW + refIdx + x] = p[−1 + refW][−1 − refIdx]
x = nTbW + 2 + refIdx..refW + refIdx
No
intraPredAngle< 0
Yes
x = 0..nTbW − 1, y = 0..nTbH − 1
iIdx = (((y + 1 + refIdx) * intraPredAngle) >> 5) + refIdx
iFact = ((y + 1 + refIdx) * intraPredAngle) & 31
x = −nTbH..−1
ref[x] = p[−1 − refIdx][−1 − refIdx + Min((x * invAngle + 256) >> 9, nTbH)
predSamples[x][y] = ref[x + iIdx + 1]
No
cIdx =0
Yes
No
iFact!= 0
Yes
fc[iFact][j]
No
j = 0..3
fT[j] = filterFlag
Yes
predSamples[x][y] = ((32 − iFact) * ref[x + iIdx + 1] + iFact * ref[x + iIdx + 2] + 16) >> 5
predSamples[x][y] = Clip1(((ΣfT[i]× ref[x+iIdx+i]3i=0) + 32) >> 6)
x = 0..nTbH + refIdx + 1
ref[x] = p[−1 − refIdx] [−1 − refIdx + x].
ref[x] = p[−1 − refIdx + Min((x * invAngle + 256) >> 9, nTbW)][−1 − refIdx]
No
intraPredAngle< 0
Yes
x = −nTbW..−1
x = nTbH + 2 + refIdx..refH + refIdx
x = 0..nTbW – 1
y = 0..nTbH − 1
iIdx = (((x + 1 + refIdx)×intraPredAngle) >> 5) + refIdx
iFact = ((x + 1 + refIdx) × intraPredAngle) & 31
ref[refH + refIdx +x] = p[−1 − refIdx][−1 + refH]
No
cIdx =0
Yes
j = 0..3
No
iFact ≠0
Yes
fC[iFact][j]
fG[iFact][j]
fT[j] = filterFlag
No
Yes
predSamples[x][y] = ((32 − iFact) × ref[y + iIdx + 1] + iFact × ref[y + iIdx + 2] + 16) >> 5
predSamples[x][y] = ref[y + iIdx + 1]
predSamples[x][y] = Clip1 ((($\sum_{i=0}^{3} fT[i]ref[y + iIdx + i]$) + 32 ≫ 6)
End

Figure III.9 : Flowchart of Angular intra prediction mode.

III.3.3.2 MATLAB implementation and Simulation result ofAngularintra prediction mode

Matlab implementation and Simulation result ofpredsamples in Angular intra prediction mode are giver in Figure (III.10) and Figure(III.11) respectively

```
nTbW=4;
nTbH=4;
ISP_NO_SPLIT =8;
p =[1 2 4 8;9 7 6 2;3 4 8 6;5 1 7 3];  % neighbouring samples
refW=1;
refH=1;
refFilterFlag=3;
refIdx=0;
IntraSubPartitionsSplitType= 8;
intraPredAngle=6;
predModeIntra=50;
ntbs=5;
cIdx=10 ;
fG( 1,1 )=32   ;fG( 1,2 )=16  ;fG( 13 )=0;
fC( 1 ,1 )=63;   fC( 1 ,2 )=2;     fC( 1 ,3 )=0;
 if ((refFilterFlag ==1) |( refIdx ~=  0)|(IntraSubPartitionsSplitType ~= ISP_NO_SPLIT))
filterFlag =0
else minDistVerHor = min( abs( predModeIntra-50 ), abs( predModeIntra-18 ))
T= [2 3 4 5 6 ;24 14 2 0 0 ];
ntbs= T(1,3)
intraHorVerDistThres=T(2,3)
if( minDistVerHor > intraHorVerDistThres)
    filterFlag=1
else filterFlag=0
end
end
if (  intraPredAngle ~= 0)
    invAngle = round( 512*32/ intraPredAngle)
end
if ( predModeIntra >=34)
```

```
  else minDistVerHor = min( abs( predModeIntra-50 ), abs( predModeIntra-18 ))
  T= [2 3 4 5 6 ;24 14 2 0 0 ];
  ntbs= T(1,3)
  intraHorVerDistThres=T(2,3)
  if( minDistVerHor > intraHorVerDistThres)
      filterFlag=1
  else filterFlag=0
  end
  end
  if (  intraPredAngle ~= 0)
      invAngle = round( 512*32/ intraPredAngle)
  end
  if ( predModeIntra >=34)
for y=0:nTbW-1
   iIdx = ( ( ( y + 1 + refIdx ) * intraPredAngle ) *( 2^5)) + refIdx
  iFact = ( ( y + 1 + refIdx ) * intraPredAngle ) & 31
  end
 for j=1:3
  if filterFlag==1
       fT( j )=fG( iFact, j )
  else fT(j )= fC( iFact , j )
  end
  end
  end
 for x= 1:nTbW;
 for y=1:nTbH;
  ref(refW + refIdx + x) = p(1 + refW ,1+ refIdx)
 predSamples(x , y ) =( ( 32- iFact ) * ref(  1 ) + iFact * ref(2) + 16 )/(2^ 5)
  end
  end
```

Figure III.10 : Part of MATLAB code forAngularintra prediction mode.

```
predSamples =

     3     3     3
     3     3     3
     3     3     3
```

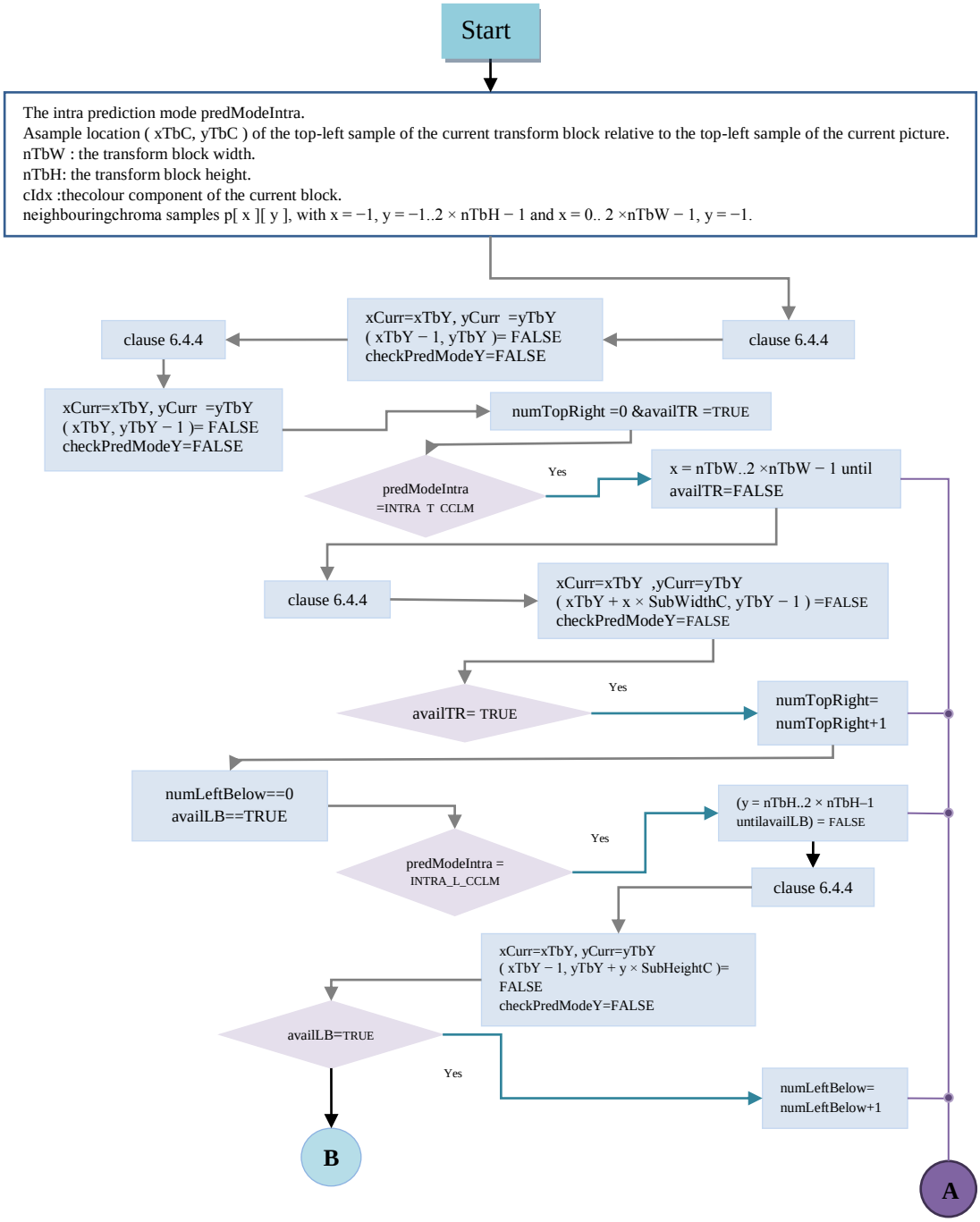
Figure III.11 : Simulation under MATLAB for Angular Intra Prediction Mode.

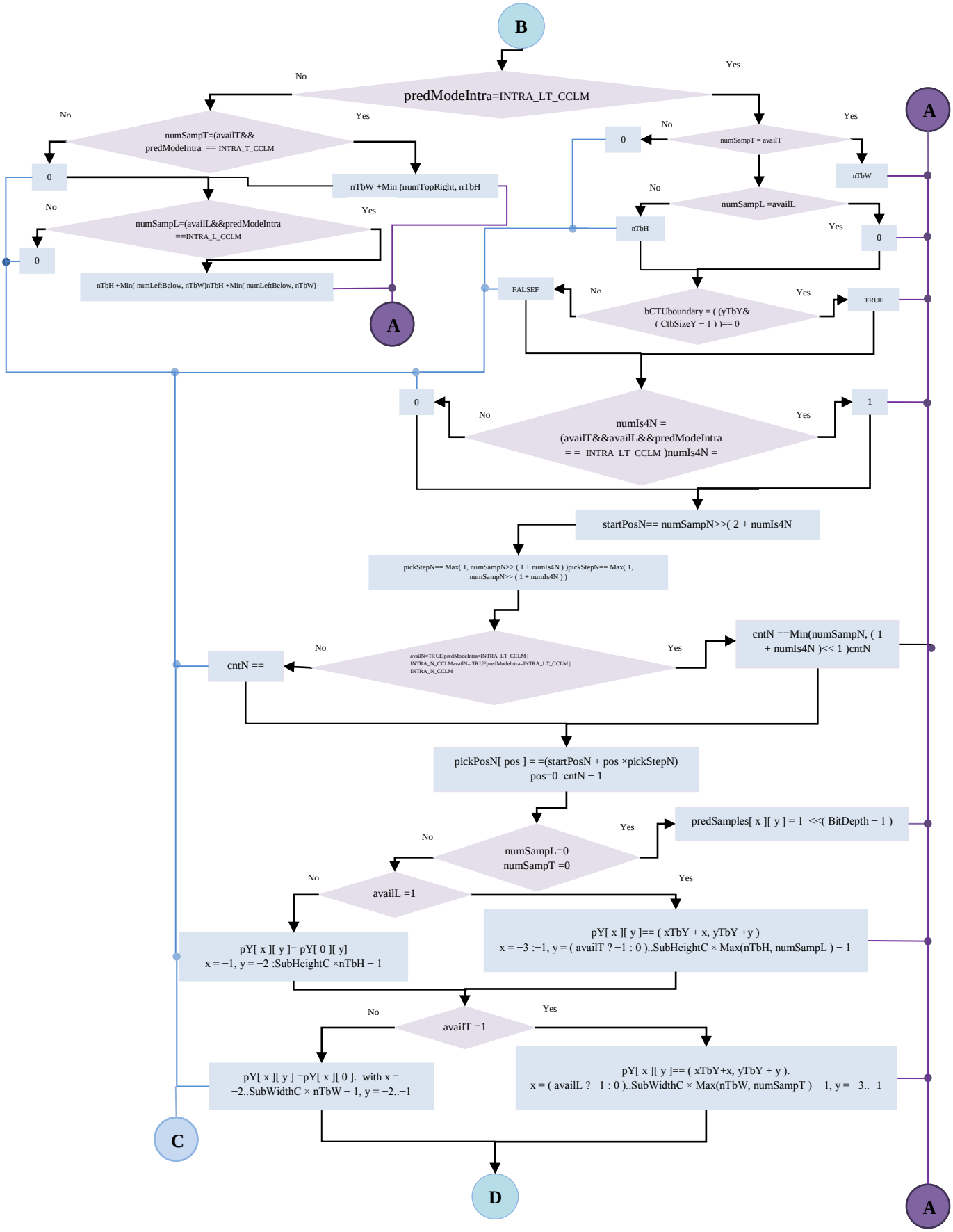
III.3.4 CCLM intra prediction mode

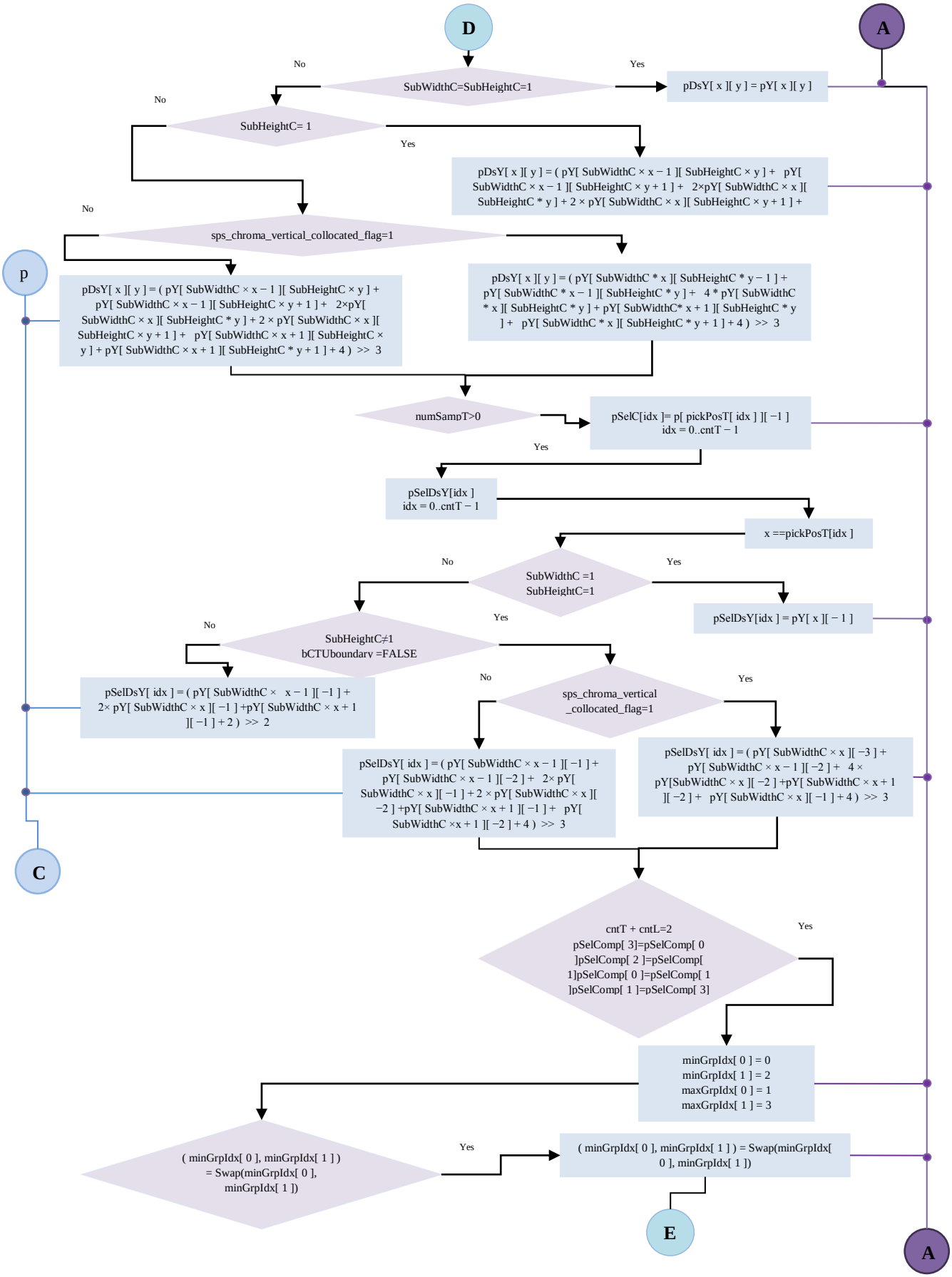
Inputs to this process are the variables: intra prediction mode predModeIntra, (xTbC, yTbC),nTbW, nTbH, cIdx, neighbouringchroma samples p[x][y], with x = −1, y = −1..2×nTbH − 1 and x = 0.. 2 × nTbW − 1, y = −1. The output of this process are predictedsamplespredSamples[x][y], with x = 0..nTbW − 1, y = 0..nTbH − 1.

3.3.4.1 Flowchart of CCLM Intra Prediction Mode

CCLM intra prediction mode computational model shown in Figure (III.12) is applied toobtain the value of predSamples.


Start
The intra prediction mode predModeIntra.
Asample location (xTbC, yTbC) of the top-left sample of the current transform block relative to the top-left sample of the current picture.
nTbW : the transform block width.
nTbH: the transform block height.
cIdx :thecolour component of the current block.
neighbouringchroma samples p[x][y], with x = −1, y = −1..2 × nTbH − 1 and x = 0.. 2 ×nTbW − 1, y = −1.
clause 6.4.4
xCurr=xTbY, yCurr =yTbY
(xTbY − 1, yTbY)= FALSE
checkPredModeY=FALSE
clause 6.4.4
xCurr=xTbY, yCurr =yTbY
(xTbY, yTbY − 1)= FALSE
checkPredModeY=FALSE
numTopRight =0 &availTR =TRUE
predModeIntra
=INTRA T CCLM
Yes
x = nTbW..2 ×nTbW − 1 until
availTR=FALSE
clause 6.4.4
xCurr=xTbY ,yCurr=yTbY
(xTbY + x × SubWidthC, yTbY − 1) =FALSE
checkPredModeY=FALSE
availTR= TRUE
Yes
numTopRight=
numTopRight+1
numLeftBelow==0
availLB==TRUE
predModeIntra =
INTRA_L_CCLM
Yes
(y = nTbH..2 × nTbH–1
untilavailLB) = FALSE
clause 6.4.4
xCurr=xTbY, yCurr=yTbY
(xTbY − 1, yTbY + y × SubHeightC)=
FALSE
checkPredModeY=FALSE
availLB=TRUE
Yes
numLeftBelow=
numLeftBelow+1
B
A


B
predModeIntra=INTRA_LT_CCLM
No
Yes
numSampT=(availT&&
predModeIntra == INTRA_T_CCLM
0
nTbW +Min (numTopRight, nTbH
numSampL=(availL&&predModeIntra
==INTRA_L_CCLM
0
nTbH +Min(numLeftBelow, nTbW)nTbH +Min(numLeftBelow, nTbW)
A
numSampT = availT
0
nTbW
numSampL =availL
nTbH
0
FALSEF
bCTUboundary = ((yTbY&
(CtbSizeY − 1))== 0
TRUE
numIs4N =
(availT&&availL&&predModeIntra
= = INTRA_LT_CCLM)numIs4N =
0
1
startPosN== numSampN>>(2 + numIs4N
pickStepN== Max(1, numSampN>> (1 + numIs4N))pickStepN== Max(1,
numSampN>> (1 + numIs4N))
availN=TRUE predModeIntra=INTRA_LT_CCLM |
INTRA_N_CCLMavailN= TRUEpredModeIntra=INTRA_LT_CCLM |
INTRA_N_CCLM
cntN ==
cntN ==Min(numSampN, (1
+ numIs4N)<< 1)cntN
pickPosN[pos] = =(startPosN + pos ×pickStepN)
pos=0 :cntN − 1
predSamples[x][y] = 1 <<(BitDepth − 1)
numSampL=0
numSampT =0
availL =1
pY[x][y]= pY[0][y]
x = −1, y = −2 :SubHeightC ×nTbH − 1
pY[x][y]== (xTbY + x, yTbY +y)
x = −3 :−1, y = (availT ? −1 : 0)..SubHeightC × Max(nTbH, numSampL) − 1
availT =1
pY[x][y] =pY[x][0]. with x =
−2..SubWidthC × nTbW − 1, y = −2..−1
pY[x][y]== (xTbY+x, yTbY + y).
x = (availL ? −1 : 0)..SubWidthC × Max(nTbW, numSampT) − 1, y = −3..−1
C
D
A


D
A
SubWidthC=SubHeightC=1
No
Yes
pDsY[x][y] = pY[x][y]
SubHeightC= 1
No
Yes
pDsY[x][y] = (pY[SubWidthC × x − 1][SubHeightC × y] + pY[SubWidthC × x − 1][SubHeightC × y + 1] + 2×pY[SubWidthC × x][SubHeightC * y] + 2 × pY[SubWidthC × x][SubHeightC × y + 1] +
No
sps_chroma_vertical_collocated_flag=1
p
pDsY[x][y] = (pY[SubWidthC × x − 1][SubHeightC × y] + pY[SubWidthC × x − 1][SubHeightC × y + 1] + 2×pY[SubWidthC × x][SubHeightC * y] + 2 × pY[SubWidthC × x][SubHeightC × y + 1] + pY[SubWidthC × x + 1][SubHeightC * y + 1] + 4) >> 3
pDsY[x][y] = (pY[SubWidthC * x][SubHeightC * y − 1] + pY[SubWidthC * x − 1][SubHeightC * y] + 4 * pY[SubWidthC * x][SubHeightC * y] + pY[SubWidthC* x + 1][SubHeightC * y] + pY[SubWidthC * x][SubHeightC * y + 1] + 4) >> 3
numSampT>0
Yes
pSelC[idx]= p[pickPosT[idx]][−1]
idx = 0..cntT − 1
pSelDsY[idx]
idx = 0..cntT − 1
x ==pickPosT[idx]
No
SubWidthC =1
SubHeightC=1
Yes
pSelDsY[idx] = pY[x][− 1]
No
SubHeightC≠1
bCTUboundary =FALSE
Yes
pSelDsY[idx] = (pY[SubWidthC × x − 1][−1] + 2× pY[SubWidthC × x][−1] +pY[SubWidthC × x + 1][−1] + 2) >> 2
No
sps_chroma_vertical _collocated_flag=1
Yes
pSelDsY[idx] = (pY[SubWidthC × x − 1][−1] + pY[SubWidthC × x − 1][−2] + 2× pY[SubWidthC × x][−1] + 2 × pY[SubWidthC × x][−2] +pY[SubWidthC × x + 1][−1] + pY[SubWidthC ×x + 1][−2] + 4) >> 3
pSelDsY[idx] = (pY[SubWidthC × x][−3] + pY[SubWidthC × x − 1][−2] + 4 × pY[SubWidthC × x][−2] +pY[SubWidthC × x + 1][−2] + pY[SubWidthC × x][−1] + 4) >> 3
C
cntT + cntL=2
pSelComp[3]=pSelComp[0]pSelComp[2]=pSelComp[1]pSelComp[0]=pSelComp[1]pSelComp[1]=pSelComp[3]
Yes
minGrpIdx[0] = 0
minGrpIdx[1] = 2
maxGrpIdx[0] = 1
maxGrpIdx[1] = 3
(minGrpIdx[0], minGrpIdx[1]) = Swap(minGrpIdx[0], minGrpIdx[1])
Yes
(minGrpIdx[0], minGrpIdx[1]) = Swap(minGrpIdx[0], minGrpIdx[1])
E
A

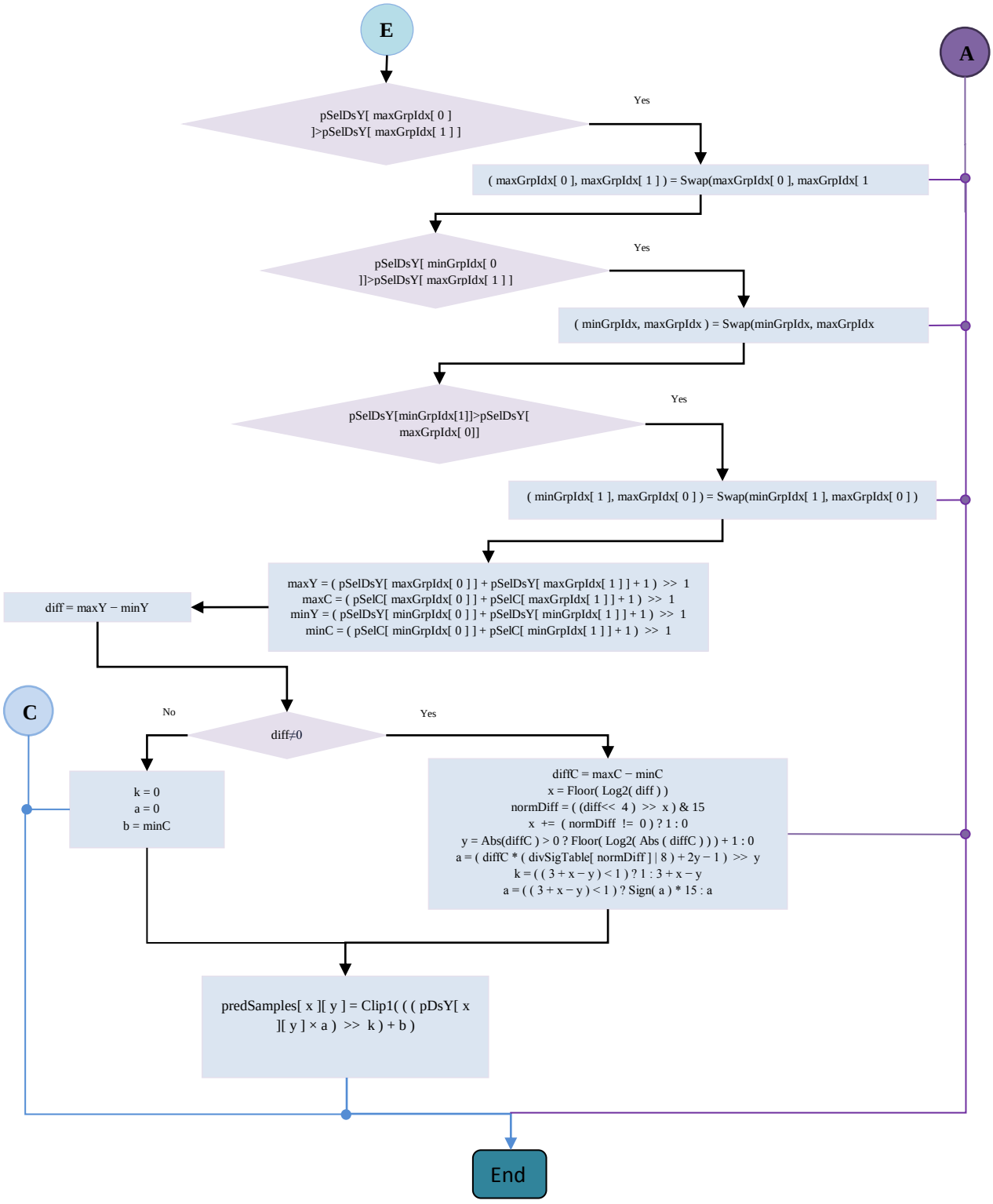


Figure III.12 : Flowchart of CCLM intra prediction mode.

III.3.4.2 MATLAB implementation and Simulation result of CCLM Intra Prediction Mode

Matlab implementation and simulation result of`predsamples` in CCLM prediction mode are giver in Figure (III.13) and Figure(III.14) respectively

```
availLB == true;
if( predModeIntra == INTRA_L_CCLM)
if ( availT==1)
numSampT = nTbW
else numSampT = 0
if ( availL==1)
numSampL = nTbH
else numSampL = 0
end
end
end
if (( availT && predModeIntra == INTRA_T_CCLM )==true)
numSampT =(nTbW +min( numTopRight, nTbH ) )
      else numSampT=0
  end
     if  (( availL && predModeIntra == INTRA_L_CCLM )==true)
         numSampL =  ( nTbH +min( numLeftBelow, nTbW ) )
     else numSampL = 0
     end
   if (  ( yTbY & ( CtbSizeY -1 ) )== 0 )
        bCTUboundary=true
   else  bCTUboundary=false
   end
if ( ( availT && availL && predModeIntra == INTRA_LT_CCLM )==true)
numIs4N =0
else numIs4N =1
end
 startPosN = numSampN *(2^( 2 + numIs4N ))
  pickStepN = max( 1, numSampN *(2^ ( 1 + numIs4N ) ))

      else numSampT=0
  end
     if  (( availL && predModeIntra == INTRA_L_CCLM )==true)
         numSampL =  ( nTbH +min( numLeftBelow, nTbW ) )
     else numSampL = 0
     end
   if (  ( yTbY & ( CtbSizeY -1 ) )== 0 )
        bCTUboundary=true
   else  bCTUboundary=false
   end
if ( ( availT && availL && predModeIntra == INTRA_LT_CCLM )==true)
numIs4N =0
else numIs4N =1
end
 startPosN = numSampN *(2^( 2 + numIs4N ))
  pickStepN = max( 1, numSampN *(2^ ( 1 + numIs4N ) ))

  if (availNs== true&( predModeIntra == (INTRA_LT_CCLM| INTRA_L_CCLM)))
      cntN = min( numSampN, ( 1 + numIs4N )/(2^1) )

  else cntN=0
  end
  for x = 1:nTbW- 1;
      for y = 1:nTbH - 1;
   predSamples(x , y ) = 1 *(2^ ( BitDepth- 1 ))
  end
   end
```

Figure III.13 : Part of MATLAB programs for CCLM intra prediction mode

```
predSamples =

     2     2     2
     2     2     2
     2     2     2
```

FigureIII.14 : Part of MATLAB programs for CCLM intra prediction mode.

III.3.4.3 Derivation process for neighbouring block availability (Clouse 6.4.4)

Inputs to this process are the variables: **(xCurr, yCurr)** of the top-left sample of the current block relative to the top-left luma sample of the current picture, **(xNbY, yNbY)** covered by a neighbouring block relative to the top-left luma sample of the current picture, **checkPredModeY** specifying whether availability depends on the prediction mode, **cIdx** specifying the colour component of the current block. Output of this process is the availability of the neighbouring block covering the location (xNbY, yNbY), denoted asavailableN.

III.3.4.3.1: Flowchart of Derivation process for neighbouring block availability (Clouse 6.4.4)

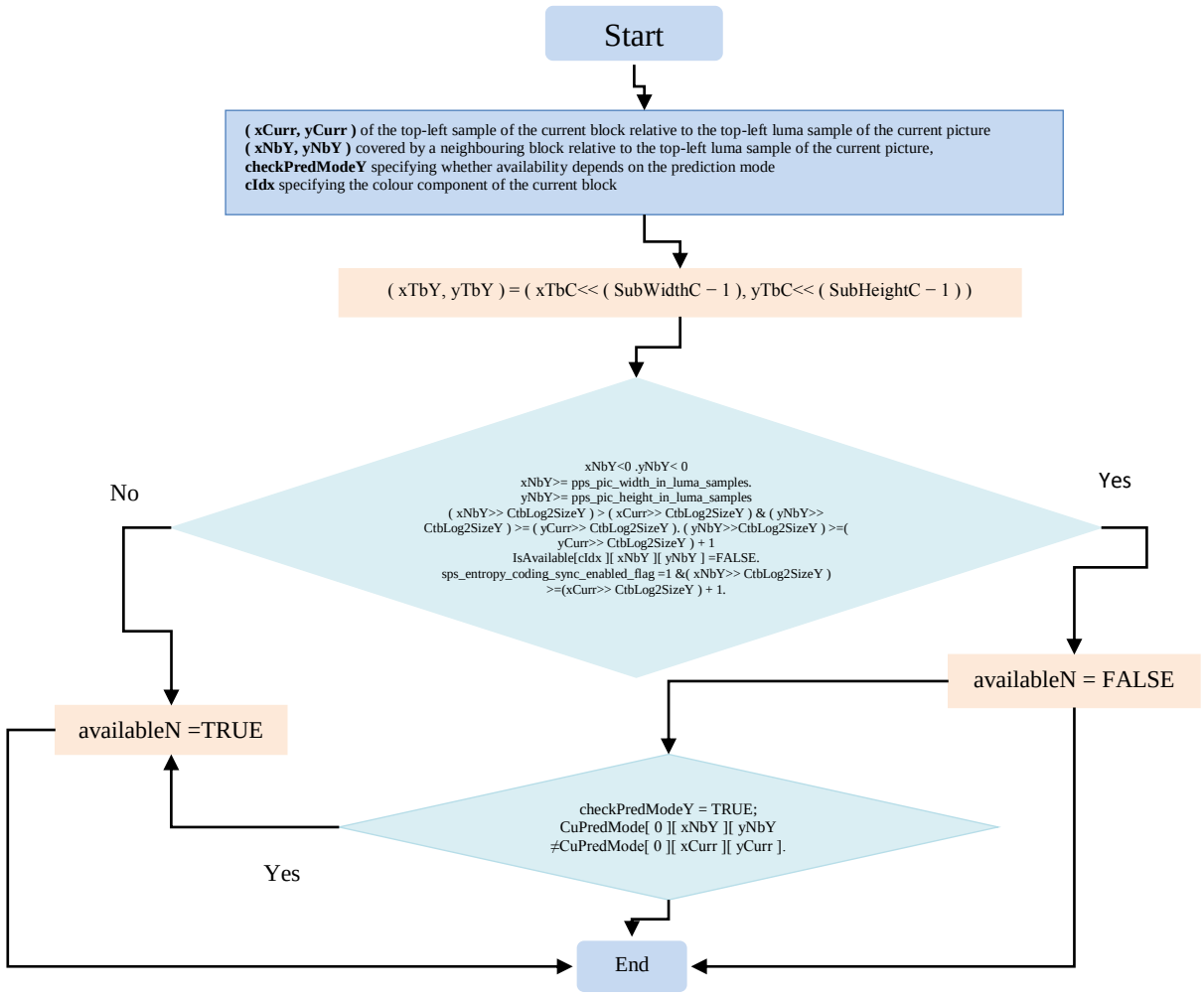


Figure III.15 : Flowchart of of Derivation process for neighbouring block availability

III.4 Conclusion

In this chapter, the various hardware and software tools used have been presented. Then we also designed flowcharts for intra prediction modes with their implementations in Matlab. This passage allowed us to master the four modes algorithms for intra prediction used in the VVC video compression standard before moving on to software description in VHDL language under ISE. For this, the next chapter will be devoted to the design and software implementation

Chapter IV

Implementation of Intra Prediction Modes on FPGA

IV.1 Introduction

This last chapter is reserved for the implementation of intra predicttion modes in VVC on FPGA (Field-Programmable Gate Array). The proposed architectures will be given in detail for each part of this algorithm followed by a synthesis under the ISE (Integrated Software Environment), the simulation under Model-Sim and the estimation of the energy consumed under the XPower analyzer ISE. We will end the chapter with a comparison and discussion of the results obtained.

IV.2 Proposed architectures of intra prediction modes

The design of our architecture is based on functional blocks where each block performs a specific task. We will begin by presenting the architectures proposed for each intra prediction mode. According to the VVC standard, each mode is responsible for calculating the prediction samplesfrom the original samples.

IV.2.1 Proposed architecture for planar intra prediction mode

Figure (IV.1) represents the calculation of the predsamples using a set of variables and fixed values, specified by the VVC standard.Theobtained RTL (Register Transfer Level) diagrams and the top level are given in figure(IV.2)

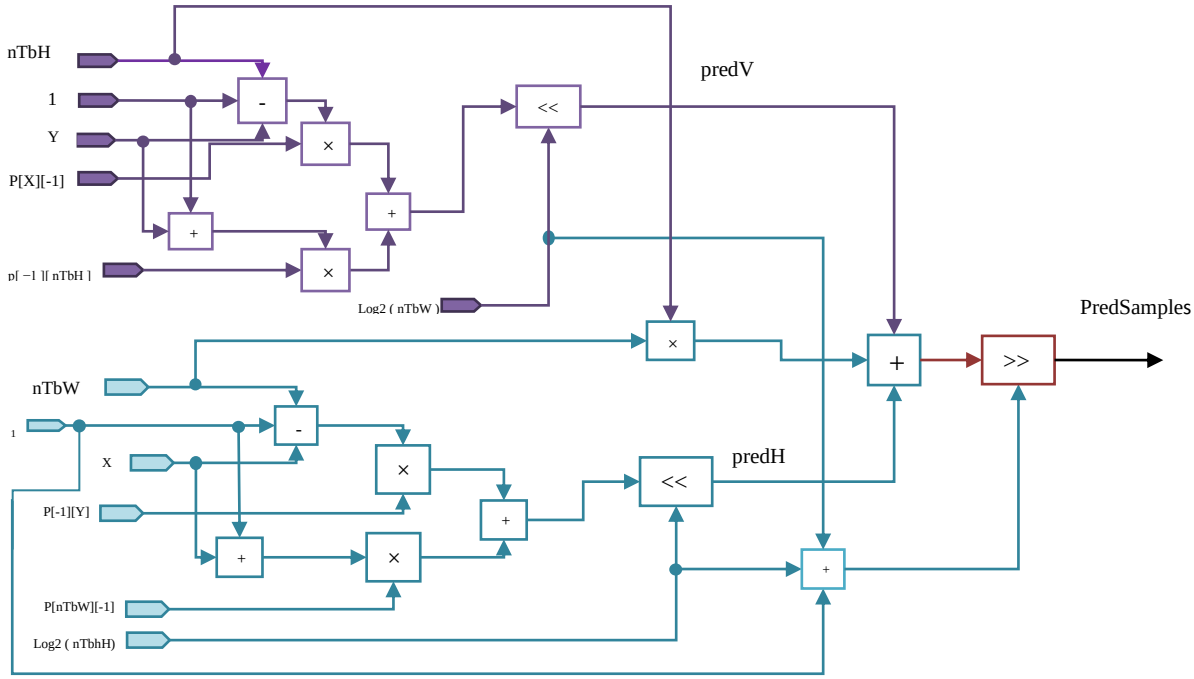


Figure IV.1: Proposed architecture of planar intra prediction mode .

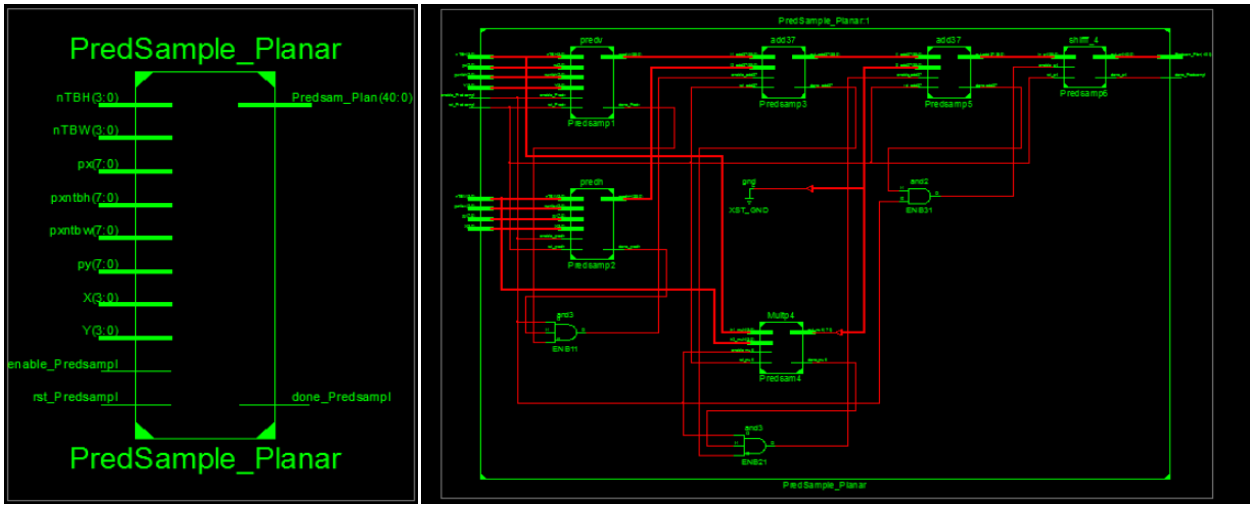


Figure IV.2: Top level and RTL schemes of planar intra prediction mode.

IV.2.2 Proposed architecture for DC intra prediction mode

Figure (IV.3) represents the calculation of the predsamples using a set of variables and fixed values, specified by the VVC standard. The synthesised RTL diagrams and the top level are given in figure (IV.4).

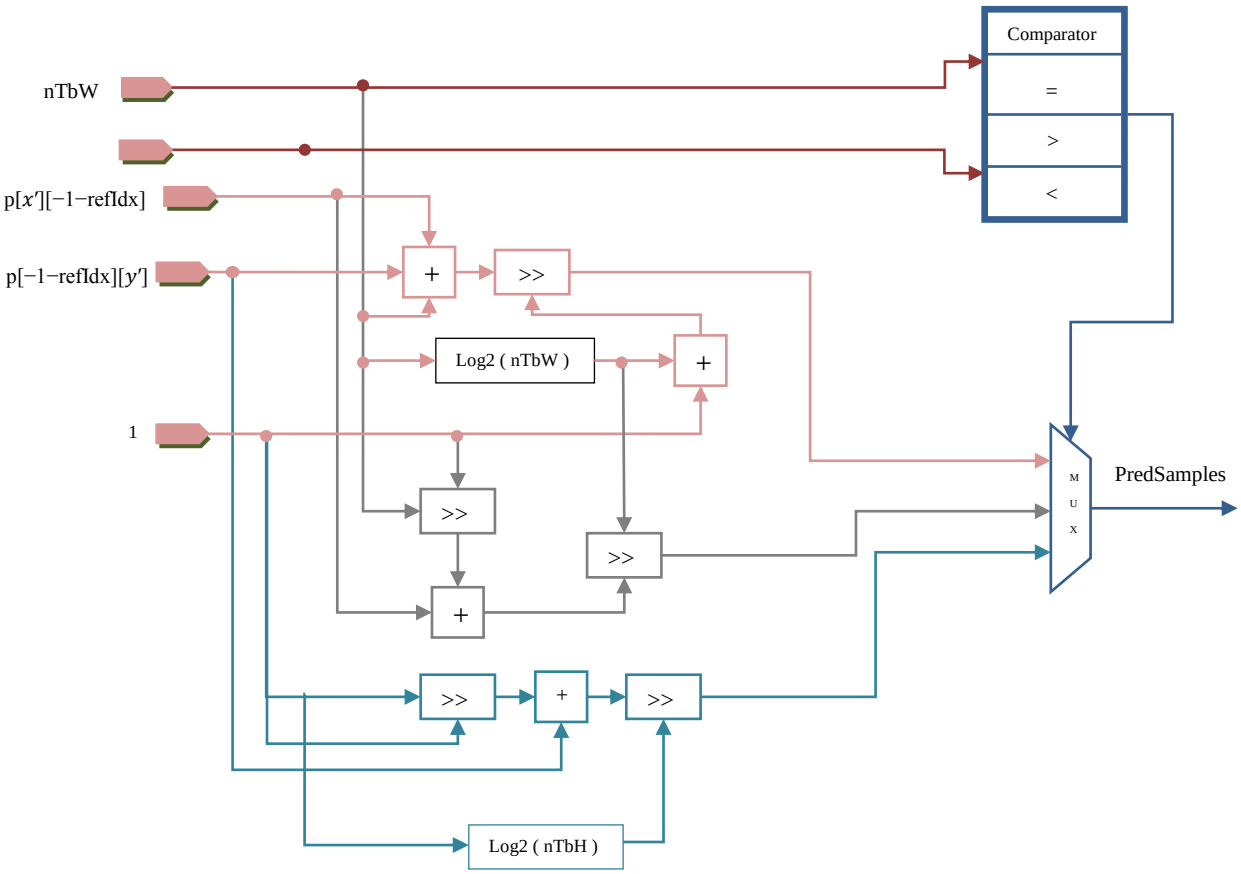
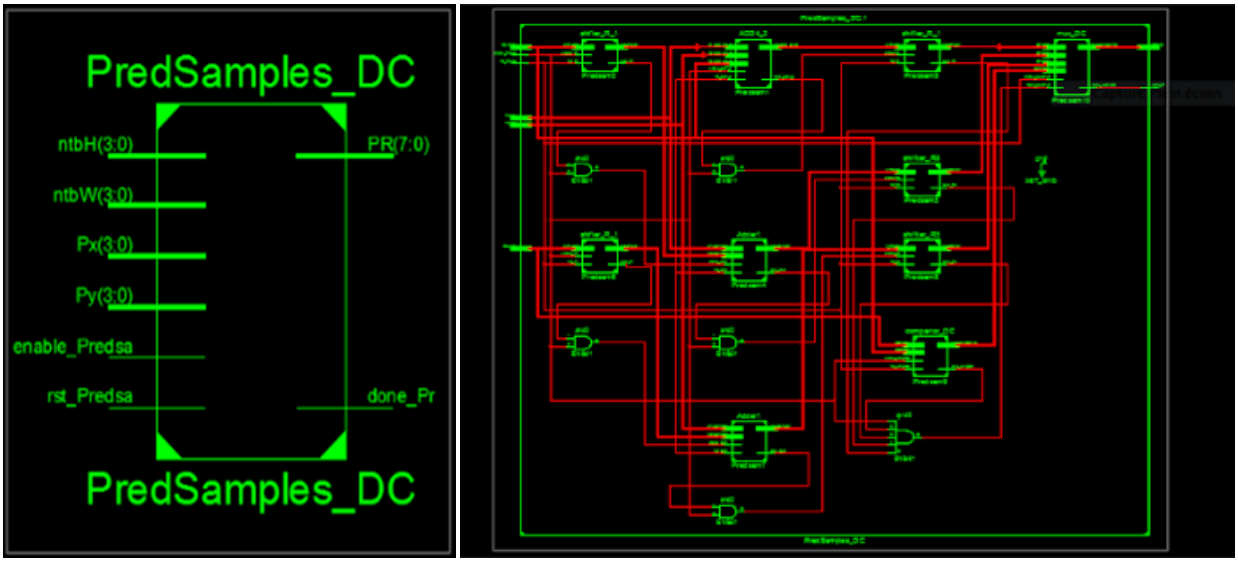


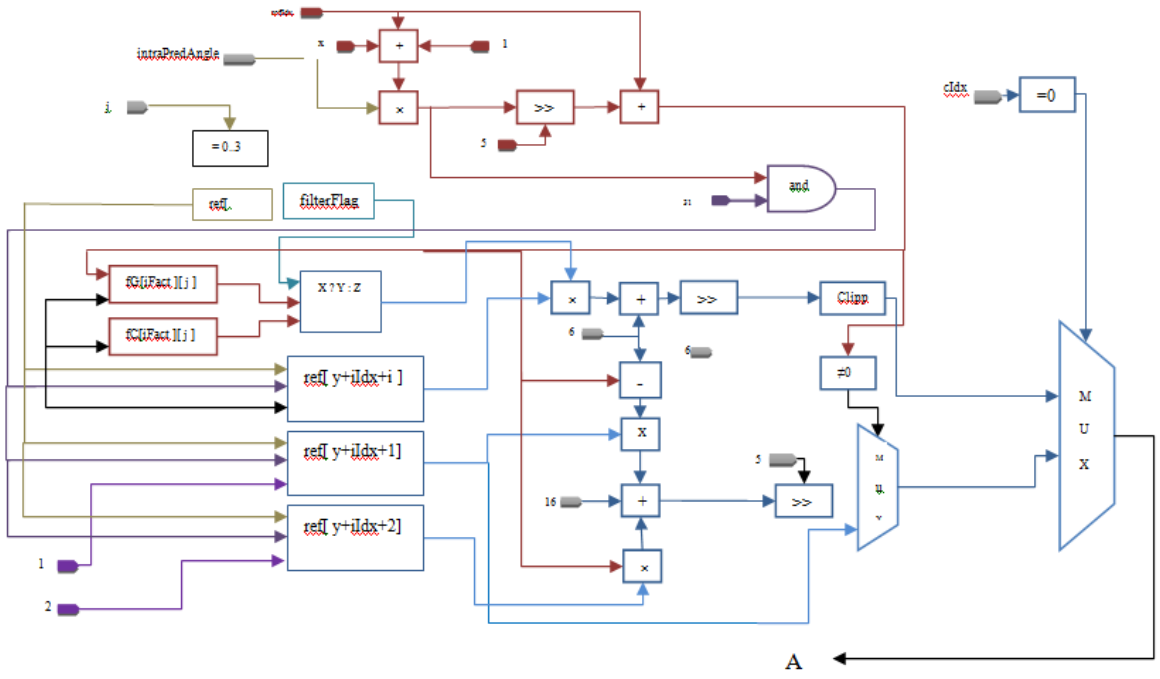
Figure IV.3 : Proposed architecture of DC intra prediction mode.

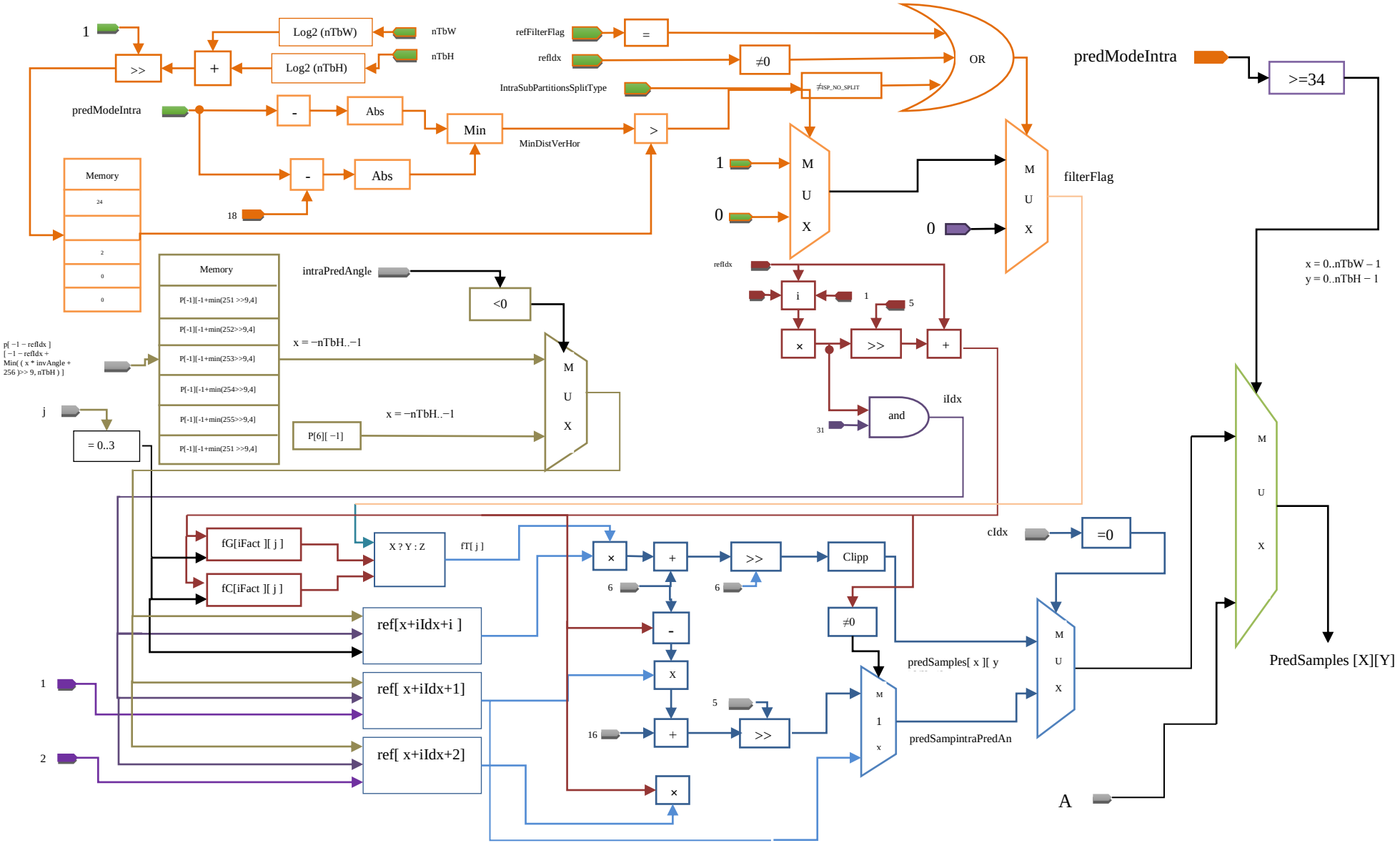


FigureIV.4: Top level and RTL schemes of DC intra prediction mode.

IV.2.3 Proposed architecture for Angular Intra Prediction Mode

Figure (IV.5) represents the calculation of the predsamples using a set of variables and fixed values, specified by the VVC standard.Theobtained RTLsynthes diagrams and the top level are given in figure (IV.6).




1
>>
+
Log2 (nTbW)
Log2 (nTbH)
nTbW
nTbH
predModeIntra
-
Abs
Min
MinDistVerHor
18
Memory
refFilterFlag
=
refIdx
≠0
IntraSubPartitionsSplitType
≠ISP_NO_SPLIT
OR
>
1
0
M
U
X
filterFlag
predModeIntra
>=34
x = 0..nTbW – 1
y = 0..nTbH – 1
intraPredAngle
<0
x = −nTbH..−1
P[6][−1]
j
= 0..3
i
×
>>
and
iIdx
31
fG[iFact][j]
fC[iFact][j]
X ? Y : Z
fT[j]
ref[x+iIdx+i]
ref[x+iIdx+1]
ref[x+iIdx+2]
Clipp
cIdx
=0
predSamples[x][y
predSampintraPredAn
A
PredSamples [X][Y]

Note :A is PredaSamples(predModeIntra<34)

Figure IV.5 : Proposed architecture of Angular Intraprediction mode .

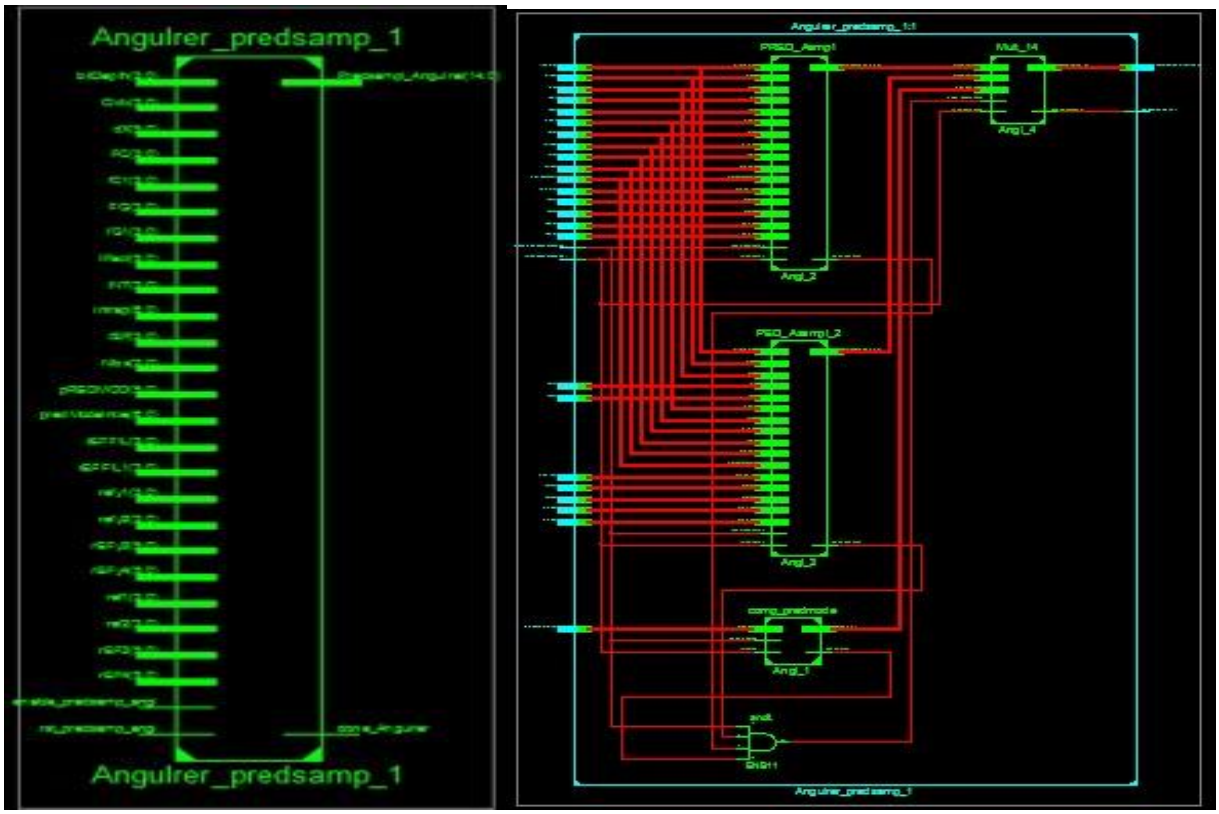


Figure IV.6 : Top level and RTL schemes of Angularcintra prediction mode.

IV.2.4 Proposed architecture for CCLM Intra Prediction

According to the VVC standard, the CCLM intra prediction mode is based on the (clouse 6.4.4) given in the a Figure(IV.7) This clouse is used to calculate the variable available N.Additionely , Figure (IV.8) represents the calculation of the predsamples using a set of variables and fixed values, specified by the VVC standard.TheobtainedRTL diagrams and the top level are represented in figure (IV.9).

IV.2.4 .1 Proposed architecture of Derivation process for neighbouring block availability (Clouse 6.4.4)

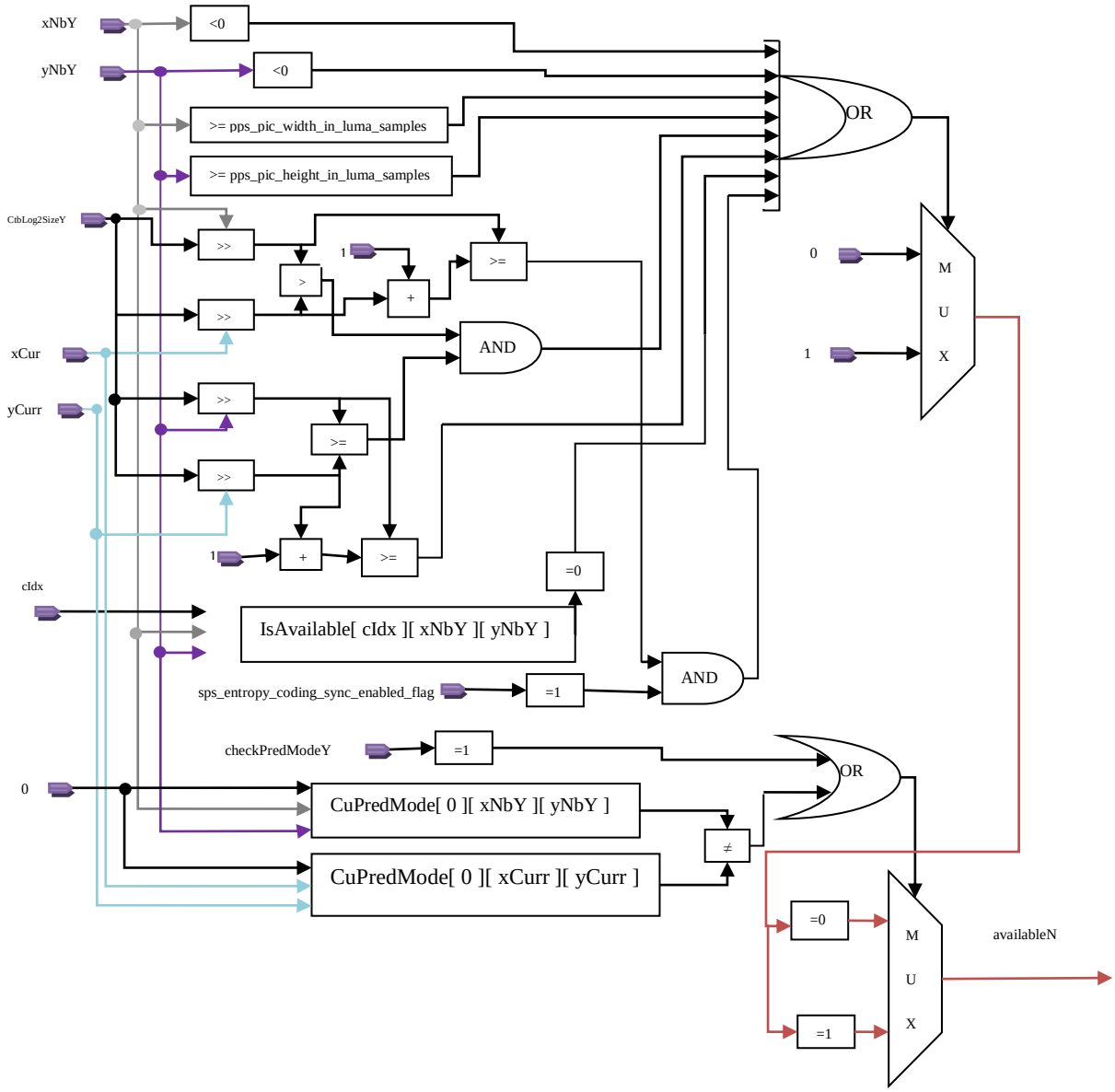


Figure IV.7: Proposed architecture of Derivation process for neighbouring block availability (Clouse 6.4.4).

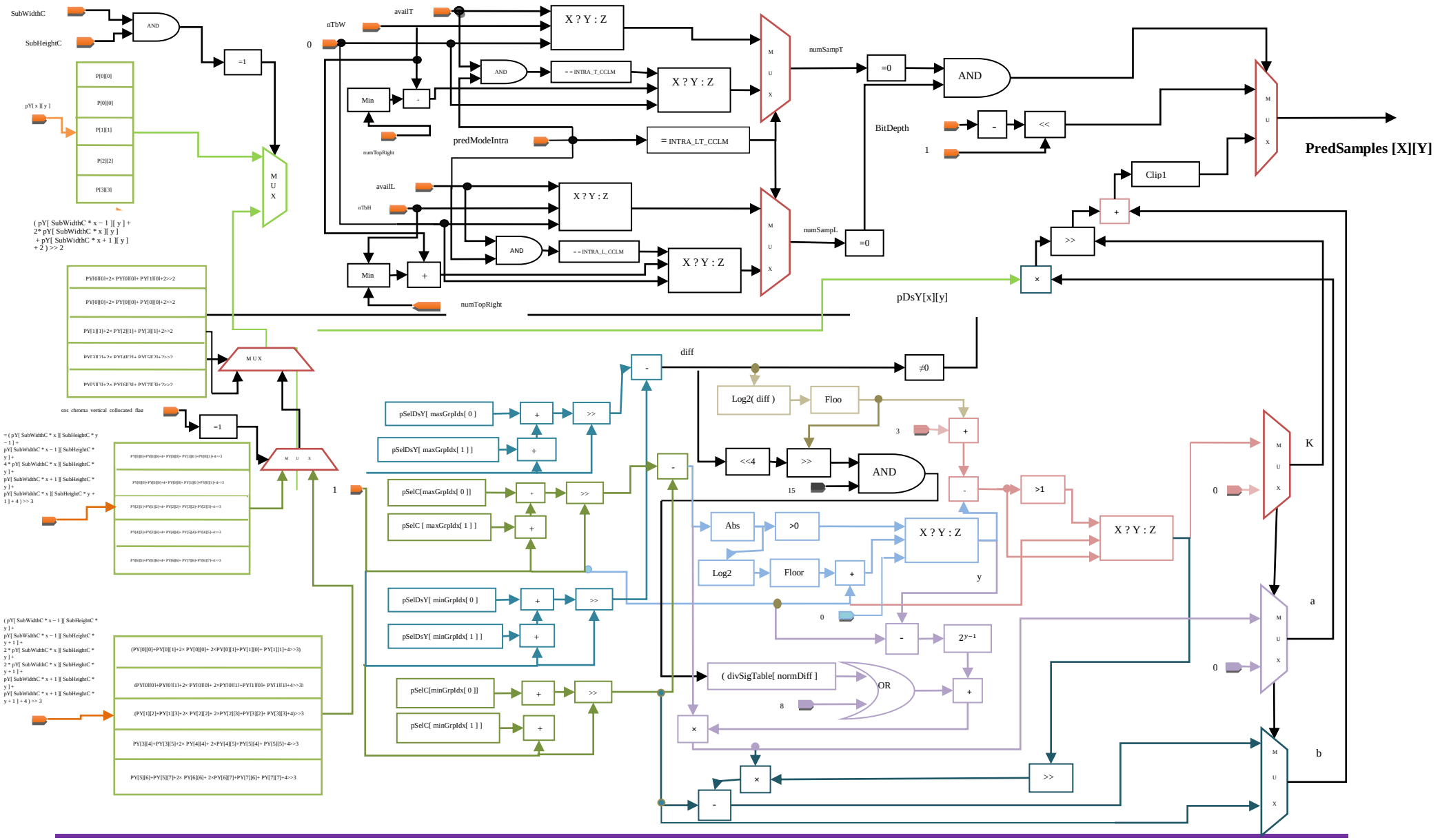

SubWidthC
SubHeightC
AND
=1
availT
nTbW
0
X ? Y : Z
AND
= = INTRA_T_CCLM
Min
predModeIntra
= INTRA_LT_CCLM
numTopRight
availL
nTbH
= = INTRA_L_CCLM
numSampT
numSampL
=0
BitDepth
<<
Clip1
PredSamples [X][Y]
pDsY[x][y]
diff
≠0
Log2(diff)
Floo
<<4
>>
>1
Abs
>0
Log2
Floor
(divSigTable[normDiff]
OR
pSelDsY[maxGrpIdx[0]
pSelDsY[maxGrpIdx[1]]
pSelC[maxGrpIdx[0]]
pSelC [maxGrpIdx[1]]
pSelDsY[minGrpIdx[0]
pSelDsY[minGrpIdx[1]]
pSelC[minGrpIdx[0]]
pSelC[minGrpIdx[1]]
K
a
b
M U X

Figure **IV.8 :**Proposed architecture of CCLM intra prediction mode .

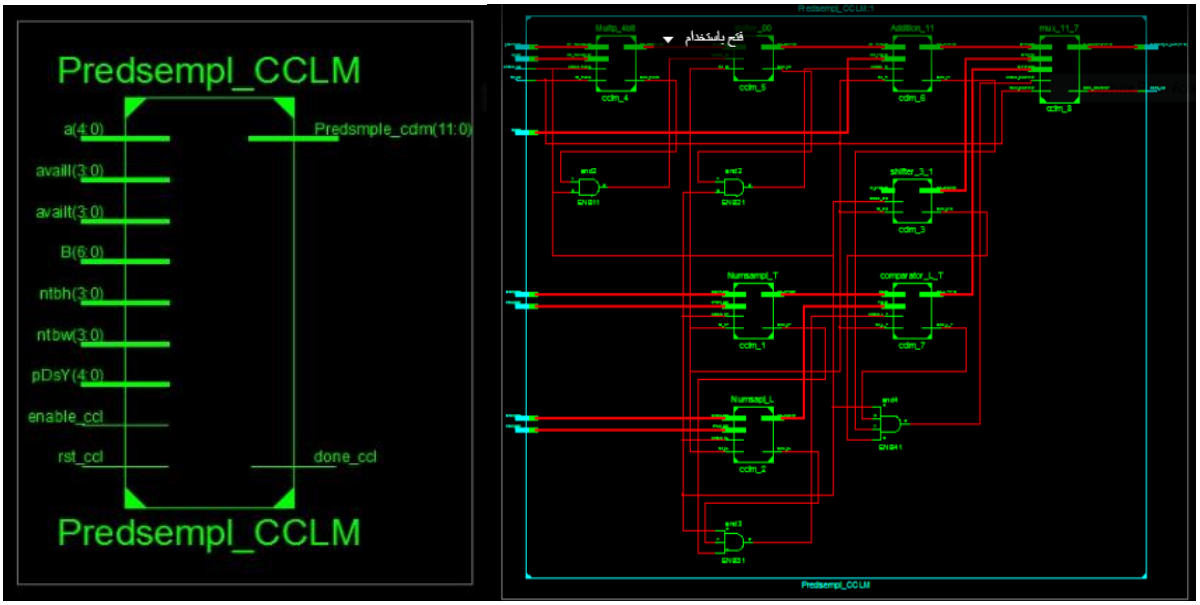


Figure IV.9 : Top level and RTL schemeS of CCLM intra prediction mode.

IV.3 Summary of proposed architectures

After designing the architectures that make the intra prediction modes, we moved on to implementation on the ISE using the VHDL language, as well as synthesis and simulation. using usingModelSim.

IV.3.1 The synthesis results of all intra prediction modes

IV.3.1.1 The synthesis results of Planar, DC, and Angular intra prediction modes

Table IV.1 shows the resources consumed and the summary of each prediction modes in terms of slices, and energy consumed of each .

Table IV.1: Summary of each intra prediction modes VVC standard.

Components	Planar intra prediction mode	DC intra prediction mode	Angular intra prediction mode
Slices	24	27	-
Slise flip flop	22	25	0
LUTs	216	47	295
Energy consumption (W)	0.042	0.042	0.042

IV.4.2 comparison and validation of the results obtained

Figure IV.10 and Figure IV.11 shows that planar and DC modes values obtained in Matlab are the same as those in Model-Sim respectively.

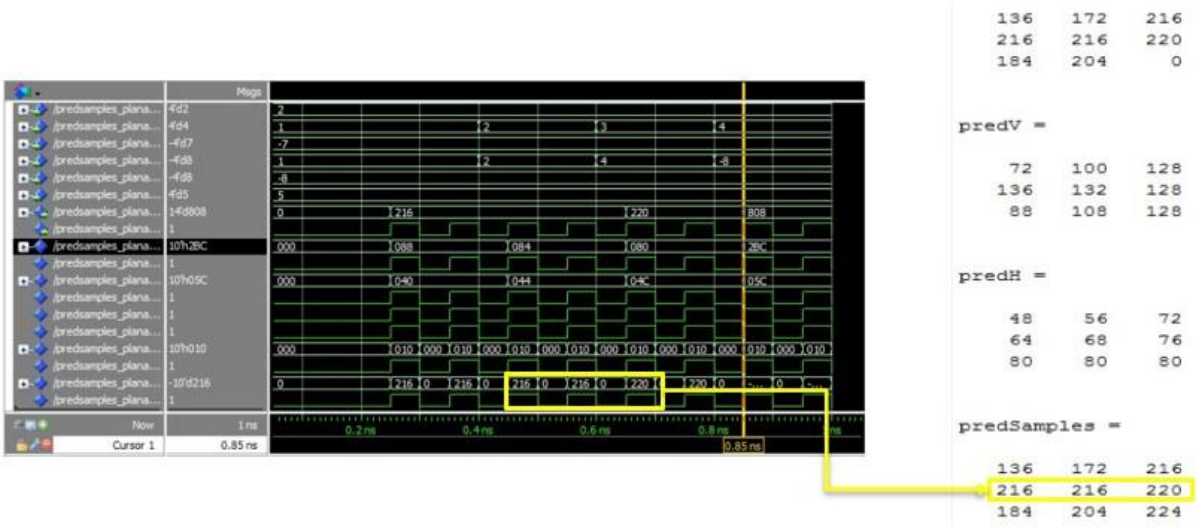


Figure IV.10: comparison of Planar values obtained with Matlab and Model-sim in Regular Mode

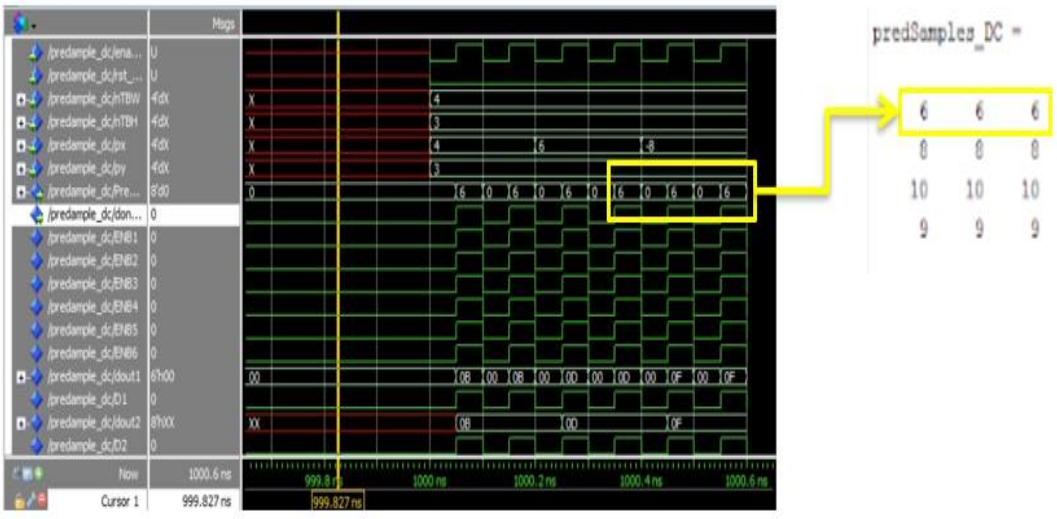


Figure IV.11: comparison of DCvalues obtained with Matlab and Model-sim in Regular Mode.

IV.4 Conclusion

In this chapter, An architecture is proposed for each mode of intra prediction , with Model-Sim emulation and ISE synthesis. At the end of the chapter, a comparison of the results obtained using Model-Sim with those obtained in Matlab is carried out in order to validate our work.

General conclusion

General Conclusion

Compressing videos is an essential process before they can be transmitted or broadcast on the Internet. The objective of our work was to study, design and implement on FPGA the intra preiction modes in the VVC/H.166 video compression standard. The intra prediction is based on four modes: Planar, DC(ComposanteDirecte), Angular, and the CCLM (Cross-Component Linear Model). to improve compression efficiency.

Our work is organi sed mainly as follows:

Firstly, a general explanation of the concept of video compression technology. then, an explanation of recent video compression standards has been and VVC compression techniques were detailed. Next, Then we highlight the different modes introduced by VVC, some of which are developed, others are new not available in other previous video coding standards to improve compression efficiency.

Secondly, we design the flowcharts of the four modes of intra prediction with implementation in Matlab.This transition from the implementation in Matlab.enabled us to master intra prediction algorithms used in the VVC video compression standard, before moving on to the in VHDL under the ISE.

Thirdly, we used Xilinx ISE version 14.5 to synthesize our proposed intra prediction modes architecture in VVC. Next, we used ModelSim to verify the architecture and confirm the results obtained with Matlab.

as perspectives we propose to implement the full VVC intra prediction modes on FPGA device additionally, we propose to optimize the energy consumption by using differentstechniquestoobtined a good visual quality.

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