



Adaptive Intra Refresh for Robust Wireless Multi-view Video

By

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A thesis submitted for the degree of

Doctor of Philosophy

in

Electronic and Computer Engineering

School of Engineering Design and Physical Sciences

Brunel University, London

June 2016

Abstract

Mobile wireless communication technology is a fast developing field and every day new mobile communication techniques and means are becoming available. In this thesis multi-view video (MVV) is also referred to as 3D video. Thus, the 3D video signals through wireless communication are shaping telecommunication industry and academia. However, wireless channels are prone to high level of bit and burst errors that largely deteriorate the quality of service (QoS). Noise along the wireless transmission path can introduce distortion or make a compressed bitstream lose vital information. The error caused by noise progressively spreads to subsequent frames and among multiple views due to prediction. This error may compel the receiver to pause momentarily and wait for the subsequent INTRA picture to continue decoding. The pausing of video stream affects the user's Quality of Experience (QoE).

Thus, an error resilience strategy is needed to protect the compressed bitstream against transmission errors. This thesis focuses on error resilience Adaptive Intra Refresh (AIR) technique. The AIR method is developed to make the compressed 3D video more robust to channel errors. The process involves periodic injection of Intra-coded macroblocks in a cyclic pattern using H.264/AVC standard. The algorithm takes into account individual features in each macroblock and the feedback information sent by the decoder about the channel condition in order to generate an MVV-AIR map. MVV-AIR map generation regulates the order of packets arrival and identifies the motion activities in each macroblock. Based on the level of motion activity contained in each macroblock, the MVV-AIR map classifies frames as high or low motion macroblocks.

A proxy MVV-AIR transcoder is used to validate the efficiency of the generated MVV-AIR map. The MVV-AIR transcoding algorithm uses spatial and views downscaling scheme to convert from MVV to single view. Various experimental results indicate that the proposed error resilient MVV-AIR transcoder technique effectively improves the quality of reconstructed 3D video in wireless networks. A comparison of MVV-AIR transcoder algorithm with some traditional error resilience techniques demonstrates that MVV-AIR algorithm performs better in an error prone channel. Results of simulation revealed significant improvements in both objective and subjective qualities. No additional computational complexity emanates from the scheme while the QoS and QoE requirements are still fully met.

Author's Declaration

I wish to state that I authored all the work in this thesis. The authors views expressed in this thesis are written to enhance robust delivery of quality 3D video over noisy channel. Brunel University is now authorized to make this thesis electronically available to the public.

Signature:.....

Sagir Lawan

Author's Contributions

- Multi-view video communication over a wireless network is the focus of this research. The research particularly concentrates on the design of Adaptive Intra Refresh (AIR) error control strategy for multi-view video communication over a noisy channel. The AIR error resilience scheme based on cyclic Intra refresh is employed to mitigate error propagation. The process involves inserting intra-coded macroblock features to a compressed multi-view video. The Intra-frames are the most important frames in a group of picture (GOP) as they do not refer to the information in the previously encoded frames. Thus, periodic insertion of Intra-coded macroblocks would refresh the corrupted frames in GOP. The crux of the matter is that the MVV encoder evaluates the compressed stream and detects those macroblock portions with a higher level of motion activity. These high motion portions of macroblocks are therefore more vulnerable to transmission errors. To determine the high motion macroblocks, the well-known sum of the absolute difference (SAD) and the predetermined threshold is employed to evaluate the activity of individual macroblocks. A table of motion affected macroblocks known as MVV-AIR refresh map is generated.
- The author conducted a subjective quality assessment of 3D video streams encoded with H.264/AVC. The subjective video quality assessment was carried out to evaluate and rate the quality of 3D video sequences transmitted using a two-way communication channel. Some groups of people referred to as the assessors of the subjective test were volunteers drawn from Brunel University, London and Nigerian Defence Academy, Kaduna. The participants consist of literate and semi-literate in the multimedia communication field and therefore have the capacity to understand some technical information. The reliable statistical data gathered from the experiments was used to analyse end-user quality of experience (QoE).
- The developed MVV-AIR refresh map generation algorithm accompanies major changes in each macroblock. As a result of these constant changes in macroblocks the MVV-AIR refresh map need to be updated based to conform to the changes in the activity of the scene. Consequently, the MVV-AIR map is employed to insert Intra-

coded macroblock in order to clean corrupted frames in a GOP and halt transmission error propagation.

- The author modified the required program code to generate the MVV-AIR map that enables the insertion of Intra-coded macroblocks to prevent compressed bitstream from spatiotemporal error propagation. To maintain a high performed algorithm an intensive simulations and experiments was conducted to validate the efficiency of the MVV-AIR algorithm. The results demonstrated that the MVV-AIR outperforms the other error resilience such as Flexible Macroblock Ordering (FMO).
- The author has diligently generated the necessary algorithm for MVV-AIR transcoding in order to validate the MVV-AIR generated map. The transcoding from multi-view to single view video would afford the decoding of compressed 3D video bitstreams on 2D video decoders such as the laptop and personal digital assistants (PDAs). The new MVV-AIR transcoding algorithm was tested under different noise channel environment. Furthermore, simulations was persistently performed over error prone networks with a view of identifying means of reducing interoperability between different devices.
- This thesis is composed of six chapters; the author has prepared and written all the six chapters. The author has arranged the final thesis in a logical order of thought to introduce readers to current trends in error resilience 3D video mobile communication technologies. After several consultation with the supervisors the author final produce the thesis. In addition to the work presented in the manuscript, the author has managed to publish, or submit for review, a number of journal and conference papers with the following details:

Journal papers:

1) Sagir Lawan and Abdul H. Sadka “Robust Adaptive Intra Refresh For Multiview Video” International Journal of Computer Science, Engineering and Applications (IJCSEA) Vol.4, No.6, December 2014 DOI: 10.5121/IJCSEA.2014. (a copy at Appendix A).

2) Sagir Lawan and Abdul H. Sadka "Robust Multi-view Video Streaming through Adaptive Intra Refresh Video Transcoding," International Journal of Engineering and Technology

Innovation, vol. International Journal of Engineering and Technology Innovation vol.5.no4, 2015, pp. pp.209-219, 2015. (a copy at Appendix B).

3) Ogri J Ushie, Maysam Abbod, Evans C Ashigwuike and Sagir Lawan “Constrained Nonlinear Optimization of Unity Gain Operational Amplifier Filter Using PSO, GA and Nelder-Mead”. International Journal of Intelligent Control and Systems Vol. 20, No. 1 March 2015, 26-34.

4) Sagir Lawan and Abdul H. Sadka “Efficient Adaptive Intra Refresh Map Generation for Multi-view Video”, Elsevier Signal Processing (Submitted for review).

5) Sagir Lawan and Abdul H. Sadka “Subjective 3D Videos Quality Assessment”, Elsevier Signal Processing (Submitted for review).

Book Chapter:

The author is selected to contribute a chapter to a forthcoming book from Centre for Media Communication Research (CMCR). The author recognizes that writing and publishing are important personal and professional accomplishments and submitted a 200-page book chapter. The co-ordinator of the book Professor Abdul H. Sadka is also a co-author of the chapter and provided support in the write-up so that the entire process goes smoothly. The co-ordinator has expressed lots of satisfaction in producing a well-crafted chapter.

Conference Papers:

1) Sagir Lawan and Abdul H. Sadka, “Enhancing Emergency Communication with Multi View Video Transmission” RESCON 2014 Conference, Brunel University, Uxbridge, UK. Brunel University London Research Student Conference

2) Sagir Lawan and Abdul H. Sadka, “3D Video Communication over Wireless Networks”, Brunel University London Research Student Conference 2015. The Three Minute Thesis (3MT).

3) Sagir Lawan and Abdul H. Sadka, “Military Deploying on Big Data Battlefield: The Role of 3D Video Communication”, Big Data Analysis Workshop organized by the Qatar UK Research Networking Programme in collaboration with Brunel University London.

Sponsored by Al Jazeera Channel, IBM Corporation Qatar, and Qatar National Research Fund (QNRF). Other contributors include British Council Qatar, UK Science and Innovation Network, and the UK Department for Business, Innovation and Skills. The workshop brought together over 100 experts, engineers and graduate students from Qatar, UK, and Canada.

Acknowledgements

All praise to Almighty Allah for enabling me to successfully complete the research work. I am greatly indebted to my academic supervisor Professor Abdul Hamid Sadka for providing me with the best supervision and guidance that a PhD student can wish for. His constructive criticism of my work always resulted in improving it. Apart from his technical expertise, I learnt a great deal from his wealth of knowledge, uprightness, honesty, and dedication to work. I would also like to appreciate Dr. Rafiq Mohammed Swash for the very fruitful discussion throughout the course of my PhD and for taking time out of his busy schedule to discuss and share ideas with me during my end of year reports.

I am also indebted to Tertiary Institution Trust Fund (TETFund) of Nigeria for awarding me the financial commitments and support for three years. The upward review of the allowances by TETFund had enable presentation of my work in greater details.

I thank my employer, the Nigerian Defence Academy (NDA) for allowing me to further my study abroad. Finally, I want to appreciate my dear wife, children, brothers and sisters for their supports throughout the duration of my PhD. I love you all.

Dedication

This work is dedicated to Alhaji Lawan Magini and Hajiya Mariya my late parents for their wonderful love, care and prayers.

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List of Abbreviations

2D	Two-dimensional
2DTV	Two-dimensional Television
3D	Three-dimensional
4k	4K Resolution
8k	8K Resolution
AC	Access Control
ACK	Positive Acknowledgement
AIR	Adaptive Intra Refresh
ARQ	Automatic Repeat Request
ATM	Asynchronous Transfer Mode
ATTEST	Advanced Three-dimensional Television System
AVC	Advanced Video Coding
BMA	Block Matching Algorithm
CABAC	Context Adaptive Binary Arithmetic Coding
CAVLC	Context Adaptive Variable Length Coding
CIF	Common Intermediate Format
CMCR	Centre for Media Communication Research
CRC	Cyclic Redundancy Check
DCT	Discrete Cosine Transform
DF	Degree of freedom
DIBR	Depth Image Based Rendering
DP	Data Partitioning
DSP	Digital Signal Processing
DTV	Digital Television
DV	Disparity Vector
DVB	Digital Video Broadcasting
DVD	Digital Video Disc
DVB-H	Digital Video Broadcasting - Handheld

DVB-T	Digital Video Broadcasting – Terrestrial
E	Expected
EC	Error Concealment
ER	Error Resilient
FEC	Forward Error Correction
FMO	Flexible Macroblock Ordering
FVT	Free Viewpoint Television
FVV	Free Viewpoint Video
GOB	Group of Block
GOP	Group of Pictures
GOV	Group of Views
HD	High definition
HDTV	High Definition Television
HEVC	High Efficiency Video Coding
HTTP	Hypertext Transfer Protocol
HVS	Human Visual System
IDCT	Inverse Discrete Cosine Transform
IDR	Instantaneous Decoder Refresh
IEEE	Institute of Electrical and Electronics Engineers
IVF	Interview Flag
IP	Internet Protocol
IPTV	Internet Protocol Television
IQ	Inverse Quantization
ISO	International Organization for Standardization
IEC	International Electro technical Commission
ISSN	Integrated Special Services Network
ITU	International Telecommunication Union
ITU-R	International Telecommunication Union-Radio communication
ITU-T	International Telecommunication Union-Telecommunication

JMVC	Joint Model for Multi-view Video Coding
JPEG	Joint Photographic Experts Group
JSVM	Joint Scalable Video Model
Kbps	Kilobits Per Second
LCD	Liquid Crystal Display
LT	Luby Transform
MB	Macroblock
MAC	Media access control
MC	Motion Compensation
MCP	Motion Compensated Prediction
MBA_MAP	Macroblock Allocation Map
MDC	Multiple Description Coding
ME	Motion Estimation
MEM	Motion Estimation Memory
MERL	Mitsubishi Electric Research Laboratories
ML	Multi-Layer
MLDP	Multiple Layer Data Partition
MOS	Mean Opinion Score
MPEG	Moving Picture Experts Group
MPEG-2 TS	MPEG-2 Transport System
MRE	Motion Reference Information
MTU	Maximum Transmission Unit
MV	Motion vector
MVC	Multi-view Video Coding
MVV	Multi-view Video
NACK	Negative Acknowledgement
NAL	Network Abstraction Layer
NALU	Network Abstraction Layer Unit
NDA	Nigerian Defence Academy

NER	Non Error Resilience
O	Observed
OTT	over the top
P2P	Peer-to-peer
PER	Packet Error Rate
PLR	Packet Loss Rate
PPS	Picture Parameter Set
PSNR	Peak Signal to Noise Ratio
Q	Quantization
QOS	Quality of Service
QCIF	Quarter Common Intermediate Format
QOE	Quality of Experience
QP	Quantization Parameter
RF	Refresh Frame
RGB	Red Green Blue
RPM	Reference Picture Memory
RTP	Real Time Transport Protocol
SAD	Sum of Absolute Difference
SD	Standard Definition
SDTV	Standard Definition Television
SEI	Supplemental Enhancement Information
SNR	Signal to Noise Ratio
SPS	Sequence Parameter Set
SSD	Sum of Square Difference
SQCIF	Sub-Quarter Common Intermediate Format
SVC	Scalable Video Coding
TCP	Transport Control Protocol
TETFund	Tertiary Institution Trust Fund
TR	Temporal Reference

UDP	User Datagram Protocol
Ultra-HD	Ultra High definition
UEP	Unequal Error Protection
UMTS	Universal Mobile Telecommunications Systems
VCEG	Video Coding Expert Group
VCL	Video Coding Layer
VLC	Variable Length Coding
VLD	Variable Length Decoder
VoD	Video on Demand

Chapter 1

Introduction

In this chapter, we introduce the entire thesis. Section 1.1 provides useful information about multi-view video communication over noisy channels. The problem this thesis addresses is highlighted in Section 1.2. Section 1.3 presents the aim and objectives of the research. Sections 1.4 – 1.7 discuss significance, scope, contribution and the thesis organization. The chapter is finally summarized in Section 1.8.

1.1 Background and Motivation

The proliferation of smartphones with a wide ensemble of applications and services is paving the way for mobile 3D video communication [1-3]. The rapid change brought about by the wireless smartphones, and 3D video technology has had a significant effect on the way people communicate worldwide. Moreover, today's smartphones are embedded with multiple cameras, microphone, accelerometer, digital compass, gyroscope and global positioning system (GPS). These collective device features facilitate seamless exchange of 3D video information across a wide variety of domains, such as social networks, safety, environmental monitoring, healthcare, and transportation [4, 5]. The smartphone coupled with free services such as YouTube or Skype provides every end-user with the capability to produce, cast and share audio-visual information in a way that emulates a studio or a media production environment.

Also, there has been tremendous increase in mobile multi-view video conferencing, movies CCTV monitoring and tele-medicine [6-8]. The Skype Technology report, confirmed that 3D video calls have evolved and the 3D video call applications surpass watching a streaming video from the Internet. Moreover, the 3D video presents an impressive sense of realism as compared to the 2D video. To this end, a number of people buy smartphone and television that have 3D image capabilities [9, 10]. There are two major reasons why 3D video communication is better than other forms of communication. The first reason is because video messages are far more engaging than text messages. Accordingly, 3D video communication is more natural than traditional 2D video. Second, 3D video can offer information that is more authentic, accurate and precise than a long email. Thus, many

organizations and agencies support 3D video communications to ascertain the accuracy of object shape, texture, size and location. Evidently, multi-view video used in C4I (command, control, communication, computer and intelligence) enabled accurate identification of criminals and specific targets. Consequently, combat communication for Global War on Terror (GWOT) exploit 3D video for superior situational awareness [11-13]. Furthermore, one area where 3D video is making an impact, though not for the first time, is in 3D video gaming. However, a dearth in the 3D video media content production of game is affecting widespread of 3D video games.

The emergence of two-way fourth generation (4G) network with mobile Internet enables 3D video streaming on laptops and smartphones. The currently deployed 4G supported by Worldwide Interoperability for Microwave Access (WiMax) and Long Term Evolution (LTE) offer much wider wireless network coverage than the fixed line Internet service. However, the fifth generation (5G) technology that is about to be unveiled will usher a new era of Gigabyte wireless system which would facilitate the use of 3D-capable smartphones and hence Internet of Thing (IoT) would become a reality [14-16]. In spite of all these technological advancement, the presence of channel errors and limitations in bandwidth mar the efficient transmission of compressed video over wireless networks. As a result compressed video bitstream are continuously altered or lost along the transmission path due to noise and interference. For example, a bit error that strikes current frames often propagates to subsequent frames and among multiple views owing to prediction techniques employed in video compression [17-19]. The information loss in a GOP structure invokes the receiver to wait momentarily for the next INTRA frame before the content continues decoding. This situation places extra pressure on the perceptual video quality which affects the end-user's Quality of Experience (QoE) [20-22].

Nowadays, mobile communication devices are fitted with multiple radio interfaces that enable them to access diverse asymmetric networking platforms, but, not all portable devices are equipped with 3D video decoders. Portable communication gargets like laptop cannot decode multi-view video coded (MVC) bitstreams. Therefore, lack of interoperability between different devices and different networking protocols is limiting the diffusion of mobile 3D video interactive services. As such, it is incumbent upon industries and academia to take the initiative of repurpose 3D video content for delivery over different wireless channels to varied mobile devices is needed. Video Transcoding is one such mechanism that assures format conversion and meeting targeted recipient capabilities [23-28]. In this thesis,

we focus on a multi-view video Adaptive Intra Refresh (MVV-AIR) error-resilience transcoder based on H.264/AVC codec. The main goal is to disseminate high-quality 3D video information across the various communication channels using all available bandwidths [29, 30]. The video proxy MVV-AIR transcoder operates at a central point, the algorithm uses spatial and view downscaling system. Figure 1.1 depicts the distribution scenario block diagram of the MVV-AIR transcoder. The robust AIR error resilience transcoding technique will suppress the effect of transmission errors [31-33].

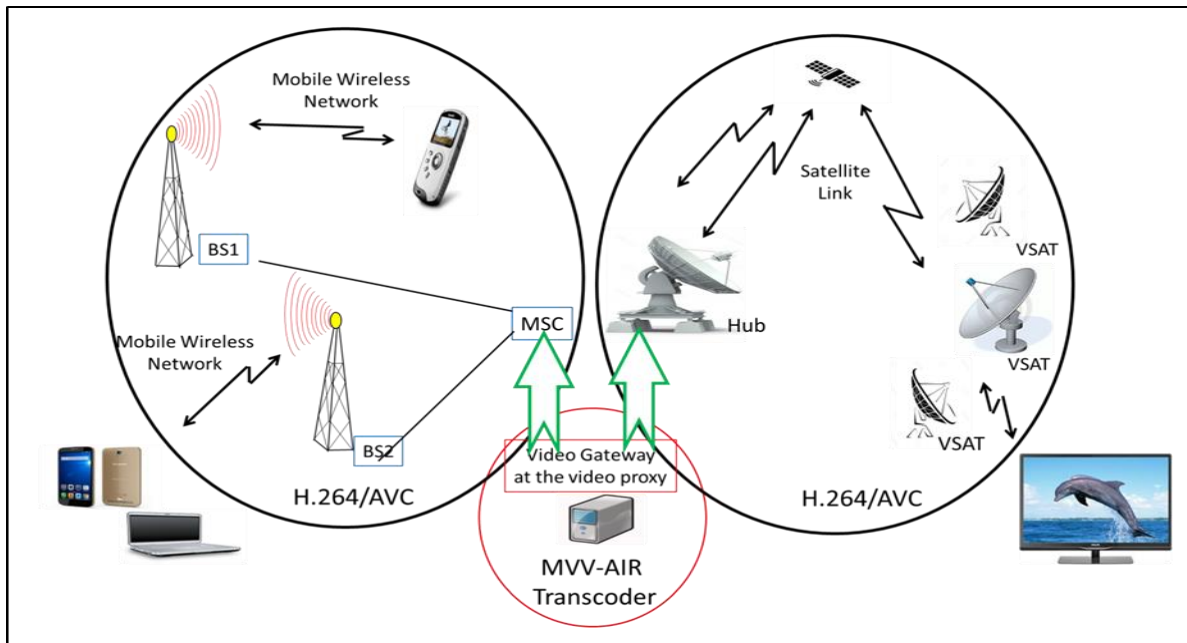


Figure 1.1: MVV-AIR Transcoding Scenario

The MVV-AIR transcoder gateway is located between a low resolution network and a relatively high resolution network. The cascaded transcoder can adaptively scales down the compressed 3D video bitstream to a 2D video format. Thus, adding AIR error resilience features to our proposed MVV transcoder will enable robust conversion of 3D video to 2D video. To ensure robustness error resilience is introduced to the bitstream at a tail end of the transcoder [34, 35].

The primary concern is how to delivery 3D video over a wireless network with efficient uses of bandwidth in order to meet the end-user quality perception. There are a wide variety of factors that affect the end-user perception of video quality. One such factor that can cause a decline in video quality occurs when a signal is faced with uncertainty and myriads of network problems. This is referred to as quality of service (QoS). Consequently, the ability of a network to provider service with reduced jitter or average packet delivery delay may result in high QoE. In the light of the preceding, we conduct a subject quality assessment in order to

evaluate the QoE of a transmitted 3D video over wireless network. The subjective assessment survey was based on ITU-T subjective quality assessment technique. The survey was an investigation combining both primary and secondary methods of data collection. In the case of primary method, a survey structured questionnaire was designed by the author. The bespoke questionnaire captures the necessary data required for the evaluation. Interviews were also conducted with the male and female volunteers drawn from Brunel University, London and Nigerian Defence Academy, Kaduna. The participants consist of literate and semi-literate in the multimedia communication field, and therefore they have the capacity to understand some technical information. The subjective test involves rating end-user's opinion on transmitted 3D video under two conditions namely noise free and noisy channel environment.

1.2 Statement of the Problem

Multi-view video communication is facing problems of massive video data, different multi-view video coding (MVC) formats, transmission errors propagation and interoperability between different networks and devices. Figure 1.2 illustrates the end-to-end delivery of 3D video. The problems associated to each block are highlighted in the following subparagraphs below.

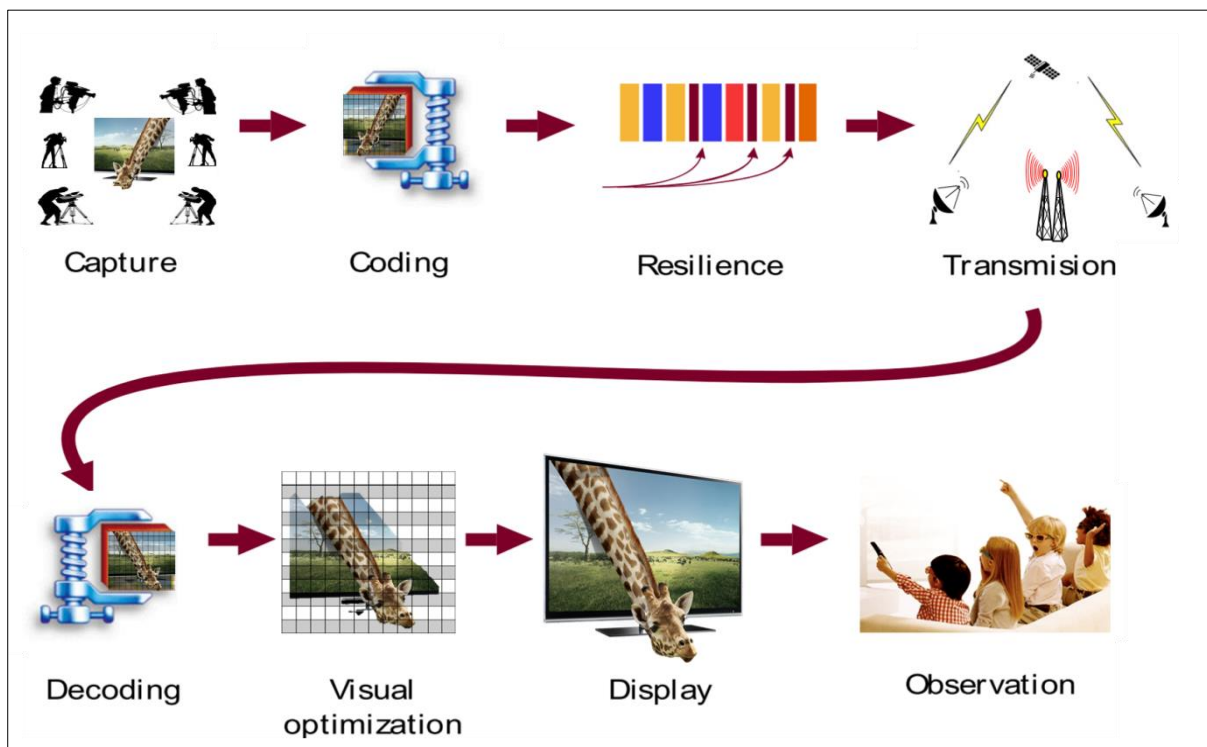


Figure 1.2: End-to-end 3D Video Delivery

- (1) **Massive video data generated by multiple cameras.** In the 3D video communication system, multiple video cameras capture a scene simultaneously from diverse angles. The multiple cameras generate massive 3D video data to be conveyed from one point to another. This massive data contains a lot of redundancies in time, space and view [36, 37].
- (2) **Different content representation Standard.** The digital video compression plays a key role in 3D video communication. To further improve wireless communication, many industries employ video compression standards for video coding. These are MPEG-1, MPEG-2, MPEG-4, H.261, H.263, H.264/MPEG-4 Advanced Video Coding (AVC) and H.265/HEVC [36-44]. It is pertinent to note that even though different video compression standards rely on the same core techniques to encode a raw video stream, there is still a considerable difference between them regarding both syntax and structure. Although the goal of these standards is to provide interoperability between different manufacturers, promote a technology and reduce costs, the problems of interoperability within the standards still exist.
- (3) **Transmission Error Propagation.** Transmission error propagation is one of the striking problems in wireless communication. The telecommunications world today features a variety of wireless access network technologies with different bandwidth limitation, network latency, jitter and packet loss etc. These differences make seamless 3D video transmission among different network platforms difficult. Furthermore, wireless environment are flaw with noise that causes random bit errors, long burst error and packet loss. As a result of these errors, the video quality of compressed 3D videos transmitted over wireless channel/network is severely affected [17, 20, 21, 45, 46]. For example, when a single bit error strikes the current frame, the error propagates to subsequent frames and among multiple views. This is because of conventional prediction coding techniques employed in standard video compression. The effect of transmission error leads to information loss in the frame. Loss of information results to synchronization problem between the receiver and the encoder. The lack of synchronization causes the receiver to pause video playback until the arrival of the next INTRA picture. These and other related problems gave rise to perceptual video quality degradation which impairs viewer's QoE.
- (4) **Interoperability between different networks and devices.** There are a variety of wireless access network with various specification protocols in the telecommunications world today [47, 48]. Due to lack of interoperability and compatibility, content of video information originally captured and compressed with a particular syntax may experience restriction in access or implementation in other devices [49-53]. This accounted for the most prominent

reason why mobile devices such as laptop cannot decode compressed 3D video contents. The unwholesome development prompted Telecommunication industries and academia to institute various research techniques with a view to proffering a better solution to the shortcomings.

It is against this background that we present our primary research questions as follows:

- a. What is the nature and state of error resilience and video transcoding over the wireless network?
- b. What are the implications of the MVV-AIR transcoding algorithm over the quality and computational complexity of the 3D video communication?
- c. How does H.264/AVC to H.264/AVC transcoder perform based on MVV-AIR motion vector information re-uses?
- d. What strategies should be applied to suppress the effects of the transmission error propagation and sustain MVV-AIR transcoding?

1.3 Aim and Objectives

The aim of this study is to mitigate transmission error propagation using AIR error resilience technique. The specific objectives are:

- a. To explore the concept of AIR error resilience multi-view video transcoding in support of 3D video communication over the wireless network.
- b. To examine the implications and challenges of converting the H.264/AVC to H.264/AVC MVV-AIR transcoder.
- c. To present the performance of MVV-AIR transcoder using motion vector information re-use in H.264/AVC to H.264/AVC transcoder.
- d. To proffer strategies that will suppress the impact of transmission error propagation for sustainable 3D to 2D video transcoding over wireless networks.
- e. To develop 3D video subjective quality assessment model using QoE term to capture subjective feedback.

1.4 Significance of the Research

The key advantage of this study is that it addresses perhaps the most topical issue in multimedia communication today, which is that of mobile multi-view video transmission

over diverse networks. The thesis is expected to be of great significance for the telecommunication industries in three ways. Firstly, the research will articulate strategies to tackle the problem of devices interoperability. The MVV-AIR addresses both the device and network interoperability problem. As a result of this high-quality 3D video can be made viewable to 2D video devices. Secondly, the research fills a gap in knowledge and stimulates further study on multi-view video error resilience compression. Thirdly, this research also contributes to knowledge and serves as reference material for researchers in the field of video transcoding and error resilience.

1.5 The Thesis Scope

The field of error resilient and video transcoding scheme is very broad. This research is limited to developing robust multi-view video communication over wireless networks using AIR error resilience technique. The research is versatile in nature and involves the applications of MVV-AIR error resilience transcoding. Thus, the main research work was implemented in a four-step approach. Figure 1.3 provides a broad overview of the step by step scope and framework applied in this thesis.

1.5.1 A Survey of Literature

Normally, literature review is the first step in an academic study. In this thesis, the literature defines and discusses the three major issues that are central to this research. These three issues are the concepts of wireless communication, error resilience and video transcoding.

1.5.2 Multi-view Video Quality Assessment

Quality assessment for subjective evaluation of multi-view video plays a significant role in determining user's perception of the transmitted video [54]. A subjective video quality survey was conducted to assess the end-user's perception of the transmitted 3D video. The subjective test focuses on the technical factors that influence QoE. The QoE is a wider term that captures user experience and delight of the delivered service [55].

Step 1 – Survey and Review of Current 3D Video Communication System

Concept of Wireless Communication

- Mobile cellular network
- 3D video over future networks
- Bit error and 3D video quality
- 3D video acquisition and display

Error Resilience

- Error resilience encoding
- Adaptive Intra Refresh
- Data Partitioning
- Multiple Descriptive Coding
- Reversible Variable Length Coding
- Video coding standard

Video Transcoding

- Concept of Video Transcoding
- Adaptive Intra Refresh Transcoding

Step 2 – Assess Impact of 3D Video through Subject Quality Test

- 3D Video Subjective QoE Assessment
- Research Design
- Identification of Variables

- Data Source
- Data Collection
- Data Presentation , Analysis and Discussion

Step 3 – Development of a Robust Adaptive Intra Refresh

- Impact of Transmission Error Propagation
- H.264/AVC Video CODEC
- MVV-AIR Architecture
- MVV-AIR map Generation

- Cyclic line pattern MVV-AIR error resilience
- Error Detection
- Experiment, Results and Discussion

Step 4 – Sustainability through robust Multi-view Video Transcoding

- Proposed MVV-AIR Transcoder
- MVV-AIR Transcoding Architecture
- H.264/AVC to H.264/AVC Transcoding

- Algorithm Implementation
- Error Resilience MVV Transcoding

Figure 1.3 Scope and Methodology

1.5.3 Interactive Error Resilience

The study exploits interactive AIR error resilience technique to mitigate error propagation. An AIR error resilience tool requires feedback communication link between the encoder and the decoder. The feedback link would be employed by the decoder sent to the encoder the variation of the channel condition and the number of macroblocks corrupted by error using the feedback channel [56]. The encoder operates by first updating the MVV-AIR map and thereafter inserting intra-coded macroblocks to halts the error propagation.

1.5.4 Cascaded 3D video Transcoding

This thesis considers a cascade transcoder that has the following properties:

- The decoder end of the transcoder receives an incoming bitstream and decodes it using Variable Length Decoder (VLD) algorithm.
- The decoded video frame is passed into quantizer for inverse quantization. The quantized coefficients are inversely transformed using Inverse Discrete Coefficient Cosine Transform (IDCT) process.
- A copy of the IDCT coefficients employs motion compensation of reference frame for enhanced entropy coding [37, 57].

1.5.5 The 3D Video Broadcast and Streaming Applications

The proposed MVV-AIR transcoding algorithm was further validated using SIRANNON. Network protocols including HTTP and RTP can be simulated with the Sirannon software [39]. The simulation with Sirannon software was conducted to evaluate the effect channel/network errors to compressed bitstream [58].

1.6 Thesis Organization

The thesis is organized into six chapters. Three of the chapters address pertinent issues on video quality assessment, error resilience and video transcoding. However, this chapter has provided useful information about 3D video communication over wireless networks and highlighted the problem statement. Chapter two of this thesis reviews three main issues that are central to this study. These are wireless communication, error resilience, and video transcoding. The review of the basic concept and key issues was specifically based on multi-view video communication over wireless networks.

Chapter three presents a subjective quality assessment of 3D video streams encoded with H.264/AVC. The chapter highlights the roles of QoS and QoE in end-to-end multi-view video communication setting. Before addressing the variable considered in the research and the procedures adapted for sourcing data, research design requirements was presented. The experiment for validation of the collated data was presented based on ITU-R recommendation. Finally, the data obtained is then used to answer the research question and test the hypotheses.

Chapter four describes Adaptive Intra Refresh (AIR) error resilience technique we have developed for multi-view video delivery over noisy networks. The chapter briefly reviews error resilience and H.264/AVC compression. Then, we proceed to describe the impact of transmission error propagation on the compressed 3D video bitstream. Step by step procedure on generation of MVV-AIR map was presented before considering the analysis of experiments and simulations results.

Chapter five describes multi-view video Adaptive Intra Refresh (MVV-AIR) transcoding technique that we have developed. The MVV-AIR transcoder process involves variable conversion using the H.264/AVC standard. The chapter states the technical issues relate to our proposed MVV-AIR transcoding. Then, the chapter outlines the techniques used in implementing high quality less complex MVV-AIR transcoder. Experiments and simulations set-up as well as results obtained are all discussed. Finally, conclusion remarks are presented and future work in Chapter six is explained.

1.7 Summary

Chapter one briefly introduces the basic concept and layout of the thesis. The chapter presents the role of multi-view video communication over heterogeneous networks. We than highlights the degree problems facing 3D video communication including massive video data, error propagation and interoperability between diverse devices. Furthermore, we stated the aims and objectives of the research. Furthermore, the chapter presented the scope covered by the research and summarises the contributions to knowledge made by this research work.

Chapter 2

A Literature Review

This chapter reviews the three main issues that are central to this research. These are wireless communication, error resilience, and video transcoding. The review of these key features is in relation with the efficient transmission of 3D video over wireless networks.

2.1 Background

A thorough review of relevant literature was carried out to gain insight into related studies in order to fill some identified gaps in the field of multi-view video delivery over wireless channels. The literature review was presented under the following sub themes: concept of wireless communication, the phenomenon of error resilience, video transcoding, gap in literature and summary of literature review.

The last year of the 20th Century and first decade of the 21st was a period of great mobile wireless telecommunication innovation around the world [16, 47, 59, 60]. During this time, the world has seen an exponential growth of wireless communication technology. Wireless Internet access and many wireless service providers have flourished and enjoyed high success. However, there have also been records of failures in wireless communication as well, for example, the crumbling of the first generation of LANs, Iridium satellite system and Metricom [61] due to compatibility problems.

History is dotted with examples which indicate that the first wireless channels were developed during the pre-industrial age [62-64]. These early wireless systems were successful in the transmission of information over line-of-sight. According to [61] the first wireless communication technology turned out to be the Morse code signal transmission over a century ago.

Misra et al., [59], Nugaliyadde et al. [65] and Skocir in [66] stated that a long time ago the mobile wireless industry put considerable effort into systematic research to enhance the QoS and QoE for the benefit of users. Thus, wireless communications today support nearly every aspect of our daily lives. The breakthrough and extensive traffic increase in mobile wireless communication is happening on all fronts specifically, in personal, local and wide area networks technology [67-70].

Figure 2.1 shows Cisco Visual Network Index (VNI) for mobile communication data traffic forecast of 2015 to 2020 [71-73]. These findings broadly indicate dramatic growth in wireless communication using smart devices. These findings are consistent with Cisco previous prediction of mobile data traffic which is projected to increase eight-fold by 2020. The Cisco findings suggest that mobile 3D video communication will growth rapidly. Furthermore, the smartphone operation in future network may able people to be connected with the world anytime and anywhere.

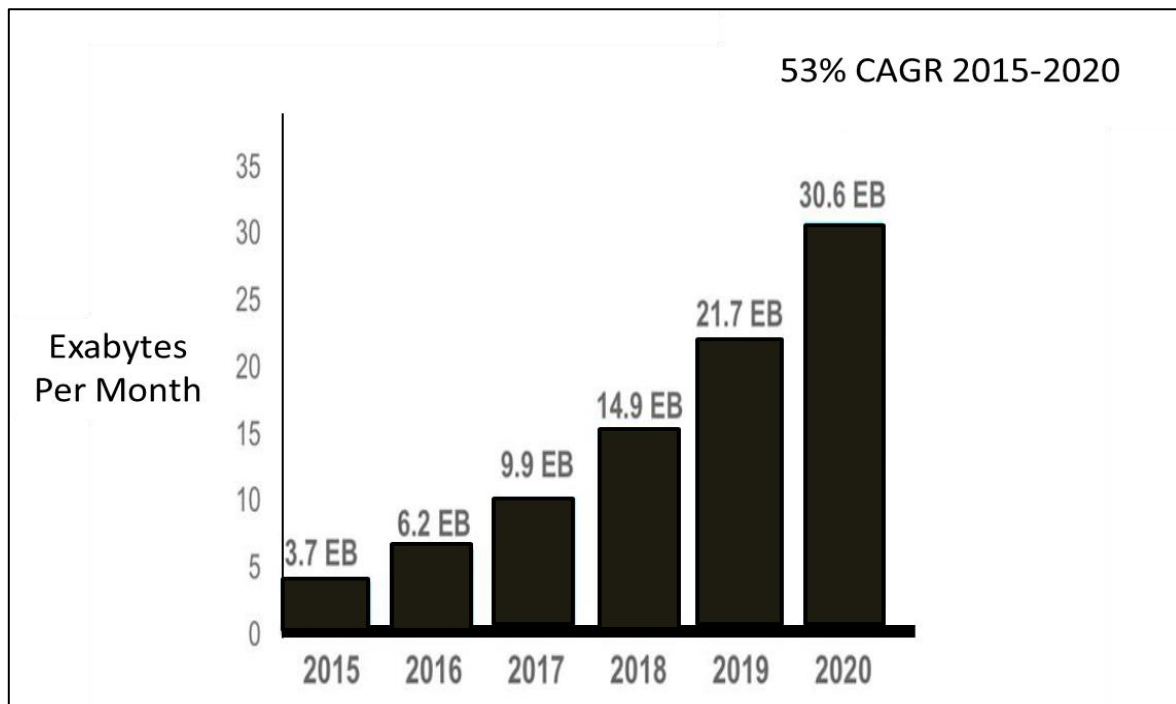


Figure 2.1: CISCO VNI Mobile 2016 [74]

The wireless communication employs the use of microwaves, satellite, radio, infrared, Bluetooth and Wi-Fi to transport multimedia information from one location to another [75-78]. From the first generation (1G) to 4G, the mobile telecommunications has seen some improvements along the line with an improved performance [79-83]. To this end, Xu et al., [84] and Chen et al [85], stated that fear of the rising tides of mobile wireless communication, big data, and 3D video require faster and more efficient wireless networks. Li et al., [70] and Gani et al., [86], envisaged that the future deployment of 5th, 6th and 7th generations of wireless networks would enhance the capability of high-quality wireless video services. The primary goal of future wireless networks is to provide reliable mobile communication link between people.

Asymmetric and symmetric communication environments are among the biggest outstanding challenge in 3D video wireless communication. In an asymmetric communication environment, channel characteristics differ in one direction as compared to another direction. In wireless networks, the bandwidth limitation encountered by different service providers affects the efficient delivery of 3D video. However, in the symmetric communication environment, the problem may be less acute as the channel characteristics are similar in both directions.

Conversely, drawing from empirical studies in [87-89], the authors stressed that compressed video bitstream transmitted over asymmetric wireless network experience massive packet losses. Consequently, wireless communication service is inherently interrupted by congestion in network, natural and manmade noise disturbances which results in packet loss. These packets loss during transmission are critically affect end-user QoE. The author in [90-92] losses of packet information and transmission bit error are attributes that affect quality of decoded video at the receiver. However, the emergence of a set of new wireless technologies such as 802.11ac, LTE-A and smart spectrum reuse has considerably eased packet information loss in wireless network [93, 94]. In this light, the authors in [2, 80, 95, 96] reiterate that the employment of terabit systems in wireless communication has improved bandwidth capacity of wireless link thereby reducing information loss due to channel errors. Information loss occurs because of poor network condition, hence efficient QoS is imperative in providing a crystal clear 3D video across an end-to-end communication [97-100].

2.2 Concept of Wireless Communication

Wireless communication is a term used in telecommunications in which electromagnetic waves carry signal over some part of, or the entirety of, the communication path. There are quite a few definitions of wireless communication, though they all necessarily mean the same thing. The word wireless in the dictionary means “having no wires” [47, 101, 102]. One of the prevailing definitions according to computer network researchers is that,

“Wireless networks are any connection between two or more points by radio waves and or microwaves to maintain communications” [103].

The geographical distance between two points for wireless communication can be a few meters for example a television remote control. The distance can also be far like the case of radio communications in free-space. Figure 2.2 shows the basic 3D video wireless communication system that consists of multiple video cameras capturing a scene

simultaneously from different viewpoints [17, 20, 29, 37 and 104]. In order to deliver MVV data from video source to a remote destination, there are sets of MVV processing, transmission, storage and display technologies introduced by ITU that guide the 3D video wireless communication process. A critical look at these processes reveals that several factors have been identified as being responsible for 3D video communication. A communication system fraught with noisy channel can only produce error corrupted bitstream at the receiver. Thus, wireless communication medium degrades the quality of transmitted video stream. Every contributor to discussion on the topic of wireless communication caution quality trade-off in strong terms.

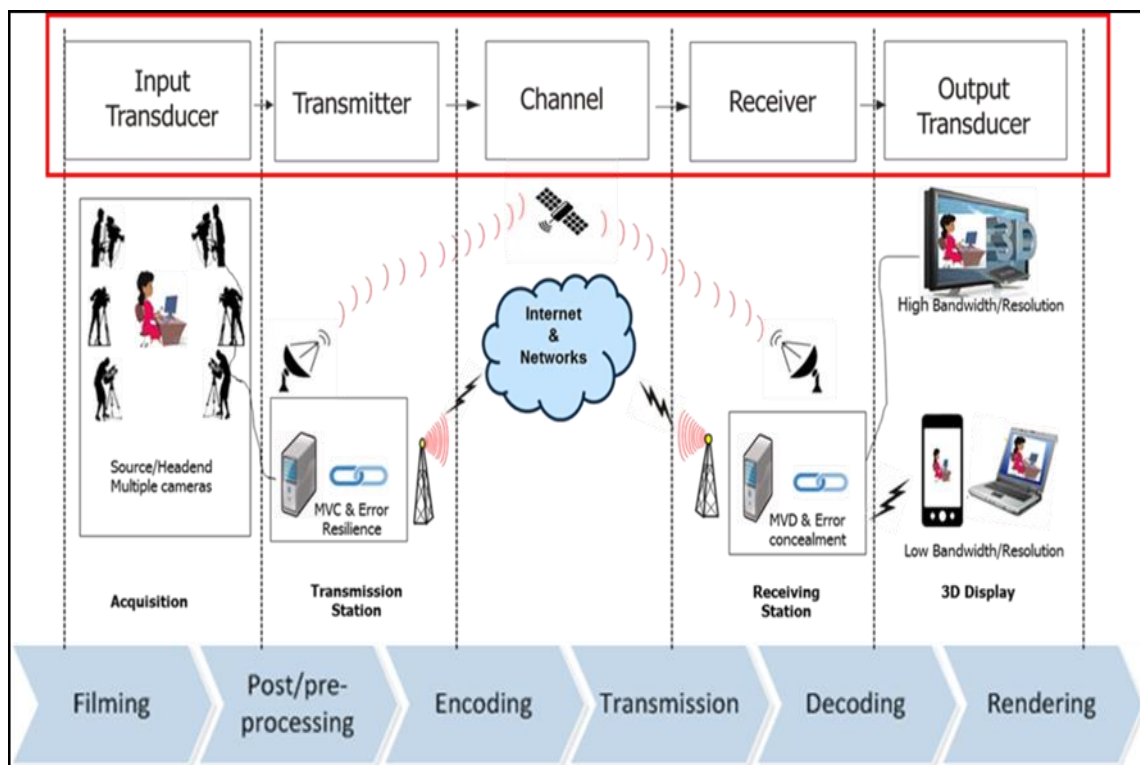


Figure 2.2: Concept of 3D Video Wireless Communication

The wireless communication methods use radio waves to convey data between devices that are geographically far apart. A literature research reveals that wireless communication can be grouped into two classes. The classes are fixed wireless and mobile/portable wireless communication [5, 70, 103, 105-109]. The fixed wireless system hooks devices through dedicated modems equipment. While the use of wireless devices or systems on the move describe portable wireless communication. The following are some of today's wireless communication equipment [110]:

- Smartphones: used for personal and business portable/mobile communication.

- Global Positioning System (GPS): used for navigation to find location anywhere on earth.
- Cordless wireless accessories: these include wireless keyboards, mouse and printers that are wirelessly connected to a computer.
- Cordless wireless telephone sets.
- Wireless home-entertainment system: A good example is the TV channel control.
- Wireless remote access garage door.
- Two-way wireless radios. Military, civilian commercial radio, marine and Amateur intensively make use of these type of radios.
- Satellite television using wireless links.
- Wireless LANs or local area networks: This is a key communication system that provides reliability business using a computer.

Wireless communication is critical in the lives of people throughout the world [111] and their absence can result in creating a social nuisance. According to [63, 112, 113], the transmission of multimedia information over a wireless network can be realized using PAN (Personal Area Network), Local Area Network (LAN) and Metropolitan Area Network (MAN). Other types of wireless communication to industries and researchers include infra-red (IR), satellite, Bluetooth, broadcast radio-frequency, microwave, Wi-Fi, Zigbee, cordless telephones, GPS, etc. The existing wireless networks deployed are the 4G networks, Bluetooth and Wi-Fi technologies [114].

Furthermore, the recent migration to the digital broadcasting system by the International Telecommunication Union (ITU) has brought to light a new phenomenon for integration of fixed and mobile video transmission worldwide [55, 115 and 116]. The universal transition from analog to digital broadcasting has now been implemented in many countries (see Figure 2.3). The digital terrestrial television broadcasting (DTTB) and mobile television broadcasting (MTB) particularly favour the delivery of 3D video content [117, 118].

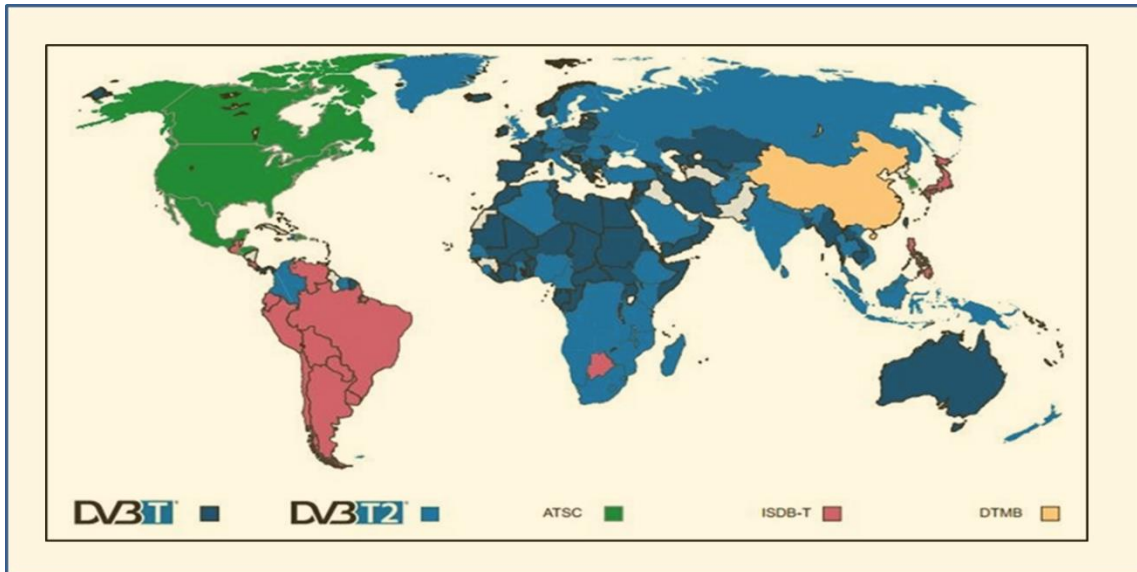


Figure 2.3: Status of Digital Television Broadcast [119]

2.3 Mobile Cellular Networks

The cellular telephone system has perhaps been the most successful application of mobile wireless networks. According to [120, 121] a cellular radio network distribute information over land for a fixed-location. These fixed-locations are referred to as cells; collection of cells can provide wireless radio coverage to a large geographical region. These cell wireless radio service enable mobile user equipment (UE) to communicate with another far distance UE [122, 123]. The most important advantages of mobile cellular communication networks that have made them accepted worldwide are flexibility (wirelessness), ease of use and durability. Despite these benefits, cellular networks are faced with compatibility issue and privacy protection.

The study in [124] appears to support the argument that on the face of the advancement in mobile communication technology, the cellular communications also face a significant challenge. For example, cellular network has to locate a given UE wherever it is among billions of globally dispersed mobile terminals. Locating a particular UE is not a simple task likes wise routing a call to the UE as it moves with a speed of up to 100 Km/hr.

Gani el al., [86] examine the set of resources for traditional cellular technologies. These resources include the Global System for Mobile (GSM) Communication, General Packet Radio Service (GPRS), Universal Mobile Telecommunication System (UMTS), 3GSM and Code Division Multiple Access (CDMA).

It is estimated that the GSM communication began in the early 1980s [125-127]. Before this period, there has been a rapid expansion of analog cellular telephone systems in many countries in Europe. Though, each of the Europe state developed different cellular system, the difference in syntax leads to interoperability problem [128]. To address this interoperability issues, Conference of European Posts and Telecommunications (CEPT) in 1982 established a working group that developed the GSM. Figure 2.4 shows the progressive development of the cellular phone communication as summarized by Ofcom [129] . According to [130], the rapidity in GSM phone development was based on the desire to meet up with high speech quality, low-cost handheld terminals and international roaming compatibility. The author in [131], viewed the GSM services as a platform for transmitting video. The combination of GSM with time division multiple access (TDMA) and frequency division multiple access (FDMA) technologies increases the availability of more channels. Gohil el al, [132], and Madhavapeddy el al, [133] pointed out that GSM has the capability for international roaming which promotes the desire to convey videos worldwide.

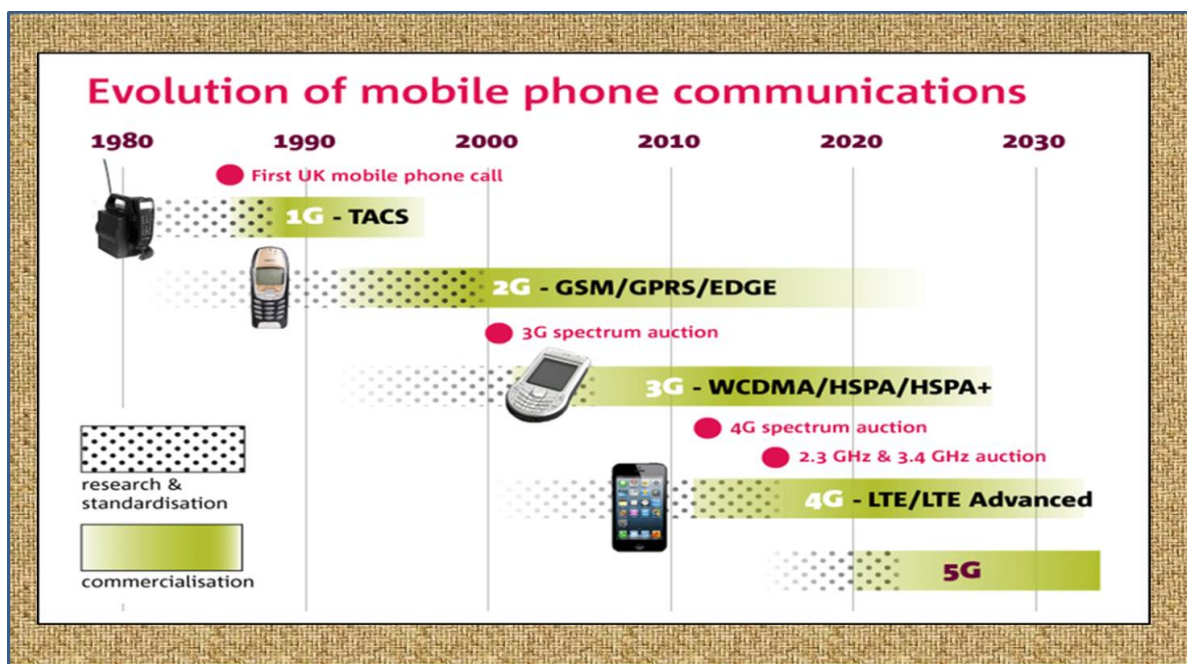


Figure 2.4: Evaluation of Mobile Phone Communication [124]

There is a considerable body of research which suggests the use of GPRS (general packet radio service) to enhanced cellular network [134]. In [31], Dogon el al, described the GPRS as the most promising and attractive solution to mobile video wireless communication. The authors emphasize that GPRS technology provides access for mobile GSM communications and time-division multiple access (TDMA) users. In [135], the author stated that GPRS

fosters the migration toward third-generation (3G) networks. The 3G networks allow for the provision of Internet protocol data services for integrated voice and data applications [135]. The GPRS facilitation enables a variety of services to the mobile wireless subscriber. The authors of [134] categorized merits of GPRS mobile services into three types namely mobility, immediacy and localization. Thus, communication on the move and when needed can be offered to GPRS mobile subscribers.

Again, Patil et al. [136] referred UMTS (Universal Mobile Telecommunication System) as a 3G mobile wireless communications system. According to [127], the UMTS has far reaching implications for broadband services and mobile communications development. The UMTS could preserve the credibility of networks because it facilitates delivery of pictures, graphics, and video information. Different researchers have identified the implication of UMTS to video sharing. For instance, Tripathi et al. [121] identifies UMTS as a video data sharing medium that extend the capabilities of 2G, GSM/GPRS and Code Division Multiple Access (CDMA) technology. Consequently, UMTS and 2G standards have made possible access of portable video sharing with picture-phone functionality and Internet video server [67].

The currently deployed 4G network technology has transformed the world into mobility and networking era, in which almost all end-user communication devices operate on wireless networks. The 4G technology fits well into the 3D video communications, providing major bandwidth improvement and numerous new features that facilitate delivery of high-volume data. However, the deployment of 3D video will still face a challenge regarding bandwidth and computational capability of the wireless mobile equipment. Notwithstanding, the 3D video data volume at the receiver endpoint will be multiple of a single view of 2D system, and hence, the 3D video computational capability requirement will be high.

Unlike the 3G the 4G network is a key factor in improving the video communication over Internet networks [137]. According to [138] the goal of 4G wireless systems in broad coverage areas was to provide data service at 144kbps to 384kbps. These services include supplementing wireless access for multimedia services of mixed voice, video and data streams. Besides, the authors in [64] noted that IMT-2000 (International Mobile Telecommunications-2000), CDMA2000 from America, WCDMA from Europe and TD-SCDMA from China provide adequate wireless network for enforcement of cellular communication [48].

The QoS support is essential for multimedia multi-user sessions like video streaming services [16]. It is important to appreciate that when too many packets are in the network awaiting transmission, the 3G performance degrades in such a way that damages the QoS. This situation is referred by [22] as congestion. However, congestion should have no effect on the number of packets sent into the network that was within the capacity of the system. But, as traffic increases beyond the network capacity, the network gets congested which enhances the delay in transmission throughout the network. A study by [43] suggests that flow control is required to minimize congestion. This flow control technique increases delay and packet loss that are not the desirable QoS parameters. Singh et al. addressed congestion control in [139]. In this scheme, a new data user can be rejected, admitted as an active user or queued in a finite buffer at the base station (BS) depending on the status of the network. A pricing based congestion control approach is proposed by Hui et al. in [140]. The objective of this scheme is to maximize the effectiveness of wireless resources.

In [115], the performance of services of the widespread deployed WCDMA was investigated. The study include monitored web surfing over wireless networks and file transfer transmission. A look at the literature research on the suggested wireless cellular networks shows that all stakeholders in wireless network have different roles to play. The GSM, GPRS, UMTS, 4G and the future 5G have to play their roles of providing dynamic information access. Coulibaly et al., [141, 141] add that the lack of integration can lead to severe personalized video quality degradations. According to [142], the 4G networks can integrate several wireless network radio accesses and enhance QoS for fixed Internet service. This kind of integration combines multiple radio access interfaces and seamless roaming capabilities as the user move from one part of the world to another [143].

2.4 The 3D Video over Future Networks

The future networks (FNs) are networks that are beyond next generation network (NGN). With the future systems, we shall see person-to-person and person-to-group 3D video communication with acute high resolution. However, many challenges are facing the wireless application of the emerging future networks. These challenges cover all aspects of wireless system design. According to [143], the FNs are in the deployments phase state and expected to enjoy early realization around 2020 [14]. The future networks would enable people to use 3D video simply in everyday workflow. Xichun et al. [144] distinguishes 5G, 6G, and 7G as

the future networks that will provide services, capabilities and facilities far exceeding those achievable with existing technologies.

According to Cisco [145], the 5G network would in the future provide robust and high-quality performance wireless communication. The future 5G network will support 3D video call and a countless emerging variety of applications. Liu et al. [2], stated that the 5G will follow the footsteps of 4G and 3G, supported by existing networks such as IPv6, OFDM, UWB, MC-CDMA and Network-LMDS. Prof Rahim Tafazolli stated that "5G will be a dramatic overhaul and harmonization of the radio spectrum" [146]. That means the 5G deployment will be the moment for connecting future smart cities, remote health centres, future driverless cars and the Internet of Things (IoT). The IoT would allow people and machine-to-machine (M2M) to hook up and communicate anytime and anyplace. Misra et al. [59] gives the different perceptions of IoT. He opines that IoT are perceived by media experts as network that controlled remotely objects across existing communication network infrastructure. For industries, IoT operation with 5G network technology is an opportunity for integration of physical world through algorithm using computer systems.

The 5G handheld phones (see Figure 2.5) would offer improved efficiency and provide features for connectivity service between M2M [80]. This development means that a client can also connect their 5G technology smartphone with other communication devices such as Laptop to get broadband internet access. Singh et al., [139] described various aspects of 5G features to include a camera, video recording, large telephone memory, high dialing speed, audio player and much more we cannot begin to imagine.



Figure 2.5: Mobile Devices [141, 142]

The future networks architecture is designed to accommodate a broad range of mobile network requirements, especially bandwidth, latency, resilience, and coverage. Thus, another significant challenge is to provide end-to-end network and cloud infrastructure slices over the same physical infrastructure. A critical issue is how to protect a very delicate 3D video portion of multimedia against hostile multipath fading environments. To comply with narrowband channel requirements, 3D video needs to be highly encoded. High multi-view video compression would make the bitstream more vulnerable to transmission noise. According to Orange et al. [147], two concepts need to be considered to become a reality in future networks expected to be deployed by 2020/5. Firstly, mobility in populated area will constitute a problem to future. Secondly, various future networks subsystems and interfaces need to be inspired by modern operating system architectures, and software concepts.

2.5 Bit Errors and 3D Video Quality

Transmission of compressed 3D video signal is performed using electromagnetic radiation. Video signal like radio waves, x-ray, ultraviolet, and visible light belongs to the electromagnetic radiation family. Figure 2.6 shows classification radio frequency spectrum used for video transmission. Since inception, electromagnetic signal propagation through a wireless channel has been experiencing random fluctuations in time especially if there are noise or shape movement that can cause reflection and attenuation [63, 103, 148, 149]. One of the prime causes of poor video quality reception is error propagation originating from noise or interference during the wireless transmission. Noisy nature and bit-error-rate characterized wireless channels, and bursty errors affect compressed bitstream [51, 150-152].

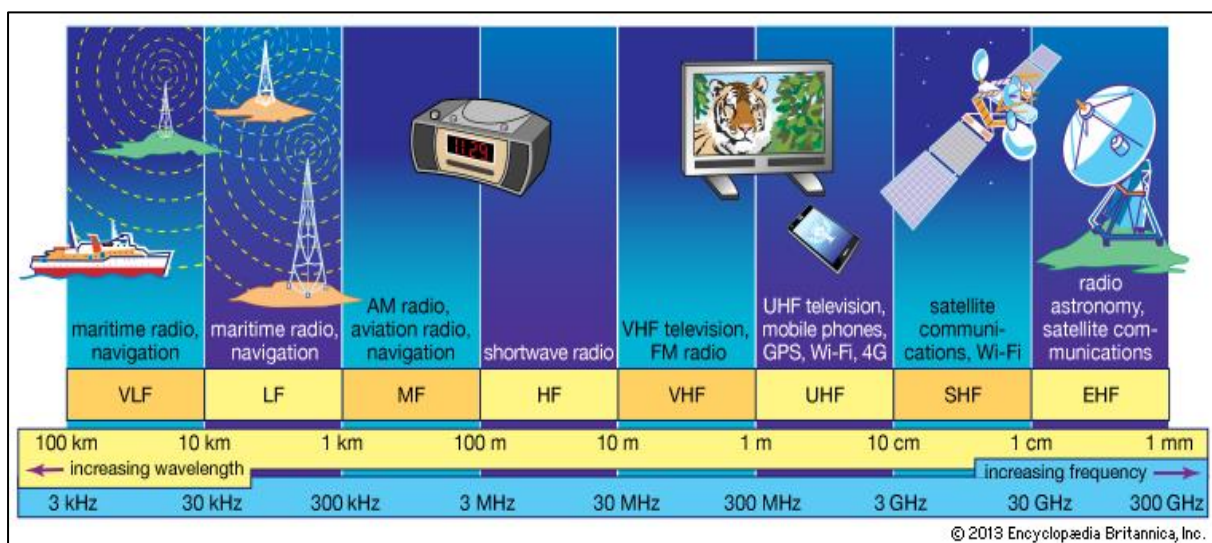


Figure 2.6: Classification of Radio Spectrum [112, 153]

Vetro et al. [20, 150, 154] maintain that when compressed bitstream is sent over a radio channel, bit errors due to multi-path effects, shadow and interference can corrupt the data. The authors also observed that a limited number of data channels leads to high throughput variations which introduce errors to compressed bitstream. The authors opine that random bit errors as a result of the imperfection of physical channel may result in bit inversion, insertion or deletion in the bitstream. Furthermore, a bit error in a frame can spread in time and space. Lack of synchronization occurs between the decoder and the encoder due to bit error [150, 155-158]. The synchronization risks are greater in multi-view video schemes because the errors propagate in time, space and among views [159]. The preceding has thrown more light on the concept of bit error; therefore, error detection is another idea that needs to be considered.

The source coding algorithm hardly detects a transmission error. Error detection is a decoder function typically performed on a block of data at the receiver end. Buchowiez et al. [160] stated that the decoder detects errors or decides to process what is assumed to be incorrect data. According to them, an erroneous bitstream can be decoded and displayed at the receiver. This display may have severed quality degradation. According to [20], a bit error in the channel is equivalent to a packet loss in the packet network. Thus, if a video decoder decides not to drop erroneous packets, the reconstructed information may experience annoying artifacts.

The foregoing shows that different writers have perceived bits and packet error in various ways although the different views are identical. It is clear from different views that packet losses are said to occur in packet networks such as ATM or the Internet [56, 161-163]. According to [164], short time system failure happens due to erasure errors in transmission systems and burst error (in storage). However, the effect of busty types of errors is much more destructive than packet loss due to the bit errors. Authors in [155, 165-167] observed that bit errors can be considered as packet losses at the decoder when the receiver could handle the introduced bit error,

In [168], the authors noted other indices such as size and location of the error in a frame as a factor that can cause synchronization failure between decoder and encoder. They observed that packet loss affecting a small size of a video frame can result in the loss of complete video frame(s) due to compression. Consequently, the decoder can conceal an error that occurs in a limited location. The authors in [169] argued that loss of many video frames may occur as a

result of burst error fashion in some networks. This bursty error may have different size and occupy a different location within a frame. Figure 2.7 show an example of the effect of busty errors on a selected Ballroom sequence. Kolker while supporting the view of Liang [170] opines that a better approach to dealing with busty error is by temporal frame interpolation. The figure shows severe quality degradation with bitrate loss of 1%, 2% and 5%.

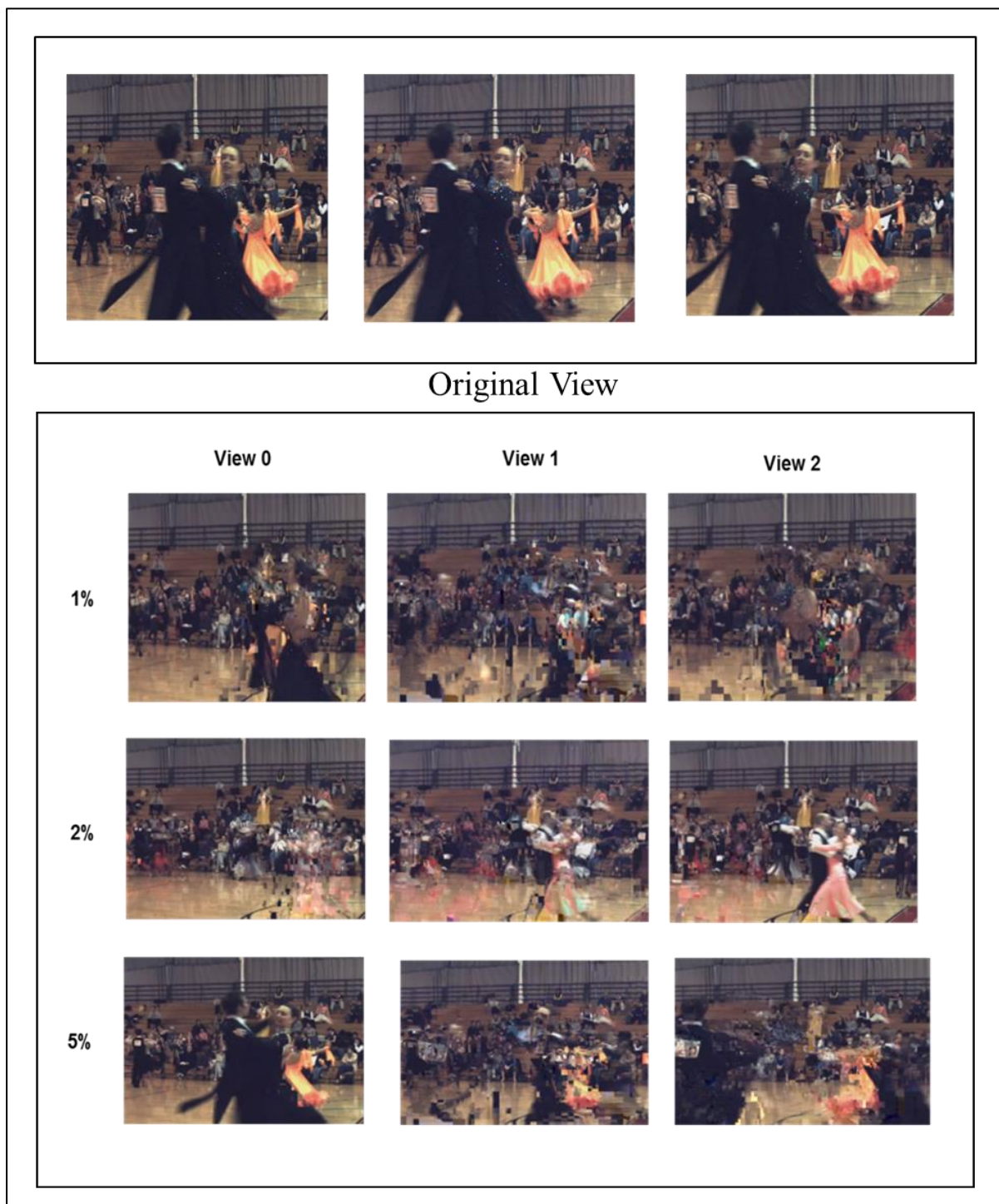


Figure 2.7: Effect of Busty Error

Another research, presented in [166] and [171], focuses on loss affecting the entire frame header. Bit errors occurring in the header data create the worst type of error damage compared to the kinds of errors mentioned above. When an error takes place in the header data, the decoder completely loses the track of the encoder and in turn discards a whole video frame.

2.6 3D video Acquisition and Display

A video data is acquired using a video camera, and multiple video cameras are employed for 3D video data acquisition [41]. According to [172-174], the John Logie Baird video camera is one of the earliest cameras used for a motion picture. Nowadays, mid-range of professional video cameras is exclusively used for television and other work (except movies). Multi-video cameras could be used for two modes. The first is for real-time coverage, where the cameras are employed for live television, security and industrial operations. Secondly, video cameras are applied for further processing especially in professional television production which combine a camera and a VCR or other recording device in one unit. Another area of the MVV camera is on Closed-Circuit Television (CCTV) for security, surveillance and monitoring purposes. Webcams are used to stream a live feed to a computer. Camera Phone- most mobile phones are incorporated with video cameras. Special camera system used on board a satellite , space probe, robotic, medical services etc. A multi-view video is typically obtained from a set of synchronized cameras, which are capturing the same scene. Figure 2.8 show an example of cameras used in multi-view system.

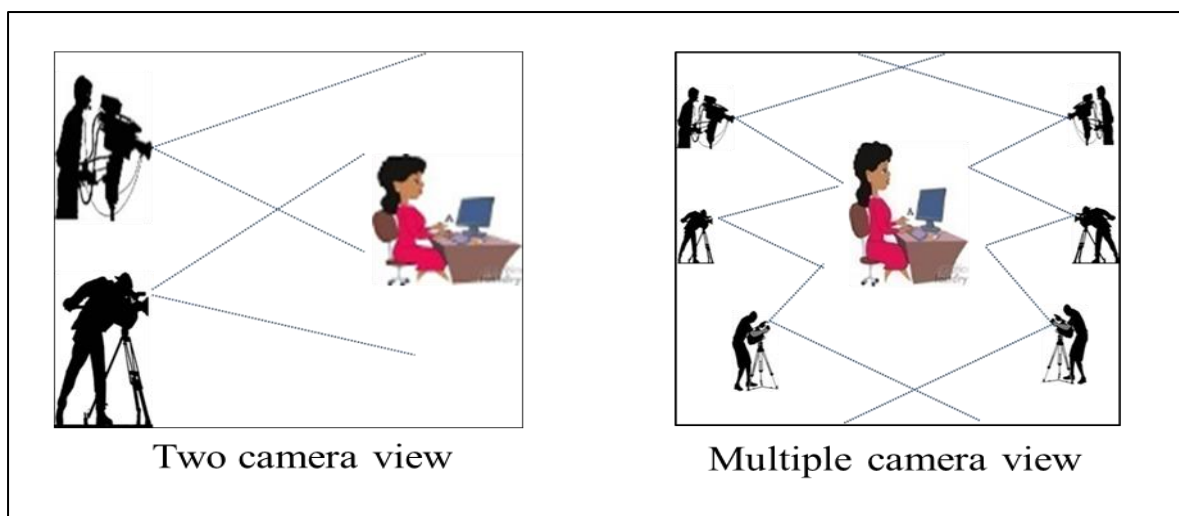


Figure 2.8: MVV Acquisition

Hashimoto et al. [10] stated that in its infancy, 3D video communication process was an ephemeral medium that was developed for a specific purpose. However, with the aid of stereo camera rigs, 3D video display was made public for commercial use. Although the potential applications of 3D video communication are many, there are several challenges to be overcome. One such challenge is that 3D video content requires specialized viewing glasses to be visualized. Figure 2.9 shows children enjoying watching 3D video with specialized viewing glasses. This has imposed some restrictions, such as viewing zones and the selected number of views [175-180]. These challenges need to be overcome before 3D video communication become widespread truly harnessed. Though there have been researches on the horizon that can allow 3D images to be viewed without special glasses, for now, they are not entirely developed.



Figure 2.9: Watching 3D Video with Glasses

Regarding availability and viewing development, the 1980s can be described as the golden ages of 3D video communication [149, 181]. However, people have to plan their schedules so that they could be available to watch 3D video shows at some designated 3D video cinema using 3D video glasses. Gradually, the viewership's of 3D video is now expanding since MVV can be made available on programmable video recorders, such as the digital video recorder, smartphones, etc [182], so people could watch programs their convenience.

Additionally, many television service providers offer a set of 3D video applications on demand to be viewed at any time. Similarly, both mobile phone networks and the Internet providers have fared too well in the aspect of delivering 3D video streams. There is already a fair amount of 3D Internet TV available, either live or as downloadable programs on YouTube [183]. Because YouTube is vast and uncharted, the authors can make no claims of comprehensiveness. The number of clips streamed on YouTube stretches to the sublime of about 1.2 billion videos a day, to enable people with Internet connection to watch a clip each day [184, 185].

Changnon et al. [185, 186] viewed that the next generation multimedia applications will be interactive 3D video that can be adapted to network conditions. This is because nowadays people now cast and share audio-visual information in a way that emulates a studio or a media production environment. Some of the 3D video display is shown in Figure 2.10. The 3D video representation, including holographic (light field), volumetric, geometric (3-D mesh models), and stereoscopic/ multi-view 3-D video are the most widely used at the moment.



Figure 2.10: 3D Video Display

2.7 Concept of Error Resilience

In this section, we review error resilience strategies. The first developed algorithms on error resilience sought to solve the requirement of transmitting 2D video over a wireless channel. Error resilience is conceptualized as anything that is done at the encoder stage to make compressed bitstream robust to transmission errors [17].

There are numerous types of error resilience algorithms employed to prevent compressed bitstream. Meyers et al. [17], stated that error resilience involves effecting some significant changes in the compressed bitstream to render the bitstream more robust to error prone networks. They also observed that in conveying video data from one point to another over wireless channels would require error resilience to suppress the effect of noise. The effect of noise to compress video is severe quality degradation at the receiver [187]. Consequently, error resilience encoding and decoding schemes is an important feature to suppress transmission errors.

According to [25, 154, 155, 157, 188-197], the most effective action to reduce the effect of transmission error is through retransmission of erroneous packets. However, the delay introduced by retransmission using Automatic Repeat Request (ARQ) may not be suitable for video delivery in a real-time application. Thus, a literature research reveals that error resilience techniques can be grouped into three categories. The categories are an encoder, decoder and feedback-based error resilience.

Figure 2.11 shows graphically how error resilience at the encoder can adversely reduce the effect of transmission error. However, encoder error resilience introduces extra redundancy bit. According to [149], error resilience at the encoder is less efficient compared to that conducted at the decoder. Thus, encoder based error resilience algorithms need to minimize introducing redundancy and computational complexity.

According to [169, 198] the decoder error concealment is used to hide the error. Kung et al. [199] stated that the I-frame error concealment method employs edge detection and directional interpolation to recover both smooth and edge areas efficiently. They also show that P-frame error concealment method can be used to error tracking and dynamic mode weighting. Thus, different decoder error resilience mode can conceals a pixel as a weighted sum of candidate pixels that are reconstructed. In [154, 200], feedback error resilience

employ a separate link to enable the encoder interact with the decoder and Adaptive Intra Refresh is an example of interactive error resilience.

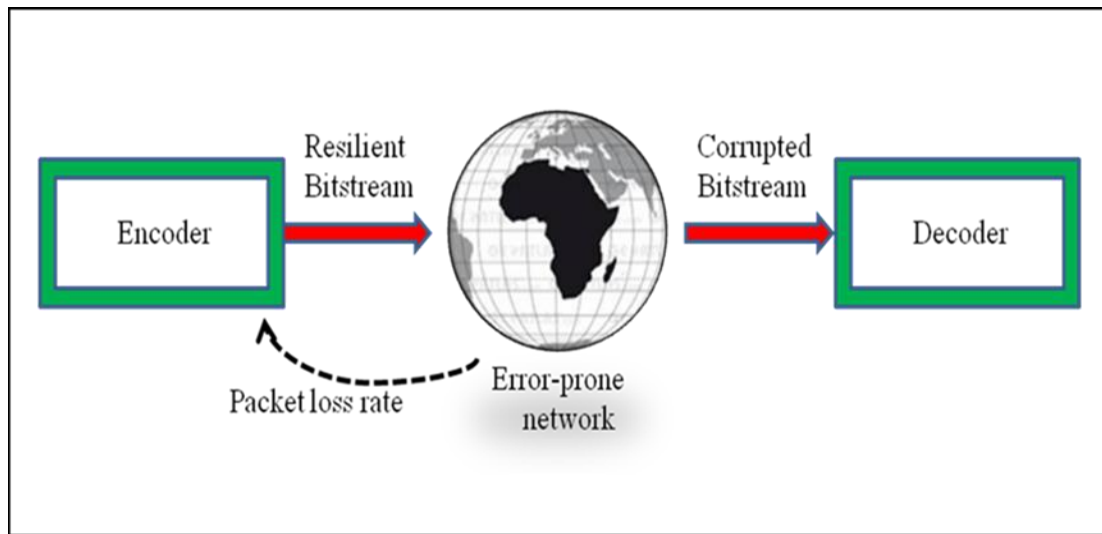


Figure 2.11: Error Resilience Method

2.7.1 Adaptive Intra Refresh

Cajote et al. [190] defines Adaptive Intra Refresh as error resilience tool used in MPEG-4 and H.264/AVC video coding standards to mitigate temporal error propagation. According to [201, 202], an initial Intra refresh method was established based on end-to-end rate-distortion model. This model takes into account several aspects of human vision such as intensity, colour, and orientation to perform Intra/inter mode decision.

Dogon et al. [31], discuss the potentials of using Intra-coded macroblock for efficient suppression of transmission error propagation. They pointed out that encoding the erroneous macroblock in the motion area using intra-coding mode is beneficial in recovering corrupted motion information quickly.

According to [166, 203-206], the authors pointed out that there are many Intra refresh methods used directly or indirectly to suppress propagation of errors. Chen et al. [191] on his part considers complete Intra refresh of a picture frame as the most efficient error resilience method. However, these techniques introduce delay. A literature research in [29, 30, 89, 166, 190, 201, 203, 205, 207-211] categories Intra refresh into many types. The categories are periodic Intra refresh, random Intra refresh and cyclic Intra refresh. Other End-to-End Rate Distortion Model (E2ERD model)-based Intra refresh, motion information-based Intra refresh and feedback-based refresh.

Jiang et al. [208] identify periodic insertion of intra-coded macroblocks as the primary means of AIR methods. They further state that E2ERD intra refresh method as a solid error resilience technique which mitigates spatiotemporal error propagation. The author in [212] indicated that for real time video streaming, periodic I-frames are used at a point of joining the broadcast stream. According to [28], reliable and efficient video communication over the error-prone network can be provided with GDR intra-refresh macroblocks. They confirmed that Intra refresh halt error propagation in a GOP. Thus, Intra refresh is needed for speedy passage and reception of video information transmitted over wireless networks.

The author of [213] stated that randomized insertion of intra-coded macroblock facilitated the exchange of video information. However, they observed that a random pattern might lead to duplication of intra-coded macroblocks in successive pictures. The author in [207] supported this assertion by stating that randomized insertion of the intra-coded macroblock is a substitute for a cyclic intra-coded line of macroblocks and other visually pleasing pattern.

Shu et al. [214] noted that feedback channel helped towards realizing full insertion of intra-coded macroblocks. Through the feedback channel, the decoder notifies the encoder about error corrupted macroblocks and the condition of the channel. Ali et al. [215] suggested that calculated macroblocks method can be employed in the absence of any feedback channel. In this process, each macroblock is examined, and the macroblocks that have a high motion activity are intra-coded.

2.7.2 Data Partitioning

As earlier stated, error resilience as a whole has different techniques, and these techniques have different effect and level of performance. However, all error resilience techniques are designed to overcome the error propagation in a compressed video bitstream. Error resilience data partitioning is a technique that supports unequal error protection during video transmission.

Zhang et al. [216, 217] consider data partitioning as a method of separating out information in a compressed bit-stream according to its overall contribution to video reconstruction. They also identify the potential of slice level data partition using Network Abstraction Layer units (NALUs) [216, 217]. In this approach, video data is partitioned into three partitions. These are partition A, B, and C. The partitioning is based on a decreasing level of sensitivity to errors. Figure 2.12 illustrates a data partitioning. The partitioning is meant to allow the most

sensitive data in slice A, for instance, to be given preferential treatment over data in other partitions.

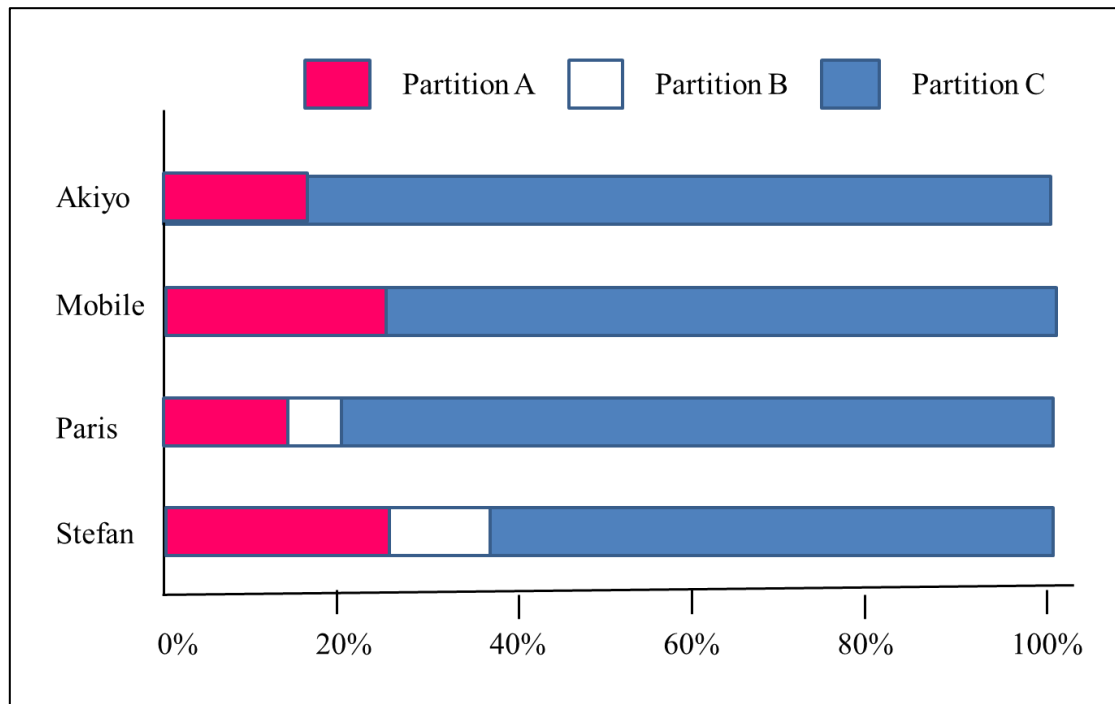


Figure 2.12: Data Partitioning into Partitions A, B, and C [196]

Ibrahim et al. [218] maintain that multi-layer data partitioning (MLDP) can produce another partitioning layer in the multi-view video bitstream for each frame. They also demonstrated that multi-layer data partitioning enhance the robustness of compressed bitstream against channel errors. Figure 2.13 shows the general architecture of multi-layer data partitioning.

Figure 2.14 shows MLDP that adopts a video slice restructures mechanism. Kumar et al. [219] demonstrated that partition A consists of highly sensitive information such as the data information of the header. This part is further subdivided into partition A1consists of view-1/frame-1 motion and header information. Likewise, frame -2/view-2 header and motion information are contained in partition A2.

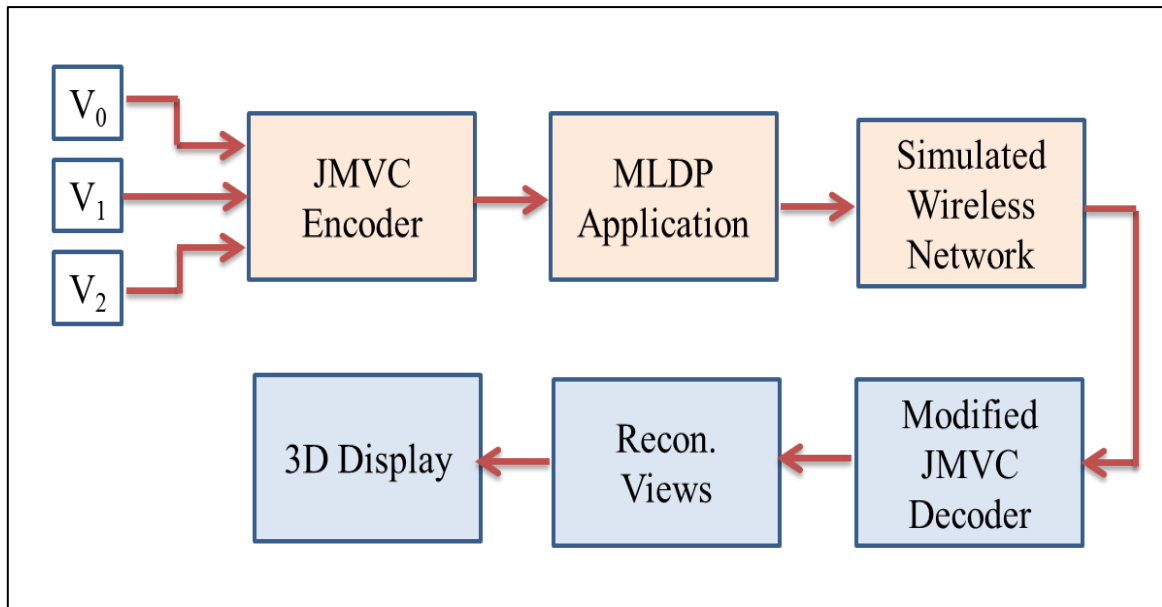


Figure 2.13: General Architecture of Data Partitioning [198]

Similarity, partition B is split into three sub-parts B0, B1 and B2. These sub-parts carry residual data information of intra-coded macroblocks. Finally, partition C is broken into C0, C1 and C2. Partition C0 is empty and the rest information about self-referencing as well as prediction frames.

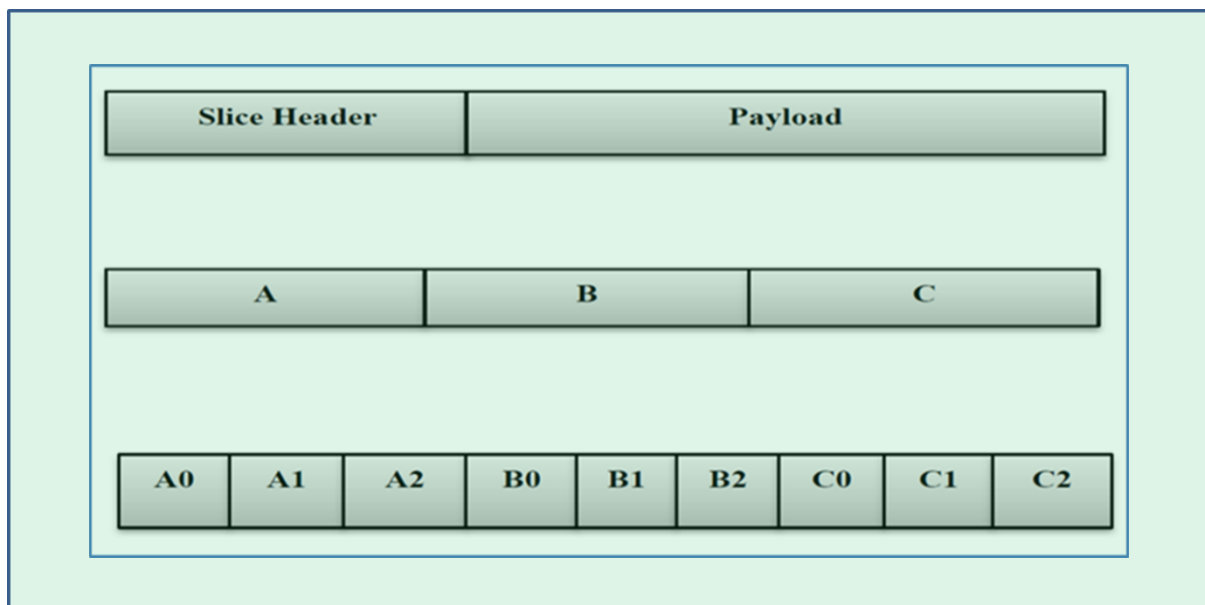


Figure 2.14: Multi-Layer Data Partitioning Restructures a Video Slice

Figure 2.15 shows the performance evaluation of the multi-layered data partitioning for ballroom sequence was better than the H.264 DP technique [219].

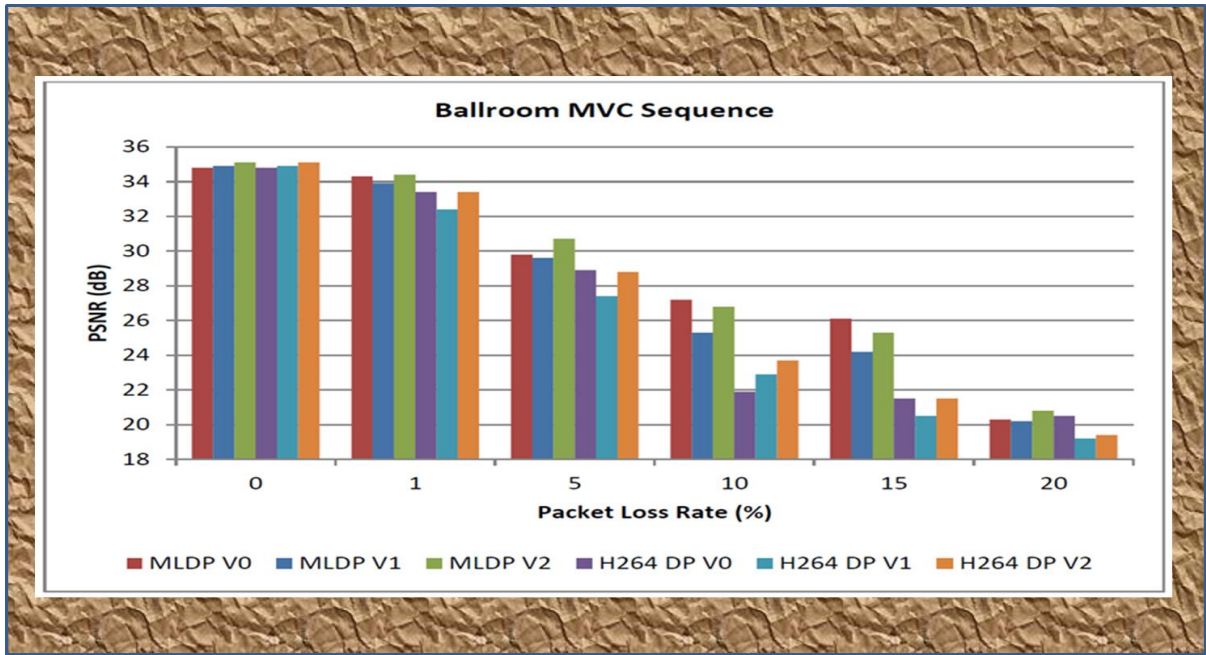


Figure 2.15: Performance Evaluation of the Multi-layered Data Partitioning [198]

2.7.3 Multiple Description Coding

Before conceptualizing Multiple Description Coding (MDC) techniques, it is necessary to define the term MDC. Norkin et al. [220] describe MDC as a coding method for communicating different source encoded description over an unreliable channel. Another fundamental concept of MDC is referred to as an error resilience technique use to combat errors by removing the base layer noise free assumption. Figure 2.16 shows a simple MDC scenario with three receivers and two channels. The reconstructed video is achieved by computing the outputs of decoder1, 0 and 2 (D1, D0 and D2).

Vaishampayan et al. [221] proposed the first MDC. Their coder used scalar quantizers and consists of JPEG coder extension. They observed that sending the descriptions from the source to the destination in different packets significantly enhances the quality of the decoded video. The authors in [222-229] apply orthogonally and other general transforms to develop MDC extension. They also identify that adding redundancy immediately after the stage of transform improves the efficiency of compressed bitstream transmitted over the lossy communication channel.

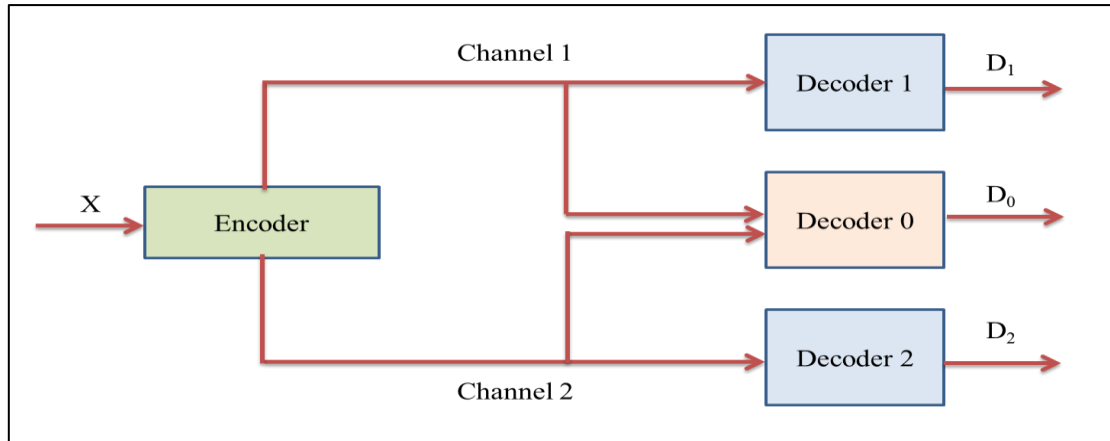


Figure 2.16: Simple MDC Framework [200]

2.7.4 Reversible Variable Length Coding

Takashima et al. [230] view variable length codes as importance error resilience technique that needs to be employed in order to get an efficient transmission of compressed video over lossy networks. Chung et al. [231] regarded RVLCs as emerging video coding standards that can effectively enhance error resilience capabilities in a wireless networks. Similarly, Jiangtao et al. [232] considers RVLCs as the process through which image coding in a JPEG are transmitted over noisy environment. They observed that RVLC offer significant improvements in PSNR during transmission over wireless channel.

Wen et al. [233] gives the different perception of a symmetric RVLC. They demonstrated that RVLC error resilience can be achieved by using palindrome codewords. The palindrome codes are identical to the reverse reading of the codeword itself. Table 2.1 illustrates the symmetric and asymmetric RVLCs constructed using Huffman codes. This is just an example of five systems, but the table could be extended to more symbols.

Table 2.1: Symmetric and Asymmetric RVLCs Huffaman Codes

Symbol	Pro	Huffman	Symmetric	Asymmetric
A	033	00	00	00
B	030	01	11	0
C	018	11	010	10
D	010	100	101	111
E	0.09	101	0110	11011
	I(C)	2.19	2.46	2.37

2.7.5 Flexible Macroblock Ordering

Lambert et al. [234] view Flexible macroblock ordering (FMO) as an error resilience technique that groups macroblocks and transmits over a noisy channel. It is also regarded as a flexible way to confine errors into a certain part of a frame thereby protecting the other part. Figure 2.17 shows different techniques of FMO, the objective behind these various methods is to avoid error accumulation by equally scattering all possible errors to the whole frame.

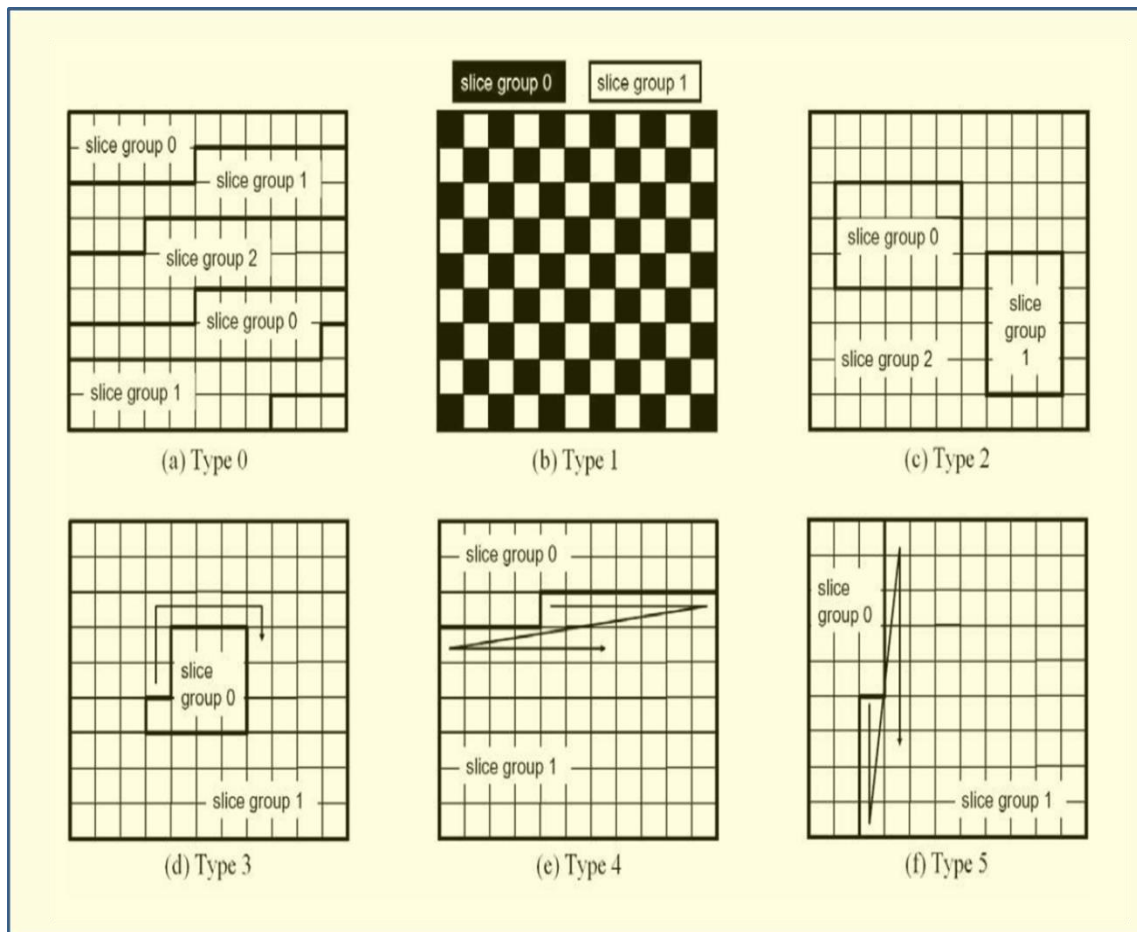


Figure 2.17: Different Techniques of FMO

Similarly, Baccichet et al. [235] consider FMO as source coding tool through which slices contain macroblocks are used to ensure interoperability. Their goal is to avoid packet error spreading through a frame in a GOP. Dhondt [236, 237] et al. gives the different perceptions of FMO instated of using a scattered pattern they combine nearby macroblocks together in one slice. This technique is useful in transmitting video data over lossy networks

The foregoing assertions imply that FMO apply a uniform working process for the different techniques. Cajote et al. [238] observed that FMO randomizes the data before transmission.

They further noted that if a packet is lost the errors are distributed arbitrarily over the frame. As the entire frame is not corrupted part of the frame can be used to conceal lost content.

2.7.6 Video Coding Standards

Advancement in multi-view video compression (MVC) technology has changed the way 3D video are transmitted over wireless networks and stored on a disc. According to Sadka [17], the emerging MVC techniques have led to the delivery of high-resolution 3D video content to a large number of users through wireless and wired Internet video broadcasting and streaming. Sagir et al. [90] stated that with the development a high number of 3D video coding standards, 3D video applications such as 3D video conferences, HD 3D TV broadcast, HD DVD storage and Blu-ray storage have been dramatically increased. In [239], the author stated that, the goal of MVC is to reduce the large video representation of the multi-view video sequence while preserving its quality. Thus, efficient reduction of multi-view video content is necessary to satisfy the different constraints imposed by decoding devices and transmission networks.

Gao et al, [214] viewed the MVC techniques as powerful tool that proves efficient reduction of raw multi-view video data to a level more practical for storage and transmission. They stated that uncompressed multi-view video contains a lot of redundancy which is a waste of bandwidth. Thus, either lossless or lossy compression is required. In lossless compression, the original pixel values are completely restored after decompression [240]. Lossy compression possesses loss of some data information hindering complete restoration of the data; it also results in the introduction of distortion artefacts in the video [220]. This distortion may or may not be visible, depending on the compression factor and the efficiency of the compression.

Le Gall et al. [241] and Merkle et al.[41] categorized video compression techniques into intra coding or inter coding. They stated that Intra coding exploits spatial redundancy in each frame in the video signal. Whereas inter coding exploits spatial and temporal redundancy between successive frames. The exploitation of these compression techniques has only been made possible through the development of the well-known ITU-T and ISO/IEC video coding standards that sufficiently reduce the size of video content for a particular application. Table2.2 presented the most common video compression standards quoted in literature.

Table 2.2; The current Image and Video Compression Standards

Standard	Application	Bit Rate
JPEG	Continuous-tone still-image compression	Variable
H.261	Video telephony and teleconferencing over ISDN	p x 64 kb/s
MPEG-1	Video on digital storage media (CD-ROM)	1.5 Mb/s
MPEG-2	Digital Television	2-20 Mb/s
H.263	Video telephony over PSTN	33.6-? kb/s
MPEG-4	Object-based coding and interactivity	Variable
JPEG-2000	Improved still image compression	Variable
H.264/MPEG-4	Improved video compression	10's to 100's kb/s
H.265/HEVC	Improved video compression	

The MPEG-4, H.264/AVC and H.265/HEVC standard are currently the most important ones in the areas of MVC [242-244]. The MVC is achieved by the exploitation of a temporal and spatial redundancy in the multi-view video sequence [220]. The MVC is based on the hybrid motion compensation and transforms coding algorithm like many of its predecessors. Figure 2.18 shows the evolution and development of the previous video coding standards. In fact, significant enhancements of the classic algorithm have been implemented in the H.264/AVC and H.265/HEVC standards to improve its coding efficiency [224]. The use of H.264/AVC and H.265/HEVC codec has greatly improved 3D video communicate in the modern concept of mobile wireless communication. For example, the H.265/HEVC, been the news video compression standard provides large bit-rate reductions (up to 50%) over its predecessor H.264/AVC [42, 188]

According to [246] intra and inter coding are the essential coordinate establish as part of the MVC strategy. The intra coding is exploited to reduce the overall bitrate of the spatial redundancy. Spatial redundancy is the redundancy between adjacent pixels in one frame. Each frame typically goes through three stages in intra coding; transformation, quantization and entropy coding as shown in Figure 2.19. Referring to the figure the source data frame images are now split on a section of 8 x 8 pixels called macroblocks. In the transformation stage, a frame is transformed into another domain using a wavelet transform like Karhunen-Loeve transform (KLT), discrete cosine transform (DCT) or some other kind of transform. In

the transformation domain, the pixels are represented by less correlated coefficients. As correlation essentially is redundant information, the transformation stage reduces the bandwidth of the signal without losing information [247]. Moreover, most of the energy in the frame is low frequent information and will be concentrated in a small subset of coefficients. Also, the eye is more sensitive to low frequencies than high frequencies [248].

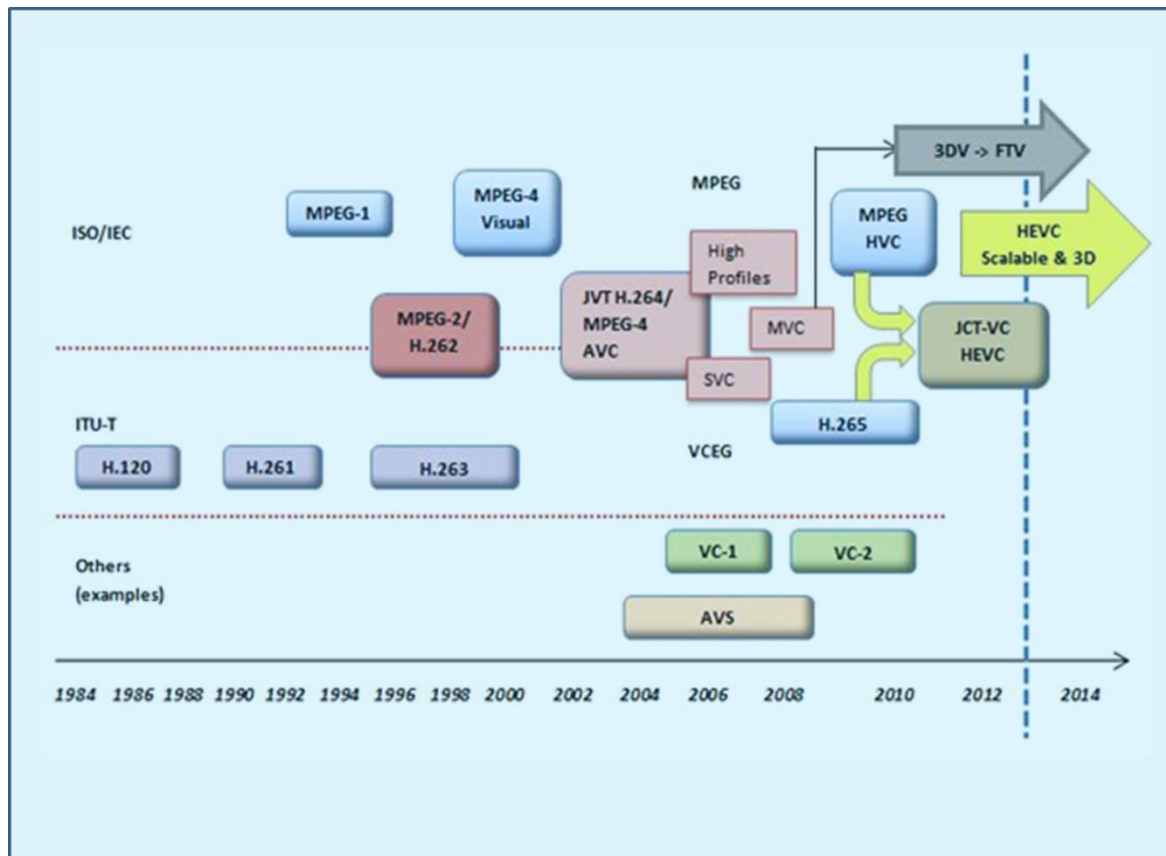


Figure 2.18: Development of video coding standards [245]

Following the transformation stage is the quantization stage. The precision of the coefficients is reduced, but in such a way that the frame is minimally degraded. Quantization preserves more of the precision in the low-frequency coefficients than the high-frequency coefficients [171]. In [16 and 220], the authors stated that quantization is a many-to-one process and has two important consequences: First, the raw video data can be compress even more for high efficiency. Second, the process is irreversible. Therefore, in the entropy stage, even more, redundancy is removed by exploiting some representation levels from the quantization stage. For example, normal levels can be 36 coded with fewer bits than less normal levels. This way, the overall bitrate is reduced. Huffman Coding and Arithmetic coding are the most common entropy coding techniques

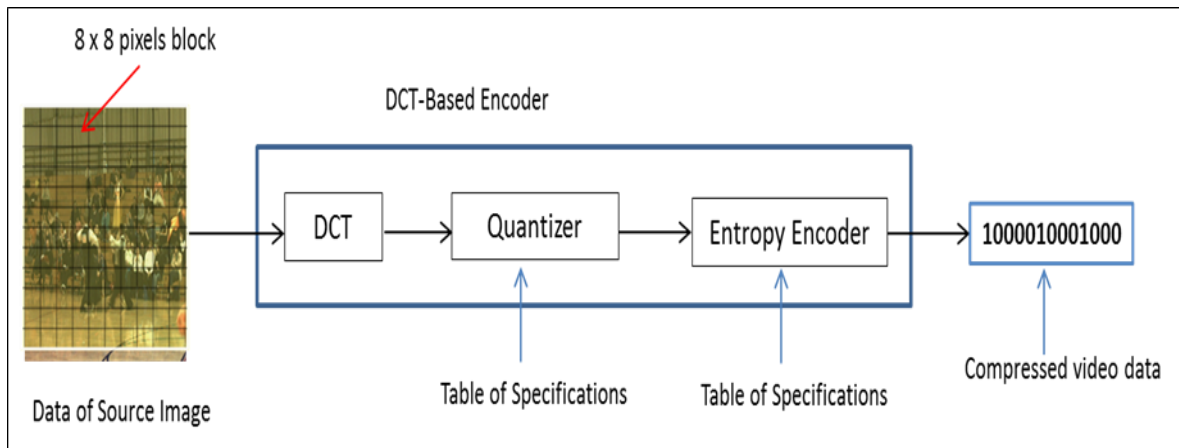


Figure 2.19: DCT based Spatial Compression

2.8 Concept of Video Transcoding

The conceptual clarification of the video transcoding is necessary for the reader to gain a better insight into the rationale behind this concept against its usage in different contexts. Linguistically the word ‘transcoding’ is Latin combining ‘trans’ which is a prefix that means "across, over, beyond” with ‘coding’ [102]. Technically it means convert, translate, transform, transfer, etc [17].

Aparicio et al. [249] view video transcoding as the technique used to convert a video file from one format to another in order, to make videos viewable on different platforms and devices. One transcoding scenario is encountered when the target device does not support the video format generated by the source. Another scenario consists of the situation whereby the video of origin and target destination have asymmetric capacity; hence, the rate of the original video stream will have to be reduced (transcoded) so that the receiver node can accommodate it. This definition discussed mainly video aspect of the transcoder. Through transcoder, a company logo can appropriately be inserted into compressed video bitstreams by TV telecasting industry for the purpose of advertising [250].

Panusopone et al. [251] consider logo insertion in transcoding as the process that requires different operation from the traditional transcoding scheme. They opine that the output of conventional video transcoder generates similar content of the input bit-stream. Therefore, there are uniform coding parameters between the input and output.

In the communication media technology, ‘video transcoding’ means the act of transforming a compressed video format into another compressed format [26]. Figure 2.20 shows that a video transcoder can change one or combination of bit-rate, frame rate, frame resolution, and coding syntax [252].

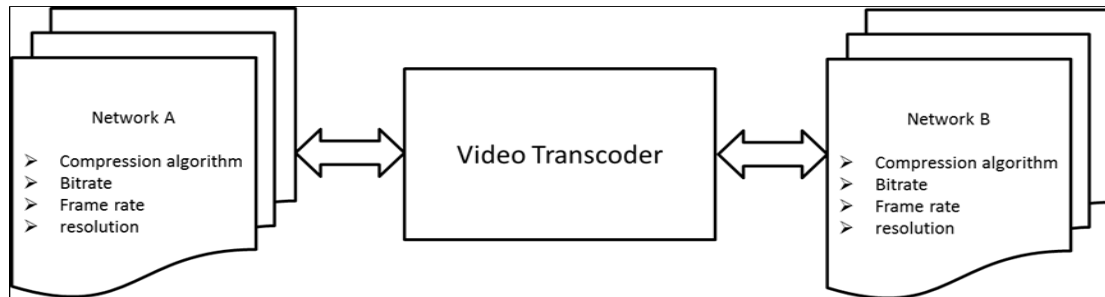


Figure 2.20: Video Transcoding

Keesman et al. [253] show that a cascaded transcoder which consists of decoder/encoder can be used to enhance interoperability between different communication system. They argued that cascaded transcoder employ motion vectors information re-used to execute the changes of input bitstream to the required target bitstream.

Xin et al. [32] give the different perceptions of video transcoding. They identify video transcoding as the physical process of converting compressed bitstream from one format to another format. Consequently, considering the foregone definitions, this thesis views video transcoding as the act of converting compressed bitstream of one standard onto the other without the need for any further decoding and re-encoding process.

Deneke et al. [254] noted that transcoder function by down scaling the bit-rate of the source to meet the bit-rate capability of the target. Lawan et al. [29] assert that for a transcoder to provide higher video quality at the receiver, certain conditions must be met. In using bit rate conversion, other factors may be included. For example, in a modest bitrate reduction, the same parameters of source input information can be reused without much compression efficiency loss. However, reduction of higher bit-rate may lead to partial loss of texture and image details owing to compression.

Grajek et al. [255] presented their work which specified issues related to spatial resolution transcoding generated from a block-based encoding paradigm. In this case, spatial resolution reduced multiple motions and Intra prediction modes to obtain fast video conversion. However, this process is not a straightforward task due to the potential inconsistent trend of

input methods. Hence, custom algorithms are required to perform this conversion without introducing a significant quality or speed penalty.

Winger et al. [256] presented an approach on how to integrate temporal resolution through transcoding. The first thing the author did was to define video transcoding as the temporal resolution reduction. They observed that to change the resolution of the video some of the frames need to be dropped. By the frame dropping, low resolution device can decode video encoded with the high-resolution frame. Thus, the performance was based on 2D videos only.

2.9 Summary

The literature reviewed reveals that wireless communication, error resilience and video transcoding are important factors for efficient 3D video communication. Different authors consider mobile 3D video communication as a process that involves video information conversion into electrical signal for transmission over wireless networks. The review mainly focusses on wireless communication particularly the existing 4G mobile networks.

Many authors and researchers have identifies the feature network platform such as 5G networks as suitable for 3D video communication. The full service of 5G network is expected around the year 2020. The 5G is designed to cater for mix bandwidth data path. The 5G networks can supply mobile internet to users at anywhere, anyhow and anytime. The future 5G mobile communications will exploit high frequency above 6 GHz. This could support a variety of new applications such as holographic projections and 3D medical imaging. The 5G mobile would deliver data at 10 to 50 Gbit/s speeds faster than today's average 4G download speed of 15 Mbit/s.

The literature review further reveals that error resilience techniques have serious implications for 3D video transport over unreliable wireless networks. Error resilience provision has become necessary within multimedia source coding. The error resilience is equally important in video transcoding. Robust video transcoding would enhance reliable and efficient interoperability of diverse communication equipment using different networking platforms.

Chapter 3

3D Video Quality Assessment

This chapter describes subjective quality assessment of 3D video encoded with H.264/AVC. After a brief introduction, Section 3.2 presents a review of related work. Technical issues on QoE versus QoS are discussed in Section 3.3. Statistical system analysis technique is presented in Section 3.4. Section 3.5 focuses on the research design. Section 3.6 discussed on data presentation. Section 3.7 highlights test of hypothesis. The chapter is summarized in Section 3.8.

3.1 Introduction

Nowadays, mobile 3D video communication is becoming widely available. The quality of mobile 3D video communication needs to be maintained at accepted ITU standard. To maintain an acceptable quality level, a reliable video quality evaluation test is necessary. Video quality can be evaluated using either subjective assessment or objective measurement. This chapter focuses on subjective video quality assessment of a transmitted multi-view video over error-free and noisy channels.

The subjective video quality evaluation of transmitted 3D video involves the use of human assessors. The assessors view a transmitted video clip and provide their opinion on the QoE. The human visual quality evaluation test is extended to pictures quality, perceived depth, and visual comfort. In the light of the foregoing, we carry out an experimental survey on subjective 3D video quality assessment. The survey involves male and female volunteers drawn from Brunel University London, UK and Nigerian Defence Academy, Kaduna. The participants are literate and semi-literate in the multimedia communication field, and therefore, they have the capacity to judge the QoE of transmitted video.

Figure 3.1 shows the setup of a two-way 3D video wireless communication link used in the conduct of the experiment. The setup process follows the ITU guidelines for subjective video quality test [55, 115]. The sending of the 3D video from the source to the display was done over wireless communication channel. First, compressed multi-view video is conveyed over error-free network and the content is viewed using 3D video glasses. Secondly, the same content is sent over the error-prone network and the same assessor watches the content. After that, the participants answer question from the bespoke questionnaires.

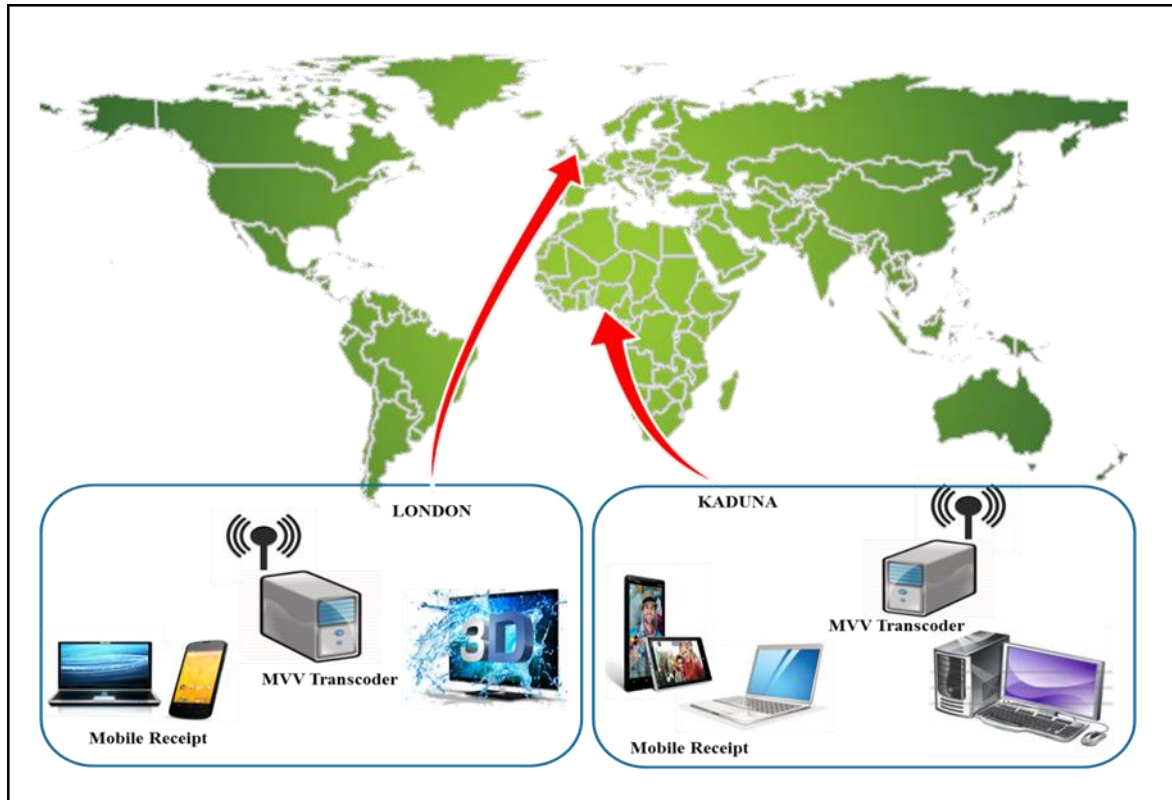


Figure 3.1: 3D videos communication link was set up in UK and Nigeria

The goal of this chapter, therefore, is to examine the results of the subjective video quality assessment survey of a 3D video communication over the wireless channel. The data that support the submission of the survey were obtained from primary and secondary sources. Information was also obtained from an interview conducted with some of the participants as well as the use of ITU reports.

3.2 Related Work

To some researchers, subjective video quality assessment is perceived as something abnormal, dysfunctional and therefore detestable. To others, subjective quality assessment is a fact of life and could be a precursor to positive changes. Different people are bound to experience one form of quality of experience (QoE) or the other. What makes a QoE of a video communication an ideal polity is the extent to which the subjective interests of the end-users are constructively managed. According to [54, 257] the most desirable way to evaluate video quality is through the conduct of subjective test using the standardized procedure.

Barkowsky et al. [258] noted that instinctive video quality assessment needs to rely on the subjective Mean Opinion Score (MOS) of the end-users. Umar et al. [259], compare methods of coding stereoscopic video for two image sequences. They used MOS for the subjective

video quality assessment to evaluate which of the compression methods produces the better result. Zeger et al. [260] observed that for comparison of stereo images, subjective assessment should employ the use of MOS of the reconstructed left and right images. Osberger et al. [261] state that, widely used, PSNR does not correlate well with viewer's opinion when assessing standard; therefore, subjective video quality assessment is the most appropriate. Wang et al. [262] consider video quality assessment using root mean square (RMS) and PSNR. They stated that these actions are simple calculations of pixel difference and provide no information about the end user's opinion on the video quality degradation. They demonstrated that PSNR alone cannot meaningfully be applied to measure perceptual distortion. Hence, subjective video quality evaluation is preferred QoE method.

3.3 QoS and QoE

Due to the increasing requirement for portable 3D video communication over wireless networks, the roles played by both QoS and QoE are important subject. Figure 3.2 presents the relationship between QoS and QoE in an end-to-end multi-view video communication system.

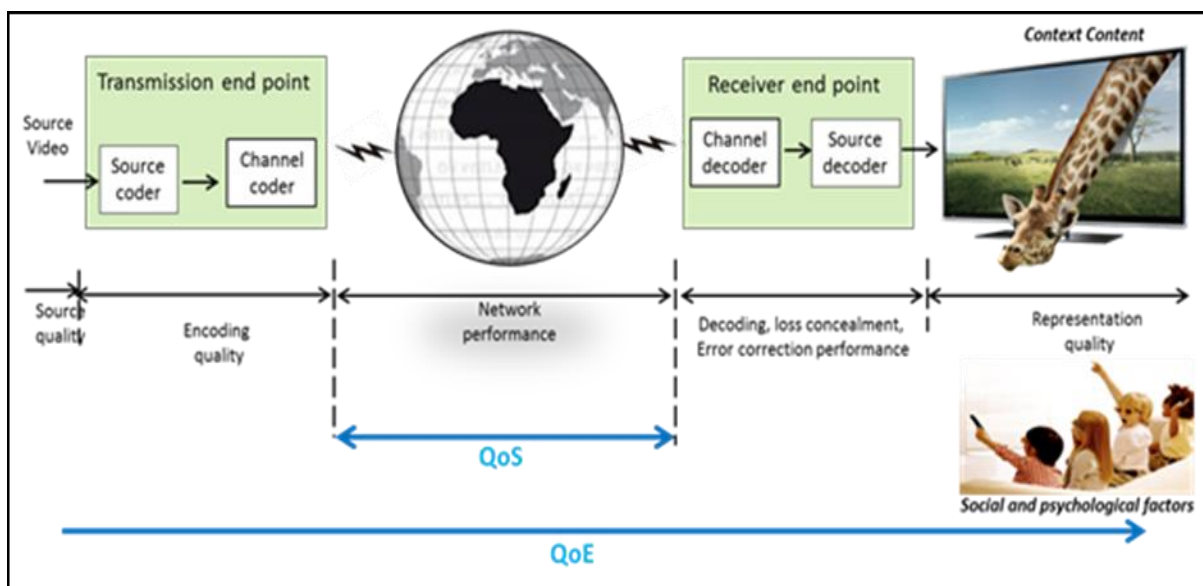


Figure 3.2: QoS versus QoE

3.3.1 Quality of Service

“Quality of service” (QoS) defines the ability of the network to provide a service at certain significance level. QoS is a standard set up by ITU [263, 264] that focus towards network performance between the transmitter and the receiver. Network impairment metrics such as,

throughput (bandwidth), packet loss, jitter and packet delay affects QoS. Thus, the QoS is the efficiency of network services providers to deliver reliable service. QoS is therefore considered to be the primary building block for reaching QoE.

3.3.2 Quality of Experience

“Quality of Experience” (QoE) is a broad term used to capture user’s experience or delight of the delivered service [265]. User experience is determined based on more than a just error-free video stream with high quality. Aspects like availability, economy, contextual information, user’s personality and state-of-mind also determine QoE. QoE can be considered as an end-user subjective feedback on the degree of delight of service.

3.3.3 Factors Affecting QoE

There are several factors that affect QoE. Figure 3.3 categorized these factors into two namely: technical and psychological factors. The technical factors that influence QoE include QoS, compression format representation, and the sensitivity of the devices software. The psychological factors that influence QoE include the way people feel during the time of watching the displayed video. The environmental impact and the expectation of end-user are all psychical issue that can affect the end-users delight.

To achieve a satisfactory level of 3D video communication and meet the end-user QoE expectations, the following need to be considered:

- a. 3D video communication should be properly engineered based on reliable network with sizing capacity and adequate security.
- b. Mobile 3D video compression algorithm should be robust with low latency.
- c. Adequate bandwidth usage to handle traffic and overlay peak video traffic.
- d. Use of QoS mechanism is fundamental in delivering high QoE.
- e. Constant monitoring and maintenance.

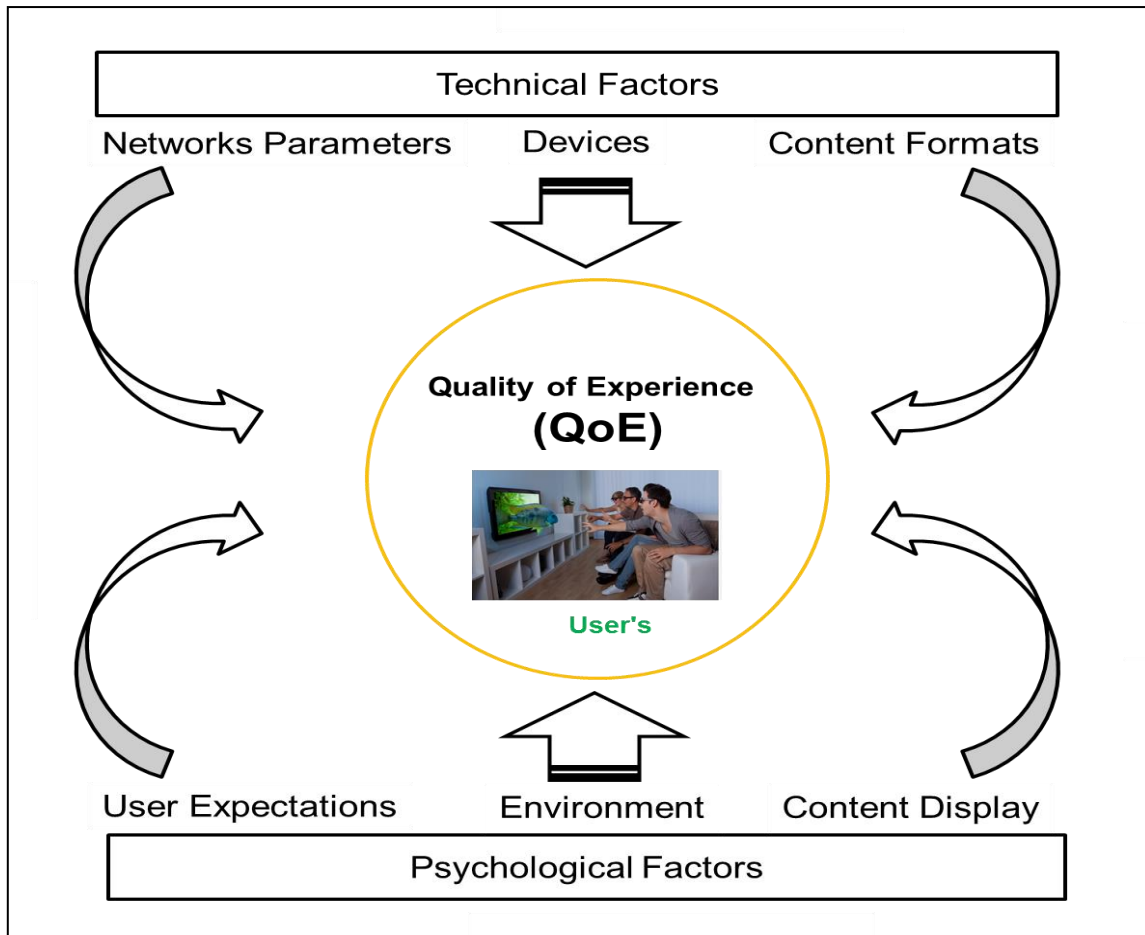


Figure 3.3: Factors Influencing QoE

3.4 Research Design

Systems Analysis Technique (SAT) is the research method adopted for analyzing the data collected from the survey conducted on QoE of a 3D video communication. This technique entails the application of both quantitative and systematic analysis in evaluating the QoE. According to Bozeman [266], the System Analysis Technique is simply the use of quantitative techniques in decision-making. In our context, SAT method is employed to evaluate the pictures quality, perceived depth, and visual comfort of the 3D video end-to-end communication. With the SAT method we relate the independent and dependent variables. Variables such as 3D video quality satisfaction, user experience, preferences, comfort, depth presences, etc. were obtained and compared.

3.4.1 Identification of Variables

There are two variables in this research. The variables are QoE and QoS. The independent variable is QoS while the dependent variable is QoE. This implies that QoS operations have a

relationship with total QoE. Consequently, changes in QoS influence the QoE operations. This study postulates the following null and alternative hypotheses.

H₀: QoE has total or partial influence by deviation from the natural properties of QoS.

H₁: QoE is influenced by the effect of QoS.

The hypothesis was tested using simple Chi-Square statistical tool. The Chi-Square inferential statistical tool is expressed mathematically as [267]:

$$X^2 = \frac{(O-E)^2}{E} \quad \dots\dots (3.1)$$

Where O is equal to the observed frequency, E means expected frequency. And X² is the Chi-Square.

3.4.2 Area of Survey

The areas of study were Brunel University, London and Nigerian Defence Academy, Kaduna. These two locations gave a fair geographic representation of different network impairments that influence QoS. Additionally, the end-user expectations of the QoE at the two different locations are not the same.

3.4.3 Sources of Data

The subjective quality assessment utilizes two sources of data for this research work, namely, primary sources and secondary sources. The questionnaires and oral interviews constitute primary sources. Secondary sources of data for this research include reports and bulletins from ITU-T Recommendation BT.500, EPFL image and video database. Others are MOS for video sequences, objective quality assessment (OQA), and PSNR. The ITU-R BT. 2021 recommendation for the evaluation of 3D-TVs prescribes that the assessor should be asked to score three factors separately, i.e. picture quality, perceived depth, and visual comfort.

3.4.4 Method of Data Collection

The method of data collection was based on phase. In the first phase, the participants were made to watch the display of the 3D video transmitted over perfect channel and error prone networks in relaxed environments using stereoscopic shutter glasses. The reconstructed 3D video was displayed on a laptop computer with a screen 1152 x 900 pixels resolution. Other

important parameters include 0.8 rad horizontal FOV, optical path length is 320 mm and 60 Hz operating frequency.

After watching the transmitted video clips, in the second phase the assessors rated the quality of the displayed videos by completing a questionnaire. The Questionnaires were used to obtain the data. The questionnaires were designed in a manner as to get realistic responses from the respondents. Each issue in the questionnaire has a 5-point Likert Scale namely, strongly agrees, agree, uncertain, disagree and strongly disagree. The Likert Scale is used to assess the strength/intensity of QoE. A sample of the survey questionnaire is at Appendix C.

Besides the use of the questionnaires as an instrument of data collection, the researcher also holds face to face oral and personal interviews. The interviews were structured to acquire more valued information from the wealth of experience of the participants. This discussion provided a more relax environment for validating relevant data. The empirical data obtained from the questionnaires was organized in tables. The data collected were sorted accord to the variables, and a table of MOS was developed using SPSS. The MOS data view and variable views are illustrated in Tables 3.1 and Table 3.2 respectively.

Table 3.1: Variables View of the MOS

	Name	Type	Width	Decimals	Label	Values	Missing	Columns	Align	Measure	Role
1	Id	Numeric	2	0	Group id	{2, 2}...	None	8	Right	Scale	Input
2	Group	Numeric	8	0	Group of Partici...	{1, Renmne...	None	8	Right	Nominal	Input
3	Gender	Numeric	2	0	Gender	{1, male}...	None	8	Right	Nominal	Input
4	Age	Numeric	2	0	Participant age	None	None	8	Right	Scale	Input
5	Videquality	Numeric	2	0	3D video quality	{1, poor}...	None	8	Right	Ordinal	Input
6	Comfort	Numeric	2	0	viewing comfort	{1, Not impo...	None	8	Right	Ordinal	Input
7	depth	Numeric	2	0	percieved depth	{1, No impa...	None	8	Right	Ordinal	Input
8	presence	Numeric	2	0	feel presence	{1, strongly ...	None	8	Right	Nominal	Input
9	problems	Numeric	2	0	problem associ...	{1, strongly ...	None	8	Right	Nominal	Input
10	perception	Numeric	2	0	human percepti...	{1, No}...	None	8	Right	Ordinal	Input
11	impact	Numeric	2	0	Input of eye do...	{1, Not impo...	None	8	Right	Ordinal	Input
12	user	Numeric	2	0	user views	{1, Not impo...	None	8	Right	Ordinal	Input
13	qoe	Numeric	2	0	qiality of experi...	{1, Not impo...	None	8	Right	Nominal	Input
14	preference	Numeric	2	0	3D or 2D	{1, 2D}...	None	8	Right	Nominal	Input
15	viewing	Numeric	8	0	type of viewing ...	{1, analgypi...	None	8	Right	Nominal	Input
16	satisfaction	Numeric	8	0	Leceel of satisfi...	None	None	10	Right	Scale	Input
17	ageing3	Numeric	5	0	age divided into...	{1, 15-20}...	None	10	Right	Ordinal	Input
18	influence	Numeric	8	0	influence of enc...	None	None	8	Right	Scale	Input
19											
20											
21											

Table 3.2: Data Set and Variable View in SPSS

	Id	Group	Gender	Age	Videoquality	Comfort	depth	presence	problems	perception	impact	user	ope	preference	viewing	satisfaction	ageing3
1	2	1	1	16	4	1	1	1	5	1	1	2	3	3	2	40	.
2	3	1	1	33	5	2	1	2	.	1	4	1	2	2	1	60	.
3	4	1	2	26	3	3	5	5	4	1	4	2	3	3	1	30	.
4	5	1	1	46	1	4	5	4	4	1	41	2	2	2	1	70	.
5	6	1	1	22	2	5	5	3	4	2	1	2	1	3	2	70	.
6	7	1	2	46	4	2	4	3	5	2	3	3	1	1	1	80	.
7	8	1	1	50	4	3	3	4	5	2	4	1	2	1	2	60	.
8	9	1	1	36	4	2	1	4	4	3	3	4	3	13	2	40	.
9	10	1	1	36	3	1	1	4	5	2	2	5	2	1	2	50	.
10	11	1	1	38	3	3	2	4	4	2	4	4	2	3	2	55	.
11	12	1	1	39	3	4	4	5	5	1	3	4	2	1	3	75	.
12	13	1	1	41	3	5	4	5	5	1	3	4	3	2	4	65	.
13	14	1	1	42	3	3	1	5	5	1	2	3	3	2	3	60	.
14	15	1	1	43	2	2	4	5	3	3	1	5	1	1	2	80	.
15	16	1	1	46	2	1	4	5	2	4	1	.	1	1	3	70	.
16	17	1	2	21	5	3	5	5	3	2	1	2	3	4	4	85	.
17	18	1	2	22	2	3	5	5	2	2	2	2	3	3	3	75	.
18	19	1	1	23	3	3	4	5	2	3	3	2	3	3	2	80	.
19	20	1	2	17	4	2	1	5	5	4	4	3	2	5	1	70	.
20	21	1	1	23	4	2	3	5	4	5	2	4	2	4	3	40	.
21	22	1	1	22	5	1	3	5	5	4	4	2	1	4	3	30	.
22	23	1	1	34	3	4	2	2	3	4	1	3	2	3	3	80	.
23	24	1	2	23	2	3	4	1	4	5	3	3	1	2	2	75	.
24	25	2	1	24	4	1	1	2	3	3	4	2	1	1	2	75	.
25	26	2	1	23	2	1	4	2	5	2	5	4	1	2	1	85	.
26	27	2	1	22	4	5	3	3	2	2	3	3	3	3	2	45	.
27	28	2	2	44	4	3	3	4	4	3	4	5	2	2	3	40	.

3.4.5 Validation

The tools used in this study are valid because they are the most acceptable medium of data collection in scientific research. The instrument was also considered appropriate for the study after several criticisms and corrections by experts.

The questionnaire gave the respondents the opportunity to make informed choices in their responses. Furthermore, the questions raised in the questionnaire were simple, clear and required direct answers. Consequently, the responses were spontaneous rather than mechanical.

The secondary data source also enabled the researcher to access information already generated by experts on the subject. However, some information obtained from oral interviews was considered less reliable because some respondents avoided making categorical statements that could be quoted.

3.4.6 Weakness of study

The major weakness of the research work was the inability of the researcher to cover more areas during the research work. The sampled population was restricted to Brunel University Uxbridge London and Nigerian Defence Academy, Kaduna environs. Though, this could not be said to have affected the validity of the research. Also, all the 280 assessors were adults, amounting to a return rate of about 89.3 percent. Additionally, out of the 240 persons randomly approached for interview or comments, only 121, representing about 50.4 percent, were accepted. In the light of this, the data presented are truly adequate sample for a research study of this nature. These weaknesses did not negate the outcome of the research.

Another major problem encountered during the study was that some of the participants were reserved. Many of them claimed not to be technically qualified to provide critical information that would have helped the high technical study of this nature. This is right bearing in mind that there were still technical issues that may require the opinion of experts in media communication. This, therefore, forced the researcher to conduct face to face interview and free complete some aspect of secondary data.

3.5 Data Presentation

This Section focuses on the presentation of collated data and the variables considered in the research. The data on the subjective opinion scores is analyzed for the purpose of answering the research questions and testing of the hypotheses. Numerical data obtained was presented in tables, while bar and pie charts were used to illustrate the data to enhance comprehension and interpretation. The data expressed in percentages was rounded off to the nearest whole number to simplify calculations. The population size was considered adequate for generalization.

3.5.1 Respondent's Profile - Distribution by Age Group

Table 3.3 shows the distribution of respondents by age group categorization. The age categories covered from 20 years to 80 years. Assessors above 80 years and below 17 years were not qualified for the test.

Table 3.3: Distribution of Respondents by Age Category

Serial	Age Group	No of Respondents	Percentage
1.	20-25	46	16
2.	26-30	58	21
3.	31-35	68	24
4.	36-40	19	7
5.	41-45	24	9
6.	46-50	14	5
7.	51-56	11	4
8.	60-65	22	8
9.	66-70	10	3
10.	71-80	6	2
11.	81 and above	2	1
	Total	280	100

Figure 3.4 shows the percentage distribution of respondents by age group categorization. The bar chart demonstrates that young people between 20-35 years participate in the survey. With people of 31-35 years age category topping with 24%.

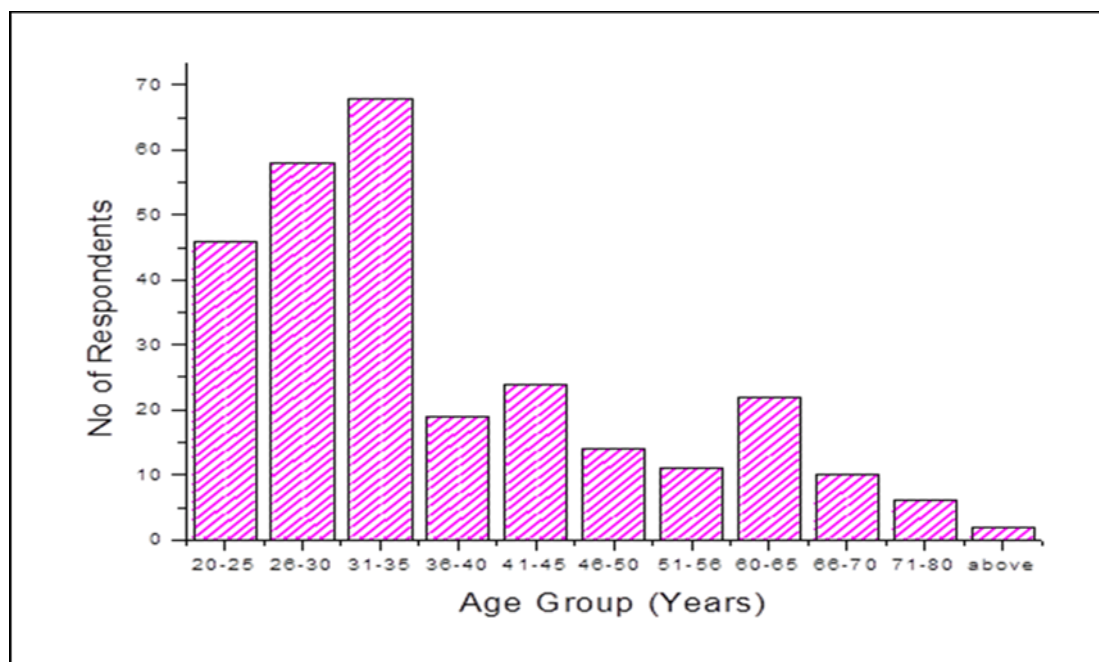


Figure 3.4: Bar Chart Showing Distribution of Respondents by Age Category

3.5.2 Distribution by Gender

Table 3.4 shows the distribution of the respondents by gender. Out of the 280 respondents, 110 were male while 170 were female.

Table 3.4: Gender Distribution of Respondents

Serial	Gender	Number of Respondents	Percentage
1.	Male	110	39
2.	Female	170	61
	Total	280	100

Figure 3.5 shows that 39% of the participants were male and 61% were female. This ratio is considered suitable for evaluating QoE of the transmitted 3D video over the wireless network.

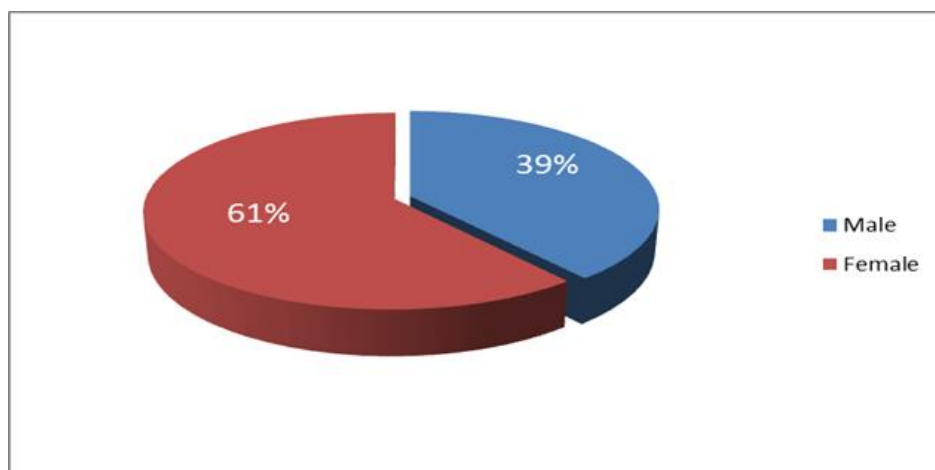


Figure 3.5: Pie chart showing distribution of respondents by gender

3.5.3 Distribution by Length of Watching Video

Table 3.5 shows the distribution of the respondents by length of watching video. From the Table, 81 out of 280 respondents have long time record of watching video by either watching TV or movie films. Only 42 people out of 280 assessors have five years record experience of watching video.

Table 3.5: Distribution of Respondents by Length of Watching Video

Serial	Length of Watching Video (Yrs)	No of Respondents	Percentage
1.	Below 5	42	15
2.	6-10	52	18
3.	11-15	60	21
4.	16-20	81	30
5.	21 and above	45	16
	Total	280	100

Graphically, Figure 3.6 shows that about 15 percent of the 280 participants have experience watched video for approximately five years. Similarly, 18 percent representing 45 respondents have experience of watched video from 6 to 10 years. Also, 60 of the interviewees have wealth of experience in watching video for up to 15 years while 81 have watched for 15 to 20 years. The remaining 21 respondents have watched for 21 years and above. From the differences in participant's length of watching a video, it is believed that the unique desires and needs of watching 3D video have been fairly covered.

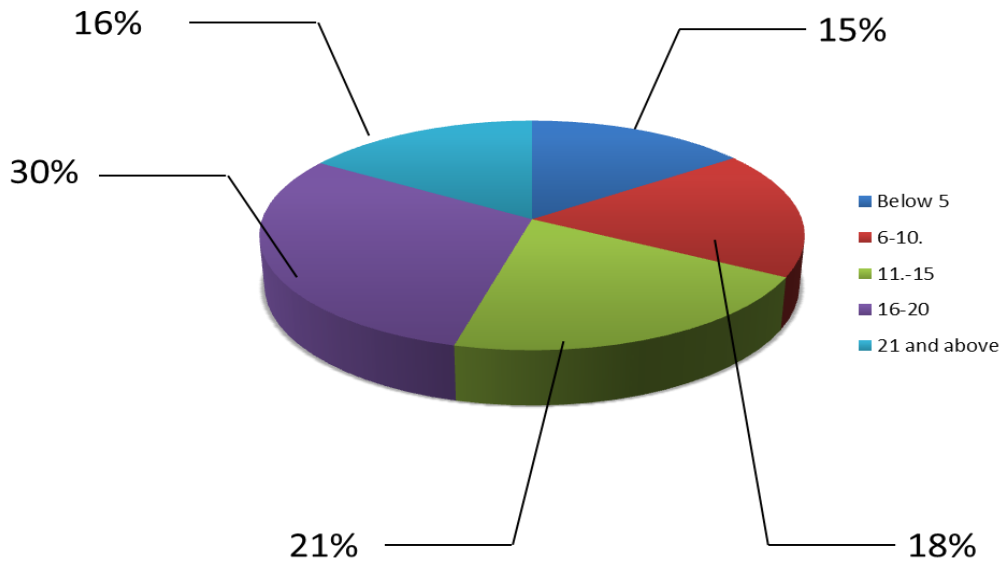


Figure 3.6: Distribution of Respondents by Length of Watching Video

3.5.4 Impact of QoS and QoE

One major question asked in the questionnaire tries to find out from the participants the impact of QoS and QoE. The questions included whether the quality of the 3D video clip received and watched is equitable? The response recorded indicates that the participants were satisfied with 3D video as compared to 2D video. Table 3.6 shows the response on how fair the participants received the transmitted 3D video.

Table 3.6: Response on Fairness of 3D video

Serial	Variable	No of Respondents	Percentage
1.	Strongly agree	56	20
2.	Agree	168	60
3.	Undecided	14	5
4.	Disagree	28	10
5.	Strongly Disagree	14	5
	Total	280	100

It was observed from Figure 3.7 that 60% agreed that the quality of the 3D video clip they watched was equitable while 10% disagreed. There was 5% that was undecided. From the statistics, it can be deduced that the 3D video clip transmitted was well reconstructed. Hence,

the algorithm for the MVV-AIR method adapted in delivering 3D video over wireless networks satisfied both the QoS and QoE requirements.

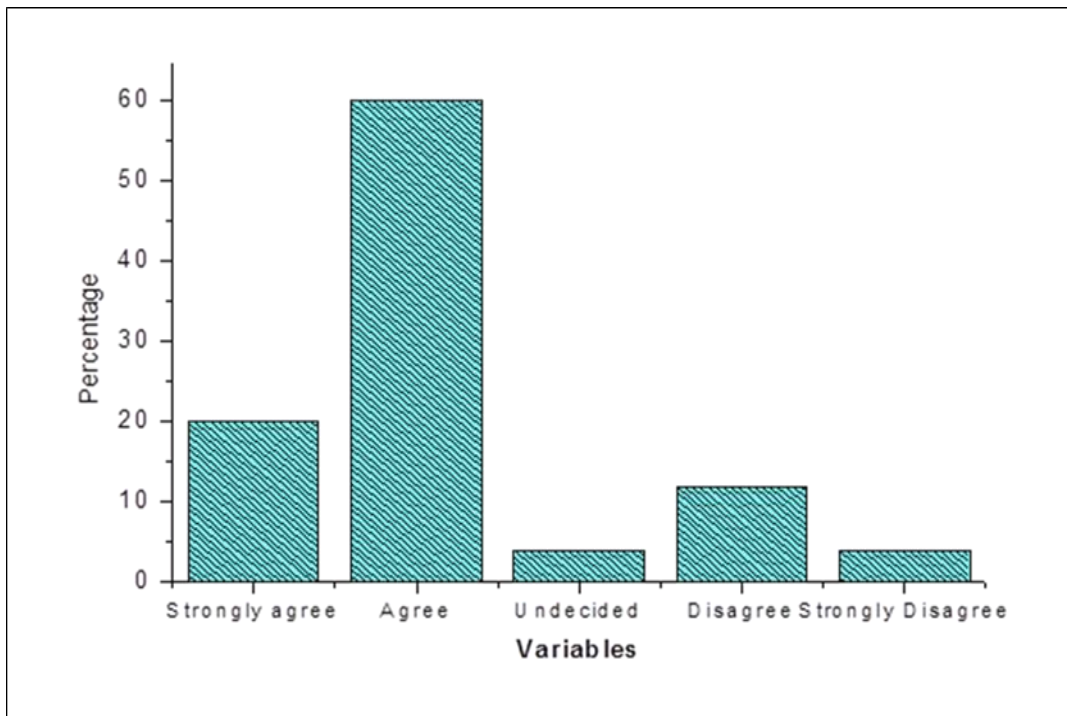


Figure 3.7: Response on 3D Video Receive is Equitable

On the issue of compressed 3D video transmission, it was observed from Figure 3.8, that only 40% agreed that they were satisfied with the quality of the compressed 3D video. Similarly, 45% responded otherwise. To this end, some of the respondents were interviewed to explain the reason of their disagreement. The responses from the majority of those interviewed focus on size of the display screen of laptop. They believe that the picture could have been clearer if displayed on a big screen with higher resolution.

Furthermore, some participants were not comfortable wearing glasses. However, we observed wearing of 3D glasses has no direct impact on the QoE. This finding correlate with that of Wur et al. [268] which demonstrate that wearing 3D glasses has no negative impact upon the perceived quality. Moreover, the majority of those who expressed dissatisfaction are not used to watching 3D video. QoE is heavily related to QoS. Even though QoS attempts to objectively measure service parameters such as packet loss and throughput, the QoS is in most time not related to viewers. Thus, subjective evaluation permits end users the latitude to expound their opinion on QoE.

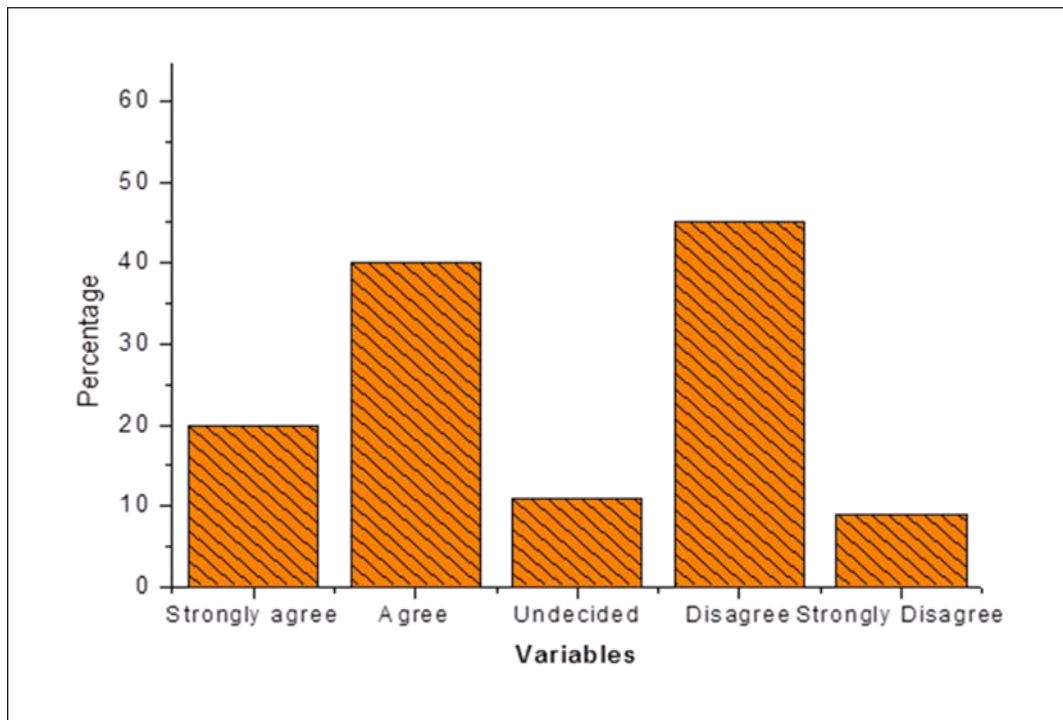


Figure 3.8: 3D Video Quality

3.5.5 Effect of Watching 3D Video with Glasses

Table 3.7 shows the data related to the number of participants who responded to the effects of watching 3D video with viewing glasses.

Table 3.7: Response on Wearing 3D Video Glasses

Serial	Variable	No of Respondents	Percentage
1.	Strongly agree	26	9
2.	Agree	56	20
3.	Undecided	20	7
4.	Disagree	164	59
5.	Strongly Disagree	14	5
	Total	280	100

From Figure 3.9, it could be seen that 59% responded negatively that there is no discomfort in using 3D glasses. Similarly, the interview conducted confirmed that there is no side effect after using the glasses. The findings corroborate Spector's explanation that 3D video glasses do not introduce discomfort; rather it assists in delivering a high quality 3D video experience to the viewer. Without the 3D video glasses, the 3D video effect would not be noticed rather

a double image would appear throughout the entire video time. The 3D video display device works by separating the light into two separate polarized filters. Each filter specifically designed to accommodate the vision capability of left and right eye. Without the glasses both images appear to both eyes and look blurry or like a double image (depending on the separation of those images at the time).

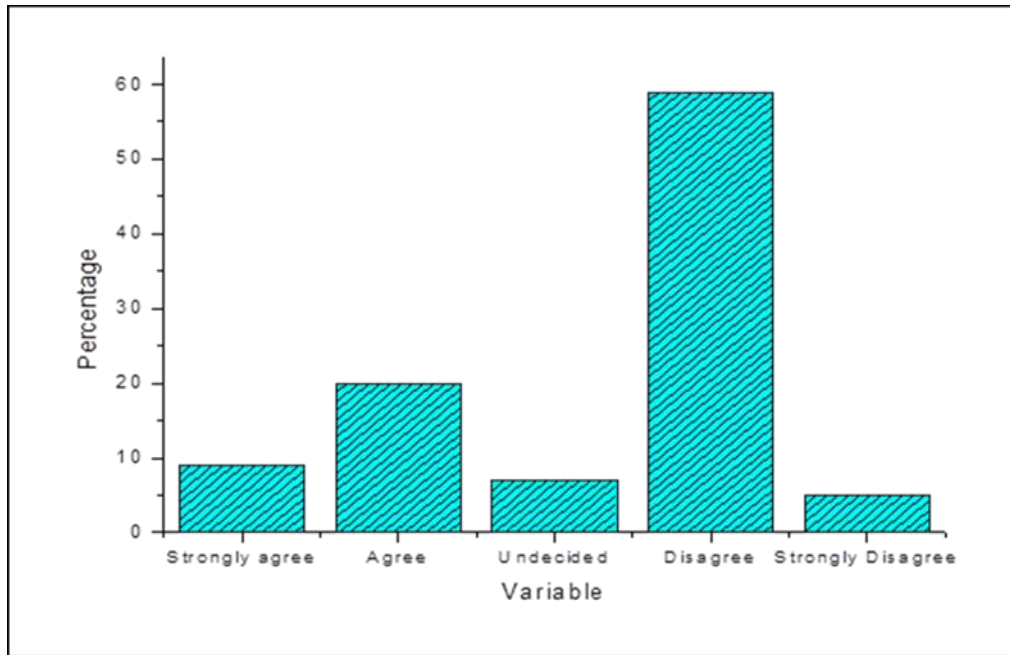


Figure 3.9: Effect of Watching 3D Video with Glasses

From the test we have carried out, there was no reported case of participant’s complaint about headaches during or after viewing the 3D video clip. Therefore, the problems of discomfort associated with wearing 3D viewing glasses can be attributed to other issues such as viewer’s position. For example, a viewer watching video may experience parallax and mismatch of the image particularly when there is frequent movement head. The resulting effect may cause discomfort to the viewer.

3.6 Test of Hypothesis

Test of hypothesis was carried out using the chi-square. The chi-square test is widely used in economics, cryptography, engineering, biology, and many other research areas. The chi-squared test is used to obtain the significant difference between the observed frequencies and the expected frequencies.

In our test, we consider the issue of testing the hypothesis H_0 that the QoS and QoE obey the uniform distribution. The problem is of interest is evaluating QoE of a transmitted multi-view video over noise-free environment and error-prone wireless network. Table 3.8 shows the result of data computed for male and female participants as relate to agreed and disagree response.

Table 3.8: Incident Table

Category of Participants	Agreed	Disagreed	Total
Male	132	68	200
Female	98	66	164
Total	230	134	364

Using the Chi square (X^2) statistical method.

H_0 – QoS satisfaction does not enhance QoE efficiency.

H_1 – QoS satisfaction enhances QoE efficiency.

The observed frequencies (O) are categorized into male and female. From the Incident Table 3.8 above, the observed frequencies for male that agreed with the statements in the questionnaire are 132 while those that disagreed are 68. Also, 98 female agreed with the statement while 66 disagreed. The expected frequencies (E) for each value are calculated and tabulated in Table 3.9. Table 3.10 presented the summary of the chi-square computation.

Table 3.9: Expected Frequency Calculation

Serial	Category of Respondents	Agreed	Disagreed	Total
1.	Male	$\frac{200 \times 230}{364} = 126.37$	$\frac{200 \times 134}{364} = 73.62$	
2.	Female	$\frac{164 \times 230}{364} = 103.62$	$\frac{164 \times 134}{364} = 60.37$	
	Total			

Table 3.10: Chi-Square Summary Table

Data Type	O	E	O-E	(O-E)²	$\frac{(O-E)^2}{E}$
Agreed Male	132	126.37	5.63	31.70	0.25
Disagreed Male	68	73.62	-5.62	31.58	0.42
Agreed Female	98	103.63	-5.63	31.70	0.31
Disagreed Female	66	60.37	5.63	31.70	0.53
	Total				1.51

From Table 3.10, the value for chi squared would be determined using alpha (α) as 0.05. To test the hypothesis the following Decision Rule is employed:

$$\begin{aligned} \text{Accept } H_0 & \text{ if } X^2 < 1.51 \\ \text{Reject } H_1 & \text{ if } X^2 > 1.51 \end{aligned}$$

The latitude and degree of freedom (df) [267] is calculated by multiplying the number of rows minus 1 by the number of columns minus 1. This expressed mathematically in equation (2) below.

$$(df) = (r - 1)(c - 1) : \dots\dots (3.2)$$

where: r = row and c = column.

Since our table is 2x2, it implies that $(df) = (2-1) \times (2-1) = 1 \times 1 = 1$. The $(\alpha) = 0.05$. is chosen to be the level of confidence. The testing statistics is carried out using the Chi square expression in equation (3). The summation of males and female participants that agree and disagree is computes.

$$\begin{aligned} X^2 &= \sum \frac{(Observed-Expected)^2}{Expected} \\ \text{Testing statistics: } X^2 &= \sum \frac{(O - E)^2}{E} \dots\dots (3.3) \end{aligned}$$

Where, 'O' represent observed values, 'E'- expected values.

$$X^2 = \sum \frac{(Observed - Expected)^2}{Expected}$$

$$X^2 = \sum \frac{(132 - 126.37)^2}{126.37} + \frac{(68 - 73.62)^2}{73.62} + \frac{(98 - 103.63)^2}{103.63} + \frac{(66 - 60.37)^2}{60.37}$$

$$X^2 = 0.25 + 0.42 + 0.31 + 0.53 = 1.51$$

From the Table 3-11 of critical values, the probability of a large value of x^2 for the critical chi-square statistic value for alpha 0.05 (95% confidence level) with 1 degree of freedom is 3.84.

Table 3-11: Percentage Points of the Chi-Square Distribution

Degrees of Freedom	Probability of a larger value of x^2								
	0.99	0.95	0.90	0.75	0.50	0.25	0.10	0.05	0.01
1	0.000	0.004	0.016	0.102	0.455	1.32	2.71	3.84	6.63
2	0.020	0.103	0.211	0.575	1.386	2.77	4.61	5.99	9.21
3	0.115	0.352	0.584	1.212	2.366	4.11	6.25	7.81	11.34
4	0.297	0.711	1.064	1.923	3.357	5.39	7.78	9.49	13.28
5	0.554	1.145	1.610	2.675	4.351	6.63	9.24	11.07	15.09
6	0.872	1.635	2.204	3.455	5.348	7.84	10.64	12.59	16.81
7	1.239	2.167	2.833	4.255	6.346	9.04	12.02	14.07	18.48
8	1.647	2.733	3.490	5.071	7.344	10.22	13.36	15.51	20.09
9	2.088	3.325	4.168	5.899	8.343	11.39	14.68	16.92	21.67
10	2.558	3.940	4.865	6.737	9.342	12.55	15.99	18.31	23.21
11	3.053	4.575	5.578	7.584	10.341	13.70	17.28	19.68	24.72
12	3.571	5.226	6.304	8.438	11.340	14.85	18.55	21.03	26.22
13	4.107	5.892	7.042	9.299	12.340	15.98	19.81	22.36	27.69
14	4.660	6.571	7.790	10.165	13.339	17.12	21.06	23.68	29.14
15	5.229	7.261	8.547	11.037	14.339	18.25	22.31	25.00	30.58
16	5.812	7.962	9.312	11.912	15.338	19.37	23.54	26.30	32.00
17	6.408	8.672	10.085	12.792	16.338	20.49	24.77	27.59	33.41
18	7.015	9.390	10.865	13.675	17.338	21.60	25.99	28.87	34.80
19	7.633	10.117	11.651	14.562	18.338	22.72	27.20	30.14	36.19
20	8.260	10.851	12.443	15.452	19.337	23.83	28.41	31.41	37.57
22	9.542	12.338	14.041	17.240	21.337	26.04	30.81	33.92	40.29
24	10.856	13.848	15.659	19.037	23.337	28.24	33.20	36.42	42.98
26	12.198	15.379	17.292	20.843	25.336	30.43	35.56	38.89	45.64
28	13.565	16.928	18.939	22.657	27.336	32.62	37.92	41.34	48.28
30	14.953	18.493	20.599	24.478	29.336	34.80	40.26	43.77	50.89
40	22.164	26.509	29.051	33.660	39.335	45.62	51.80	55.76	63.69
50	27.707	34.764	37.689	42.942	49.335	56.33	63.17	67.50	76.15
60	37.485	43.188	46.459	52.294	59.335	66.98	74.40	79.08	88.38

Decision:

Since Chi-squared (X^2) > 1.51

Therefore, H_0 is rejected and H_1 is accepted.

This implies that there is a difference between the performance of video transmission with enhanced QoS and those who are not control and monitored. Thus, enhanced QoS improves QoE efficiency.

3.7 Summary

This chapter has presented a subjective quality assessment method to appraise the human perception on transmitted 3D video with regards to QoS and QoE. The study used qualitative subjective test through participatory observation of 3D video. The research involved an evaluation and analysis of data collated on the quality of reconstructed multi-view video transmitted over wireless channels. A total of 280 respondents were made to watch 3D video clip and complete questionnaires. The study population was made up of 110 male and 170 female. It was discovered that most participant's response correlated strongly with the overall perception that QoS significantly affects QoE. The data was collected from both primary and secondary sources using questionnaires, interview and analysis of document. Data were obtained from review of documents, questionnaires and interview of participants. A SPSS data profoma was used to collate data on quality of 3D video transmitted over wireless network. Chi-square method of analysis was used to test the significance or otherwise of the hypothesis. The experiment for validation of the collated data was presentation based on ITU-R recommendation. The data obtained is then used to answer the research question and testing of the hypotheses. The statistical results demonstrated the correlation of 3D video with human perception across contents. We used Systems Analysis Technique to validate the MOS generated from the Brunel University London UK and Nigerian Defence Academy, Kaduna, Nigeria. One major limitation is our inability to use structural similarity (SSIM) index to predict the perceived 3D video picture quality.

Chapter 4

Adaptive Intra Refresh

This chapter describes Adaptive Intra Refresh (AIR) error resilience compression technique for 3D video transmission over wireless networks that we have developed. We start in Section 4.1 with a brief introduction. Section 4.2 presents a review of H.264/AVC video coding. Section 4.3 examines the impact of transmission error propagation on the compressed 3D video bitstream. Then we proceed in Section 4.4 to describe how to generate adaptive intra refresh map. Section 4.5 demonstrates the periodic insertion of Intra-coded cyclic line macroblocks. Section 4.6 presents error detection method. Section 4.7 covers experiments and discussions. Finally, Section 4.8 summarizes the chapter.

4.1 Introduction

The use of Internet and mobile wireless communication has affected the daily life of people worldwide. Cisco has asserted that five billion people employ mobile video communication technologies for their everyday activities [74]. The current wireless networks technologies usher in growth for multi-view video content to mobile devices. However, effects noise has bedevilled transmission of multi-view video over the noisy channel. The errors due to noise on the compressed 3D video bitstream severely degrade perceptual video quality at the receiver. Therefore, a guaranteed QoS is required for the successful mobile 3D video communication systems. In the light of this, to achieve a robust and resilient 3D video transmission over wireless network error control strategy is necessary.

Error resilience mechanism is one of the error control strategies that can make compressed bitstream more robust to a transmission noise. Figure 4.1 illustrates error resilient 3D video communication system. The diagram presents a breakdown of the journey for raw multi-view video from the source to destination. The raw video data is compressed by error resilient 3D video encoder in order to remove redundancy and facilitate easy transport of the bitstream through the limited bandwidth. Although error resilient coding helped in making the bitstream more resilient to a transmission error, it is observed that predictive compression is the cause of spatiotemporal error propagation. This is because the removed data creates a vacancy place within the bitstream which bits and burst channel errors easily occupied.

Consequently, Adaptive Intra Refresh (AIR) coding technique is required in the encoder to make coded bitstream resist transmission network error.

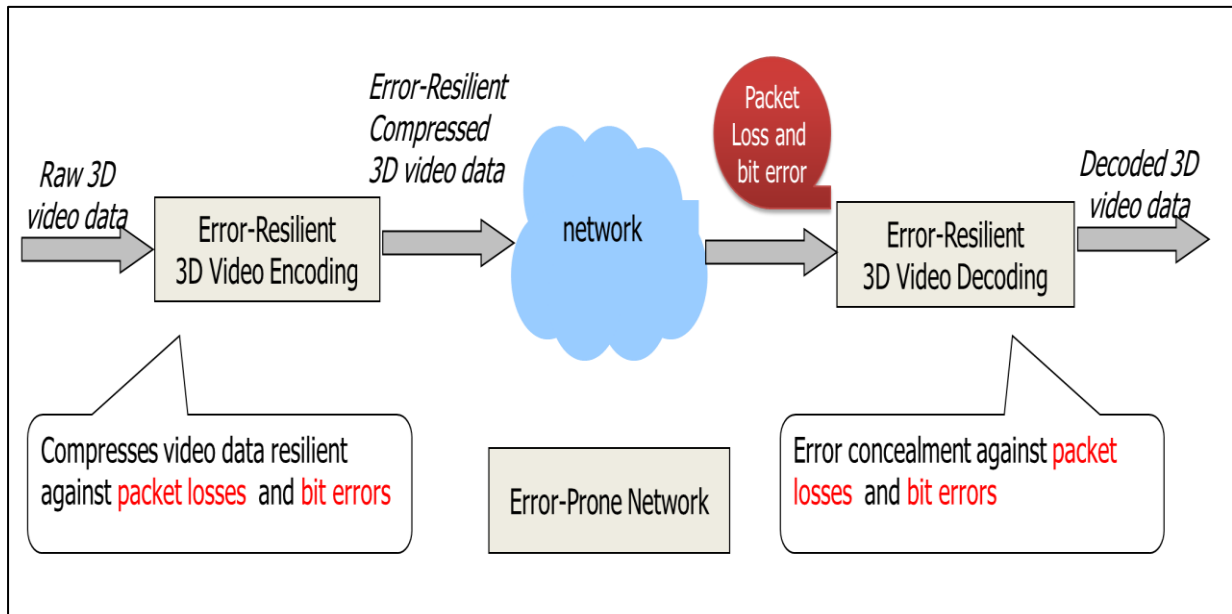


Figure 4.1: Error resilient 3D video communication system

The AIR error resilience process is an interactive error resilience mechanism which is supported by a feedback channel that connects the encoder with the decoder. Through the feedback channel, the encoder collects information of the channel condition. The keynote of the AIR process is the generation of an Intra refresh map, which is achieved by using the database obtained on the channel condition and the variations of active macroblocks. The generated refresh map table allows direct periodic insertion of Intra-coded macroblocks into a group of pictures (GOP). As motion activities and changes in channel condition increase, the generated refresh map table is instantly updated. This chapter therefore, briefly describes the AIR error resilience process and presents the simulation results of the developed MVV-AIR algorithm. It is expected that the MVV-AIR error resilience algorithm will enhance 3D video communication over a noisy channel.

4.2 Overview of AIR Error Resilience

Some video compression standards exploit error resilience tools to enhance the robustness of the compressed bitstream. In the H.264/AVC standard, error resilience refers to mechanisms in the encoder used to boost the capability of the compressed bitstream to repel channel errors. In the encoder, the error resilience tool is mainly found in the video coding layer (VCL)

[269]. Figure 4.2 illustrates various macroblock-level error resilience tools introduced to improve transmission of compressed video over wireless communication channels. The diagram also shows different types of Intra refresh error resilience at macroblock levels. In this research, we consider the interactive cyclic multi-view video Adaptive Intra Refresh (MVV-AIR) error control scheme.

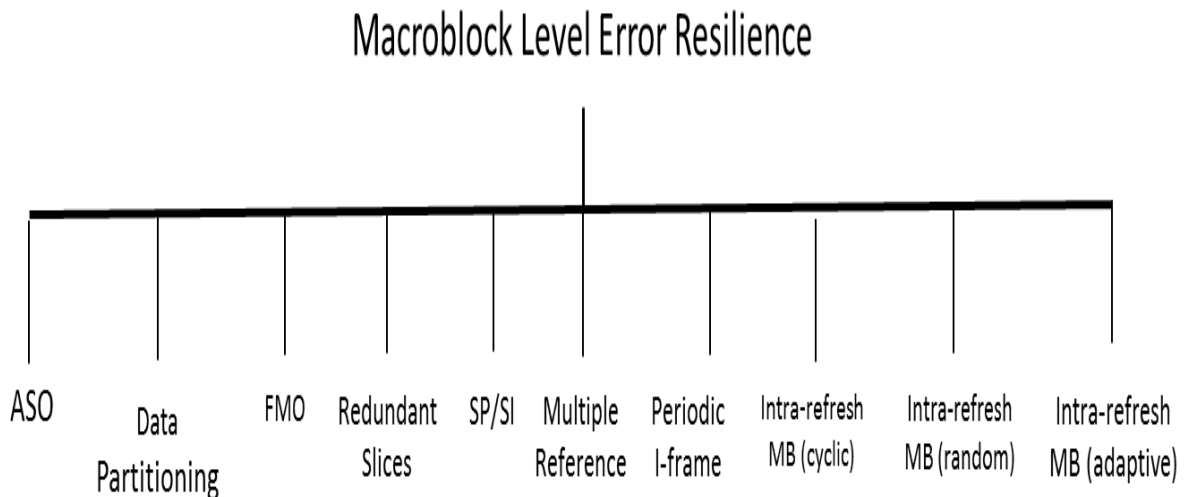


Figure 4.2: Some Macroblock-Level Error Resilience

Most of this macroblock error resilience has been discussed in chapter two therefore brief highlight is provided for selected few. The cyclic MVV-AIR algorithm is an interactive error resilience technique which uses the feedback channel technique to link decoder with the encoder. The decoder via the feedback link informs the encoder about the channel condition and the number of macroblocks that are corrupted by errors. With this information, the encoder updates the established MVV-AIR refresh map and inserts Intra-coded macroblocks for the subsequent transmission.

According to [270, 271] arbitrary slice ordering (ASO) is an efficient macroblock level error resilience that eliminate decoding delay. Wiegand et al. [272] stated that ASO allows the decoding order of slices independently of the other slice of the picture. Vetro et al [50] urged that redundant slices provide spatially distinct resynchronization points within the video data for a single frame. They further observed that slice reduction is achieved by introducing a slice header, which contains syntactical and semantical resynchronization information.

4.3 H.264/AVC Video Coding

H.264/AVC is a powerful video coding standard that finds a broad range of applications in today's wireless communication system. The use of H.264/AVC is apparent in multi-view video communication. A good example of this use is found in the broadcast and streaming of 3D video. The H.264/AVC encoder offers a unique combination of two layer application. These layer applications are the video coding layer (VCL) and network abstraction layer (NAL). Figure 4.3 illustrates the two core compression layer features in both encoder and decoder [36]. The VCL represents the video content while the NAL contain vital information such as header data. Of particular importance is the data header information which is used to link various types of networks.

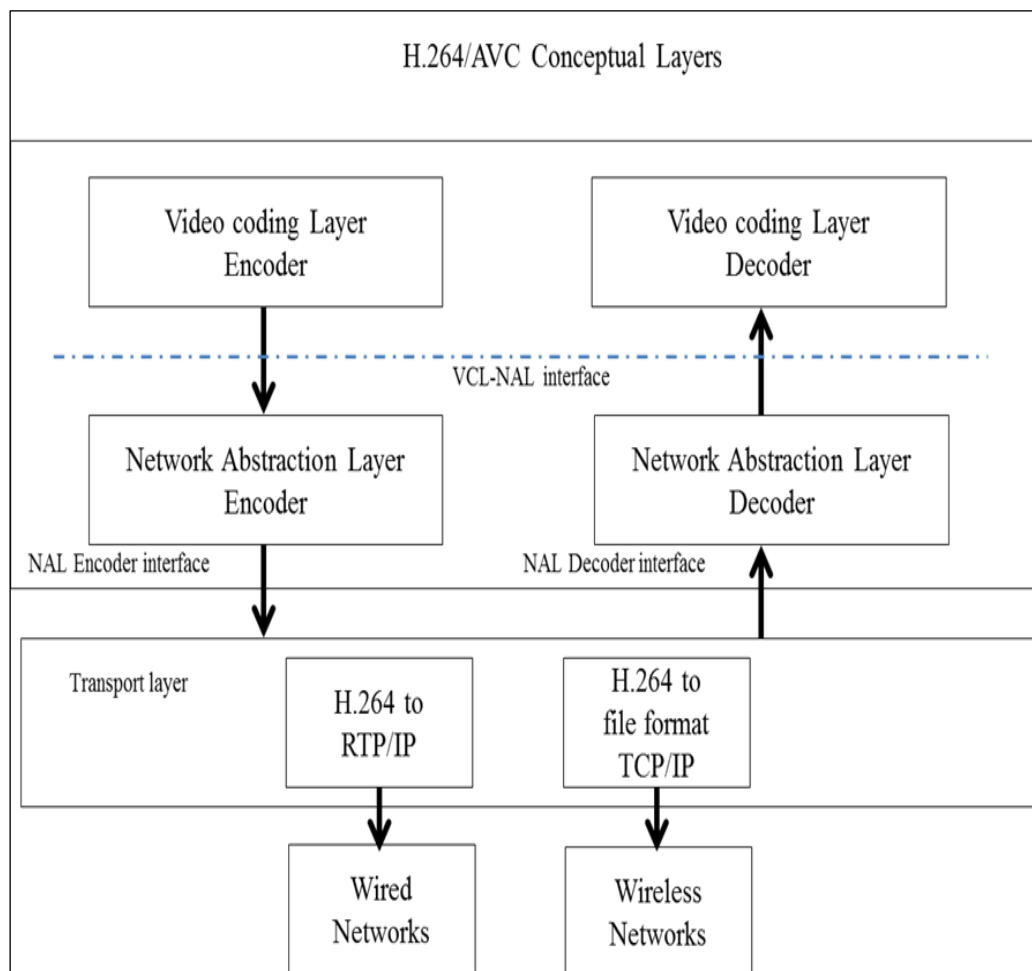


Figure 4.3: H.264/AVC Conceptual Layer

Consequently, coded multi-view video data is represented as an integer or byte in the NAL unit. In the H.264/AVC, the first byte of each NAL unit is represented by NAL unit header

and indicates the type of data in the NAL unit [35]. Figure 4.4 shows there is a different degree of the parameter in the NAL unit block. For smooth operation, the NAL units are virtually sub-divided into VCL and non-VCL NAL units. The VCL of the NAL unit comprises data of valuable information on the video picture. Similarly, the non-VCL of the NAL units predominantly use picture parameter set (PPS), Supplemental Enhancement Information (SEI) and a sequence parameter set (SPS) to contain additional informs.

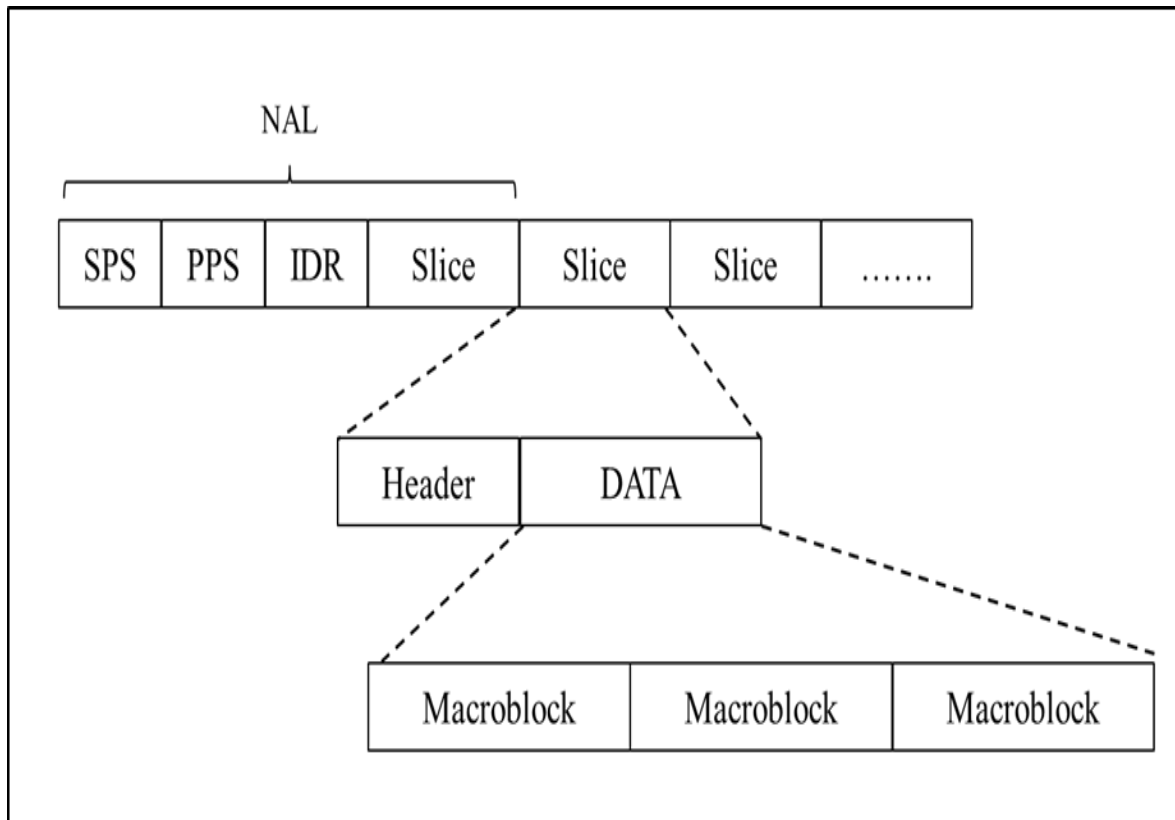


Figure 4.4: VCL and NAL Layers

In the same manner, the H.264/AVC codec is also able to sort a video sequence into various groups of pictures (GOP). The GOP is usually a set of consecutive 3 to 15 frames. This connective frames can be reconstructed without reference to other frames. Figure 4.5 shows an example of 9-frame GOP which can be used for three camera views. Owing to the great importance of a GOP to video compression, a GOP can contain all I-frames, I and P pictures frames only and I, P, and B frames.

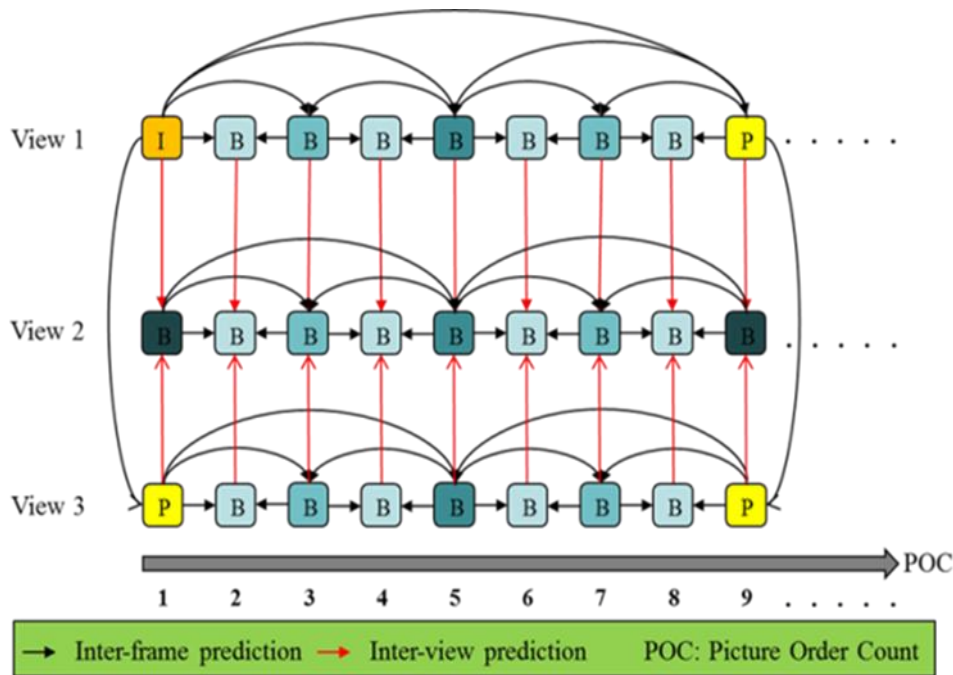


Figure 4.5: MVC Structure with a GOP

Each of the I, P and B-frames components contributes to the function of GOP in a different way. The I, P and B-frames collective effort is characterized as follows:

- I - frame (Intra-coded frame): Coded independently without referring to other frames.
- P - frame (predictive-coded frame): Coded using the reference to a previous information of reference frame (either I or P). The size is usually about 1/3rd of an I-frame. The P-frame uses motion compensation prediction from previous I or P frame.
- B - frame (bi-directional predictive coded frame). The B-frame is coded by using both future and previous reference frames (either P or I). The size of B-frame is usually about 1/6th of an I-frame.

The H.264/AVC encoder has the capability of creating bitstream that links thousand and millions of H.264/AVC decoders. Figure 4.6 shows the electronic information system process that involves motion estimation, transform, quantization and entropy coding in generating H.264/AVC bitstream.

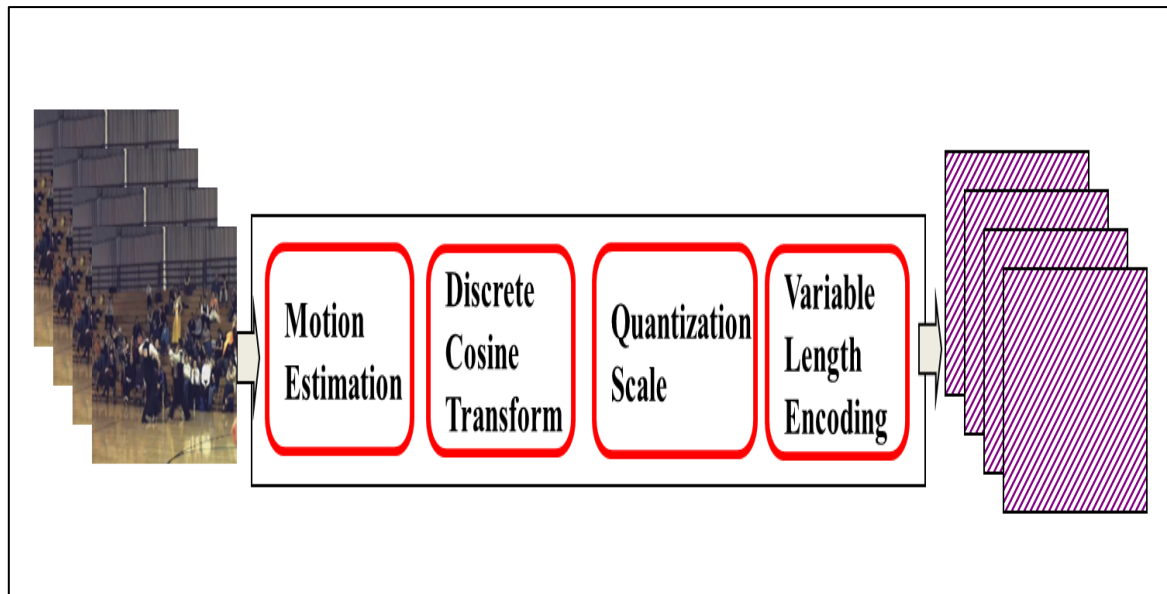


Figure 4.6: DCT based Spatial Compression

The first step in the H.264/AVC prediction cycle is to sort the macroblock into either Intra or Inter prediction level. The Intra-frame encoding takes advantage of spatial redundancy. The process involves the use of video filter to reduce spatial redundancy at chrominance plane. Similarly, the inter prediction involves temporal prediction using forward and or backward interpolation.

The next step is the discrete cosine transform (DCT) that converts spatial disparity into frequency variation. The quantization process follows the DCT. The quantization reduces the higher frequency components of the DCT coefficient to zero. The final process is entropy encoding, here the video stream are generated.

The entropy coding includes the employ run length coding or Huffman encoding to generate the coded bitstream. Thus, in order to prevent over/underflow of the data, error resilience MVC the process in H.264/AVC requires detail planning, co-ordination and execution.

4.4 Impact of Transmission Error Propagation

Wireless communication has transformed society and made the world a smaller place. More recently, smartphones have turned traditional TV broadcast into two-way conversations by providing instant video connections over a long distance. The emergence of 4G LTE, Wifi and other wireless technologies has brought wireless communication across all facets of daily human life. However, information sharing over a wireless network is affected by a transmission error. Transmission error is said to occur when the received data do not conform

with the encoded data. In the channel, loss of data can be caused by fading, multi-path, bit error, burst error, and packet lose.

Transmission error is the root cause of severe quality degradation of reconstructed video at the decoder. Figure 4.7 illustrates how a bit error changes the codes in a bitstream. The effect of bursty errors in variable length codes (VLC) could result in loses of synchronization between the source and destination devices. Consequently, lack of synchronization between the decoder and the encoder could lead to incorrect video reconstruction [50, 273-276]. The worst case scenario is when the channel error corrupts the header of a transmitted frame. In this type of case the decoder may seize to operate.

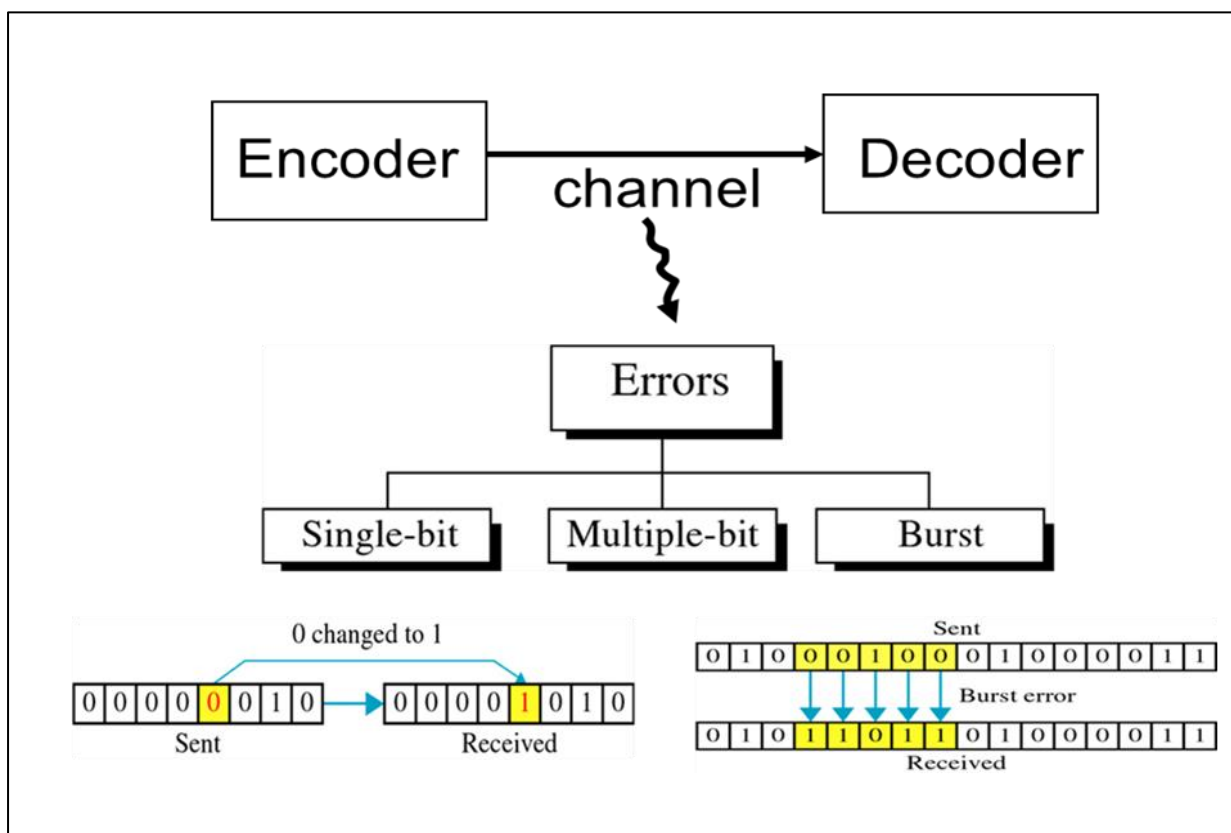


Figure 4.7: Effect of Channel Errors in a Bitstream

Due to the nature of father and child dependency in MVC, an error that occurs in B-frame or P-frame may spread temporally through the same camera views as well as to the adjacent frame in the other camera views. Figure 4.8 shows a typical example of transmission error propagation in a single view, which can be used whenever it is necessary to deliver 2D video data between two points.

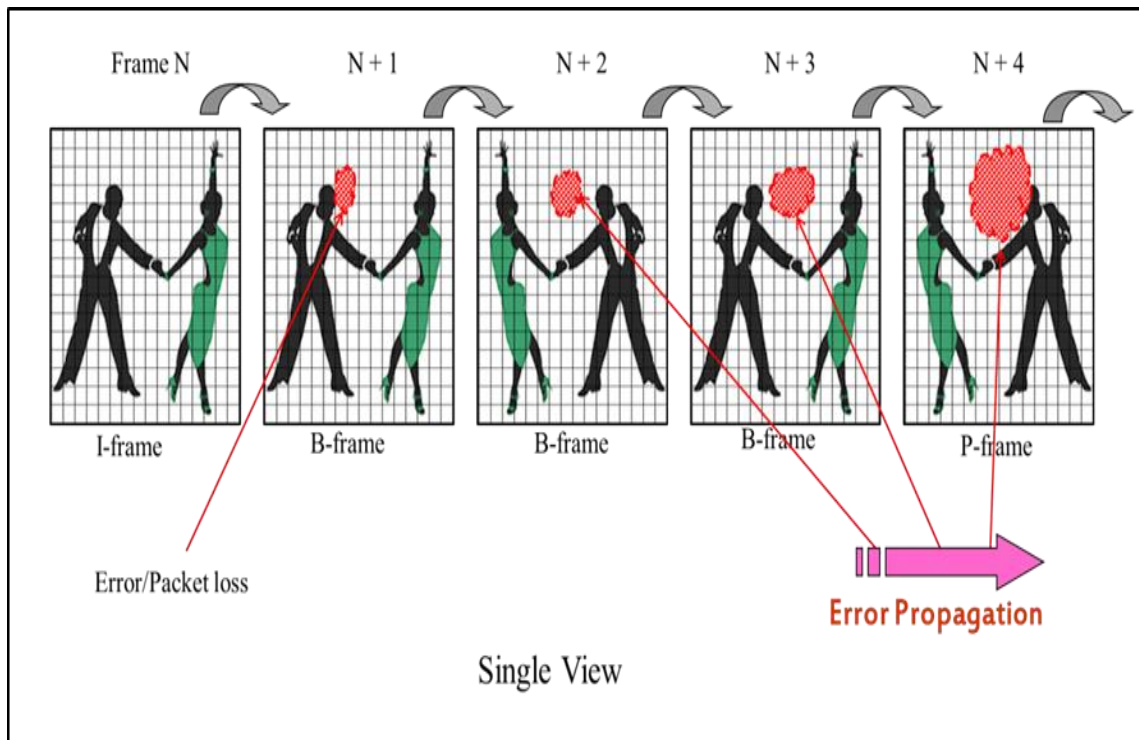


Figure 4.8: Error propagation in a Single View

Let us consider a case with three camera views in a GOP as shown in Figure 4.9. Suppose a transmission error hits B-frame at location N+1. The error spreads to frames (N+2), (N+3) up to end of the GOP. The errors as it spread engulf more number of macroblocks in both time and space. The pattern of the error propagation depends on the type of frame and view.

It is pertinent to note that, the B-frames are not good candidate for other frames prediction as such an error in a B-frame is expected to be restricted within that frame. However, in practice bursty errors affecting B-frames can trigger temporal error propagation in time, space and views. The effect of these errors is a severe quality degradation of the reconstructed video.

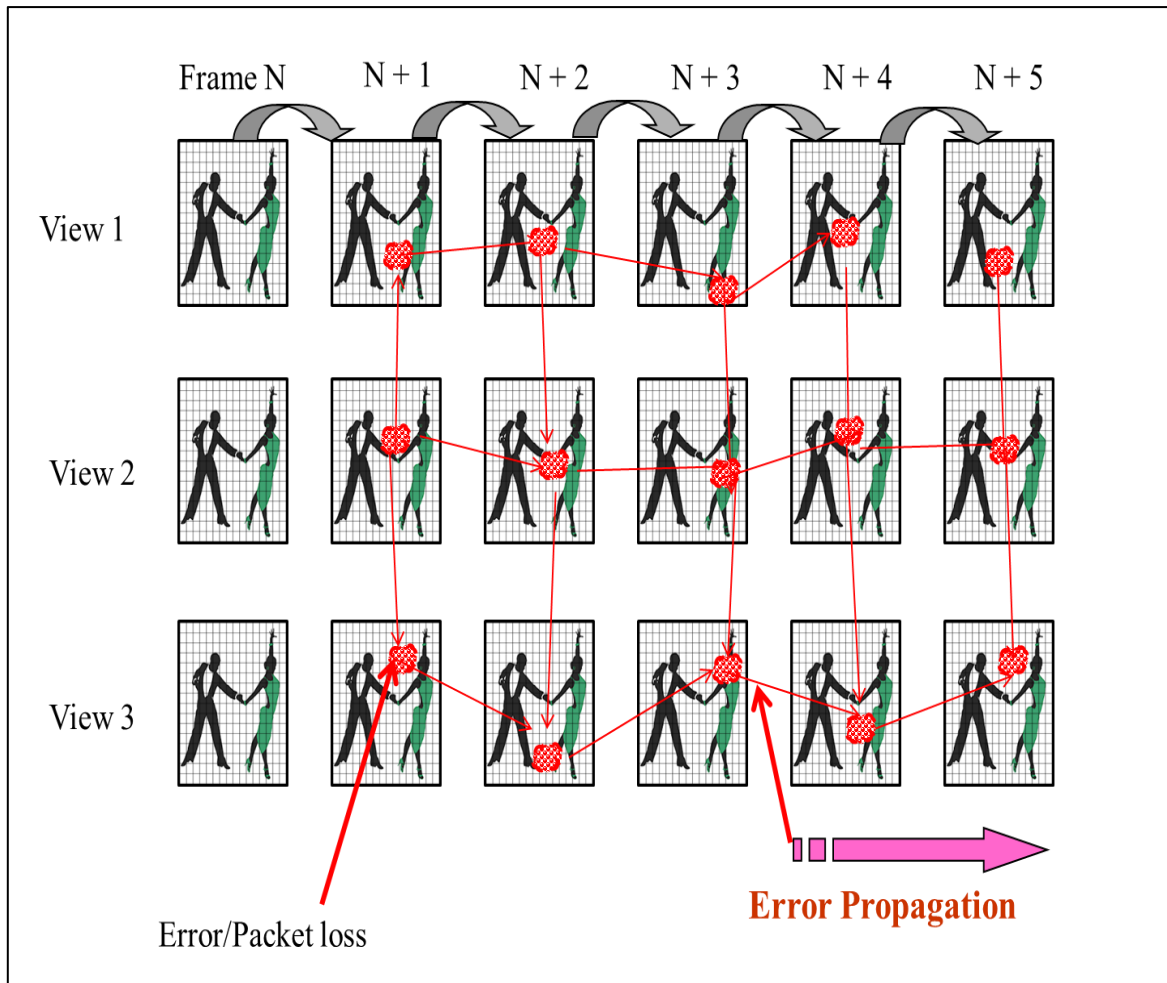


Figure 4.9: Error Propagation in Space, Time and Views

For our AIR algorithm we need to know precisely the locations of each macroblock that is affected by error. The recognition of the site of each macroblock in a frame is necessary as motion object in a scene can quickly change position. Figure 4.10 demonstrates an example of identifying the exact macroblock corrupted by error. From the diagram, it is observed that the initial error hits macroblock number 4 of frame N in view-1; at the $(N+1)^{\text{th}}$ frame, the error occupies macroblock 13 and 14 and continues spreading in time and space. The consequence of this unprecedented error propagation is the adverse effect of perceptual video quality at the receiver which leads to decreases the user QoE at the receiver end.

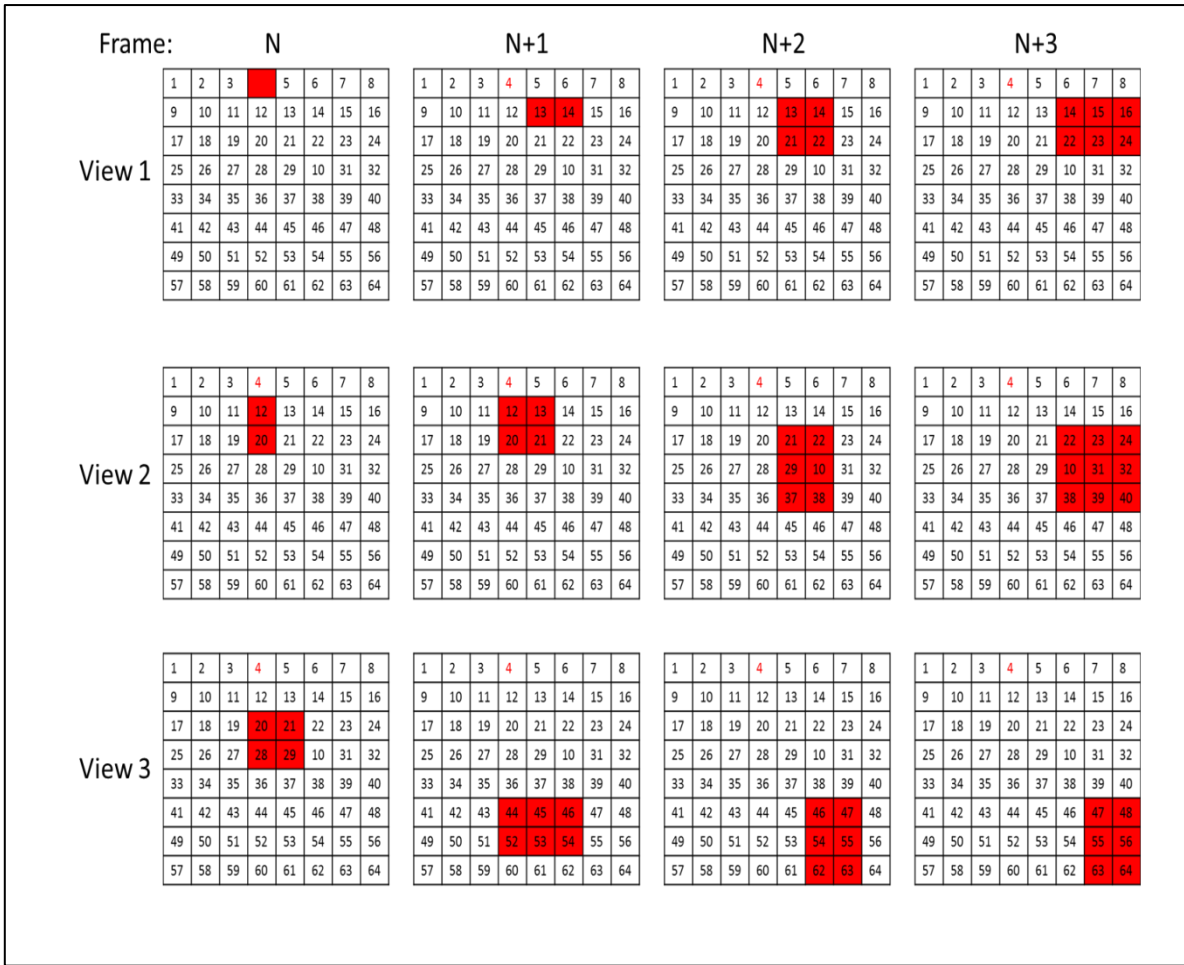


Figure 4.10: Locations of Macroblocks Affected by Error

4.5 Generation of Adaptive Intra Refresh Map

The generation of MVV-AIR refresh map can be understood by first considering the elements involved in the implementation of the MVV-AIR algorithm. Figure 4.11 shows the configuration of the three elements involved in design and implementation of MVV-AIR. Each element contributes in different ways; however, all components possess the following generic capabilities.

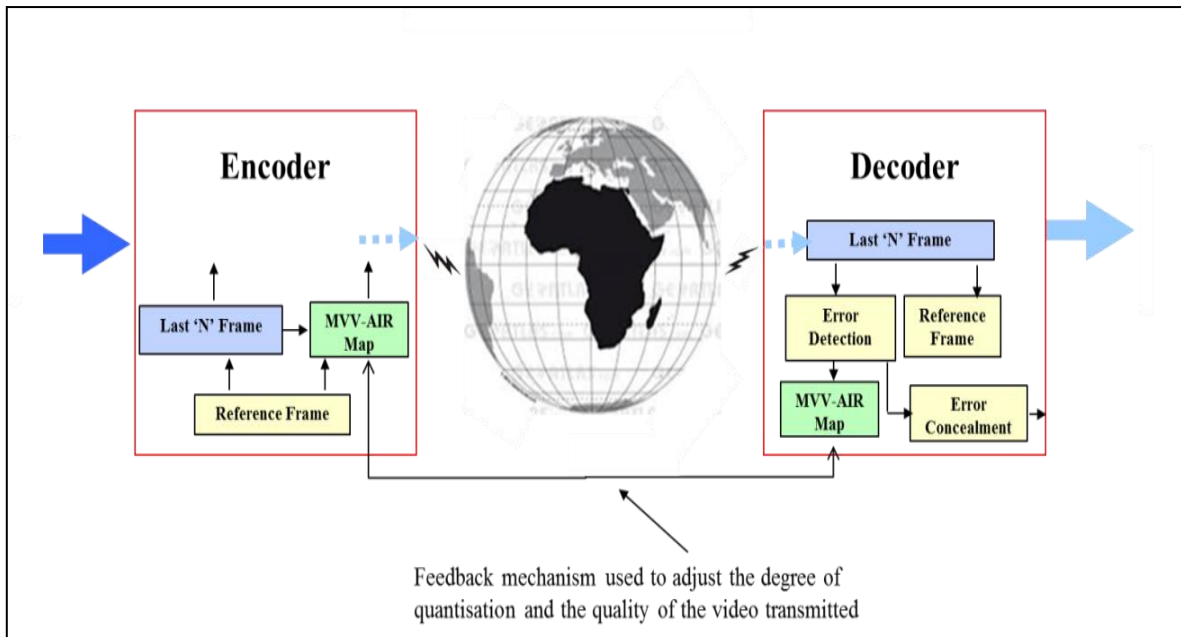


Figure 4.11: MVV-AIR Component Configurations

- H.264/AVC encoder: The encoder main function is to carry out application of compression algorithm. It often uses the baseline algorithm as a key tool in tackling the challenges of MVV-AIR map generation. The baseline algorithm has three stages: A Discrete Cosine Transform (DCT) stage, a quantization stage and a binary entropy encoding stage [277-279]. The encoder prepares robust compressed bitstream to be transmitted over error-prone networks.
- Transmission: This is the medium over which compressed 3D video is conveyed from one geographical location to another. In the communication medium, transmission errors such as bits and a random burst of errors as well as packet losses are almost inevitable, particularly over noisy channels.
- H.264/AVC decoder: The decoder carries out decompression algorithm at the destination. It employs error concealments mechanism to hide errors or message the encoder via a feedback link indicating corrupted macroblocks. [240, 247, 271, 280].

The concept of MVV-AIR map refresh table generation is illustrated in Figure 4.12 below. The process involved three blocks namely encoder action, decision layer and table updating.

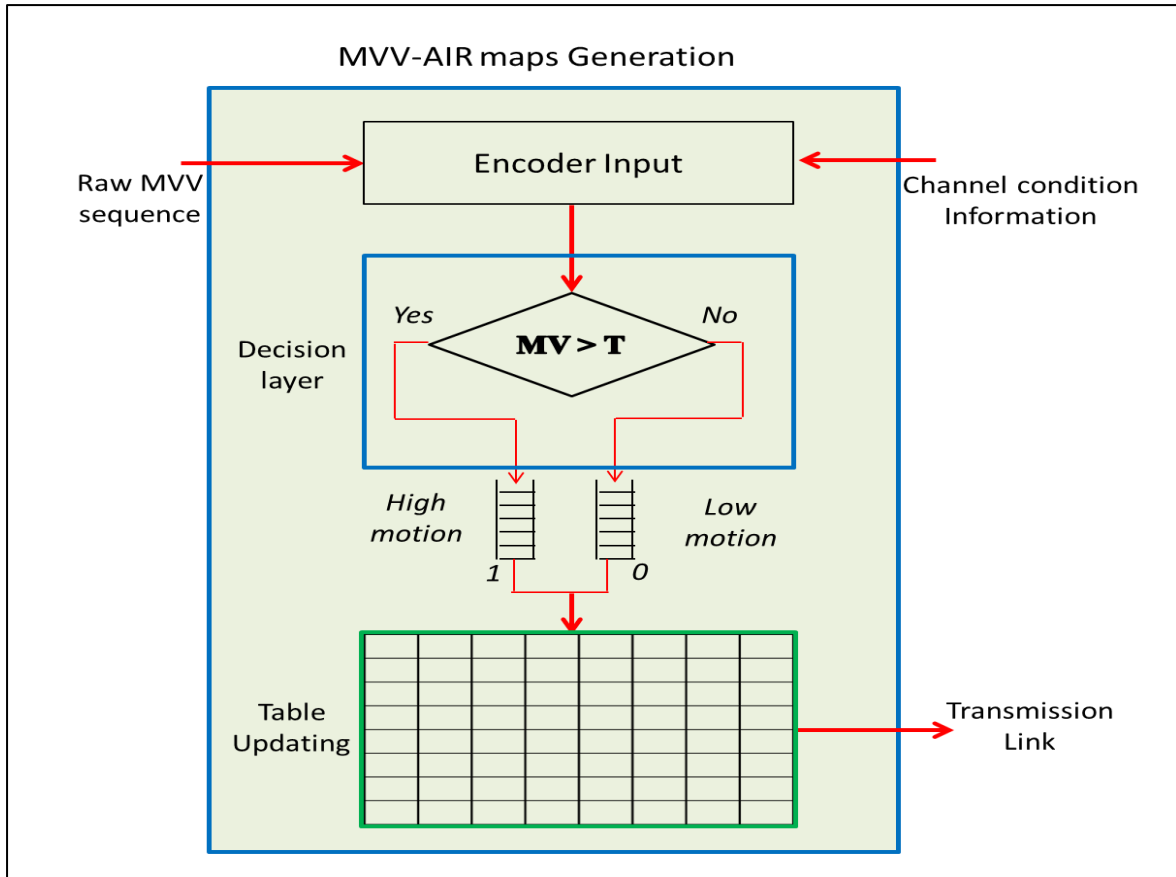


Figure 4.12: Architecture of MVV-AIR Map

a. Encoder action. The raw MVV data and information about channel variation are input into the encoder. The MVV-AIR map generation scheme begins in the encoder by tracing the high motion region of an incoming frame. The encoder operational capability to identify the motion activities of each macroblock is enshrined in the H.264/AVC codec. The H.264/AVC encoder adjusts the order of packets arrival and assigns priority to the high motion macroblock to be encoded first. These high motion macroblocks are packetized and mapped into a high motion. Then the lower motion macroblocks packets are encoded and mapped into low priority queue. It is important to identify the motion area because the transmission error normally hangs on the high motion regions of the compressed bitstream [27]. There are various methods proposed in the literature for identifying high motion regions in a frame [90].

The motion tracking method takes note of the existence of temporal redundancy in consecutive multi-view video frames. The fact is that not all the objects in a scene captured by video camera frames are in motion. Some content such as a background remains static and never changes position during a significant portion of the video sequence duration. Figure

4.13 show an example where the physical static building block that serves as background picture requires no coding refreshment. However, the objects in motion such as dancing team, moving cars that are circled in white may require parodic Intra-coding. Hence, tracing the macroblock with high motion is based movement of objects within that frame.



Figure 4.13: The Regions of Increasing Motion

Another method of tracing the high motion macroblock is the rate distortion control mechanism. The rate distortion methods exploit the sum of absolute differences (SAD) to facilitate motion energy detection.

b. Decision Layer. The decision layer takes note of the existence of temporal redundancy in consecutive MVV frames. The decision process is best carried out by comparing the motion vector of each macroblock with pre-determined threshold. The set threshold value compares the similarity metrics of the macroblocks to decide if there was high motion or not. The decision block use sum of absolute difference (SAD) to exploits the relation between motion and texture within a scene. Figure 4.14 shows flow chart of MVV-decision process. The threshold parameters used in the flow chart are expressed in the well-known Lagrangian cost function (J) equation [52-54].

$$J = D + \lambda(R + C) \quad \dots\dots\dots (4.1)$$

Where D is the variation of difference macroblocks with minimum distortion, R is the coding rate and C is the complexity constraints [54-56]. The distortion rate and computational

complexity are linked to Lagrangian parameter depicted by λ symbol for appropriate weighting.

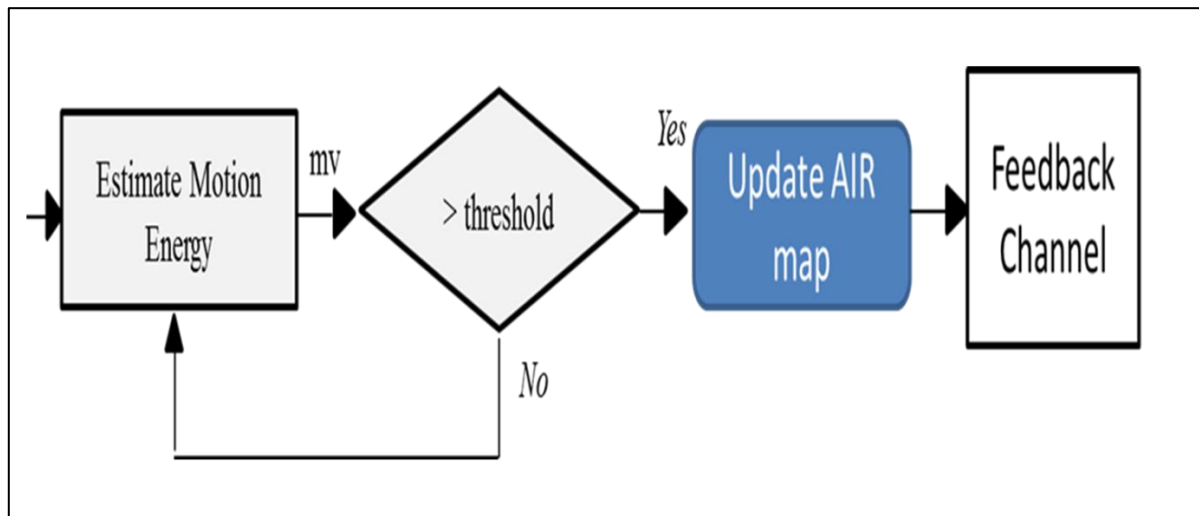


Figure 4.14: Flow chart of MVV-AIR map

Evidently, an example of a variation in motion computed with a pre-set threshold over the standard ‘Vassar’ sequence is shown in Figure 4.15. Referring to this figure, it is clear that the peak of the car movements happens around the middle of the sequence. Therefore, the MBs in the middle of the frame belong to a region of high motion activity.

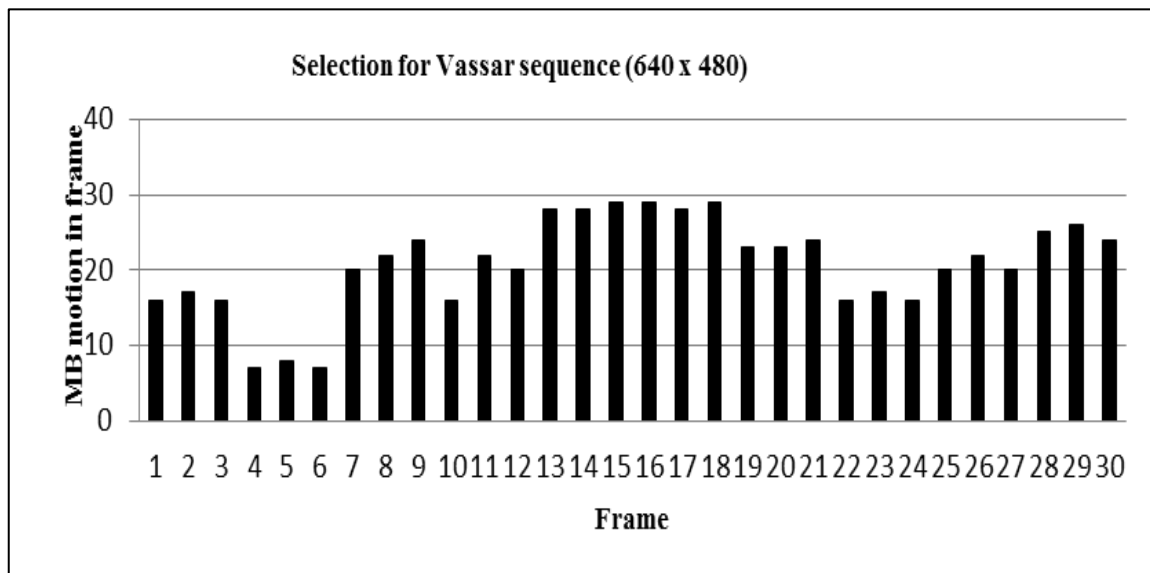


Figure 4.15: Variation in level of motion activity within the ‘Vassar’ sequence

Row destruction method is another method that is used to trace high motion. Figure 4.16 shows an example of a row based distribution method for (640 x 480) Ballroom sequence. The table comprises of rows of P and B inter-prediction macroblocks. The use of the table allow for the easy identification of each macroblock in a frame. For example, in the diagram

below the yellow area depicts B-frame high motion region. Through for a static object with a motion, for example, a newscaster reading new, the movement is only confined to the mouth area. In this case row destruction method will not be suitable tool.

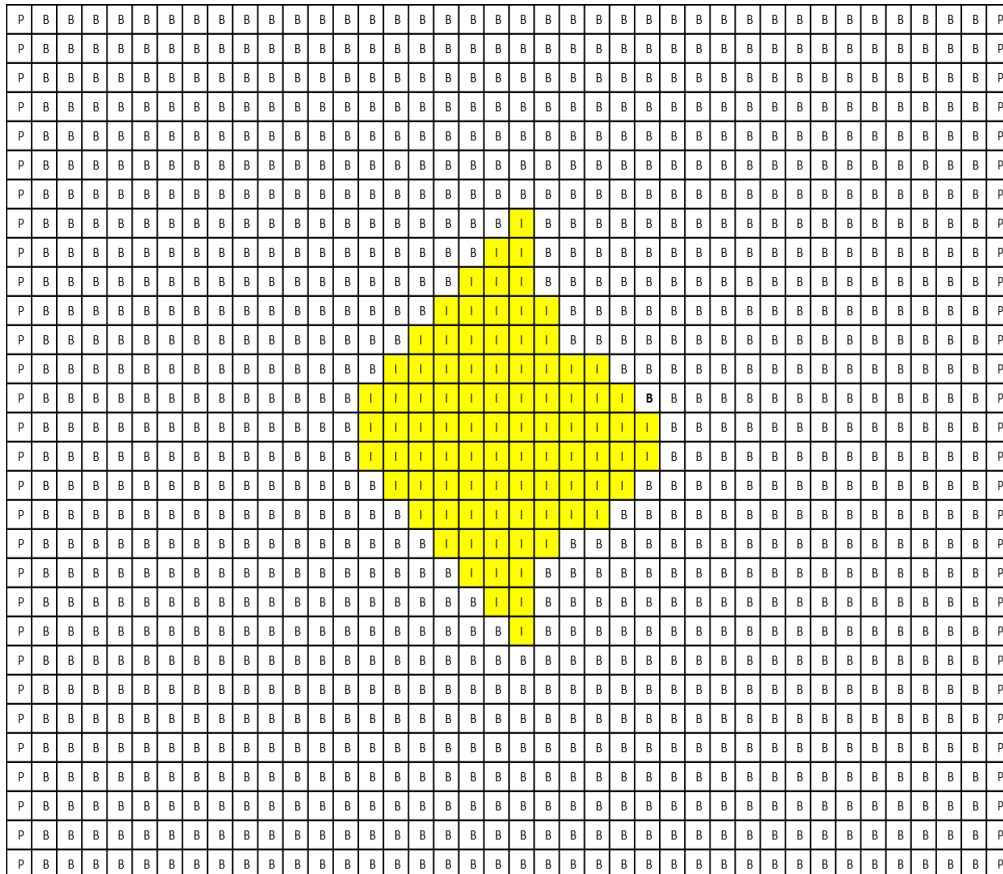


Figure 4.16: Variation in level of motion activity within the ‘Vassar’ sequence

c. Table updating. There is an expectation that database of the MVV-AIR map will continuously be updated. This is because the bit rate variation in both the MVV data and channel continue to change over time. These bit rate variation as result of motion in the scene and the variations of the communication channel condition necessitate the update of the refresh map. Accurate calculation of the high motion macroblock threshold is crucial in the process of generating MVV-AIR map. The use of a pre-determined threshold to decide on the actual location of the macroblock with high motion in a frame is commonly employed in various algorithms. The process involves setting a threshold predetermined value and comparing this predetermined value with the similarity metrics of the macroblocks. The presence of a high motion macroblock is decided if the corresponding motion vector (MV) is greater than the preset threshold. Consider the frame in Figure 4.17, if the motion vector

exceeds the threshold value (T) it implies high motion. This is mathematically represented as follows [282]:

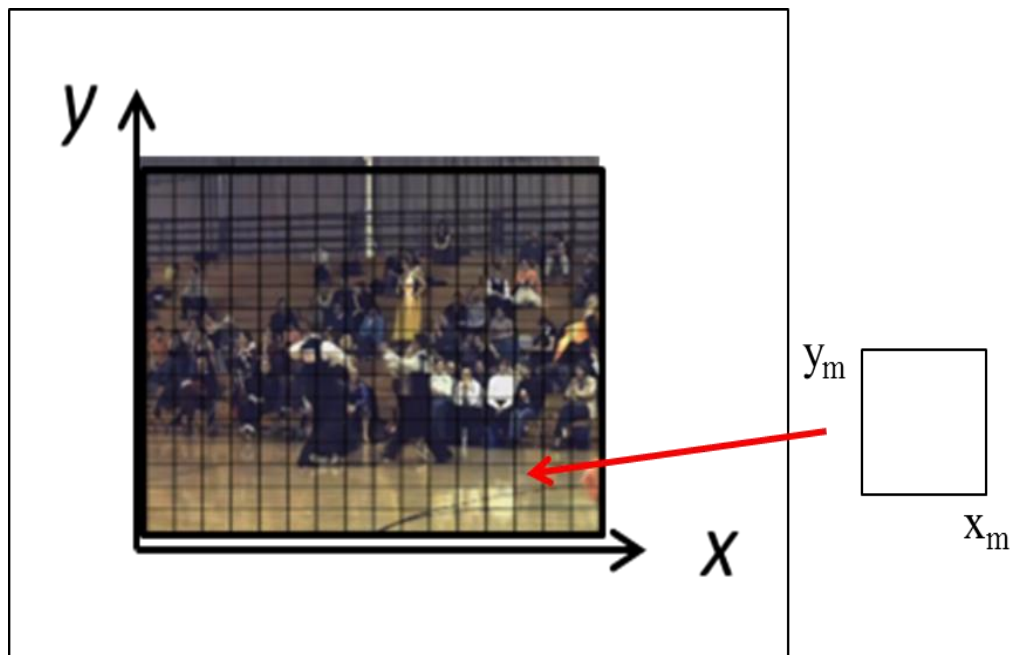


Figure 4.17: Motion Vector Comparison

$$MV(x,y) > T \begin{cases} 1 \text{ high motion} \\ 0 \text{ no motion} \end{cases} \dots\dots (4.2)$$

Where, MV represent the motion vector, (x,y) are the horizontal and vertical coordinate respectively, and T is the predetermined threshold.

The (x,y) coordinate of a particular macroblock indicate high motion or low motion. If $x = 0$ and $y = 0$, this indicates no motion. Conversely, when $x = 1$ and $y = 0$, this implies that there is high motion. Also, $x = 0$ and $y = 1$, this implies that there is high motion.

The choice of threshold values is largely attributed to a multiplicity of activities within the frame. The value of the predetermined threshold can also affect the rate at which Intra refresh macroblock is to be inserted in the MVV-AIR coding. Also selection of large values of the predetermined threshold may lead to the accumulation of errors. Thus, the best way to select the appropriate threshold value is through the conduct a series of experiments.

Table 4.1 illustrates results of an experiment and the residual value of macroblocks in frame 10 of the “Ballroom” sequence. In this case, the motion is measured by the residual of macroblocks. Macroblocks with motion level equal to zero imply that the macroblocks belong to the background of the frame. Likewise, high motion macroblocks belong to the region of interesting (ROI) of the frame space. We can see that the order of high motion macroblocks and low motion macroblocks are interlaced. Thus, the order of packets arriving at the high priority macroblock queue and the low priority macroblock queue is following the motion activity.

Table 4.1: Macroblocks Residual Value for Ballroom Sequence

0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	461	938	476	0	0	0	0
0	0	0	0	345	345	771	789	0	0	0
0	0	0	4	567	222	1020	567	0	0	0
0	0	0	0	890	33	356	892	0	0	0
0	0	0	345	987	89	123	205	0	00	0
0	4	45	5	332	446	456	45	21	34	0
0	0	450	567	34	77	765	800	56	567	0
0	123	78	692	455	67	56	342	234	67	0

To adjust the order of arriving packets, we adjust the order of encoding macroblocks in a frame by using open MVV-AIR map. Table 4.2 shows an example of changing encoding order. Accordingly, macroblocks with high motion (pink macroblocks) are encoded first. After that, the low motion macroblocks (white macroblocks) are encoded. Thus, the high importance packets will be mapped into the high priority queue first. The low importance packets are mapped into the low priority queue.

Table 4.2: High Motion Macroblock after Reordering for Ballroom Sequence

122	324	788	56	778	980	560	430	420	550	89
462	801	73	100	461	938	476	69	673	503	52
972	98	908	467	345	345	771	789	904	307	813
7	9	80	767	567	222	1120	567	320	98	530
156	1054	90	678	890	0	0	0	0	0	0
332	943	390	141	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0

An example of a perfectly generated MVV-AIR map table of a ballroom dance with winding movement is illustrated in Figure 4.18. In the beginning, all the refresh map entry for the present macroblocks is zero coded. Then, a new updated map is constructed for the incoming GOP. As soon as motion activity is detected within the GOP, the threshold value is used to computers identifies the new high motion macroblock and subsequently the MVV-AIR map is updated. Figure 4.18 illustrate the first update for a single view and Figure 4.19 shows an example for three camera views. A more elaborated generated MVV-AIR map is shown in Appendix D.

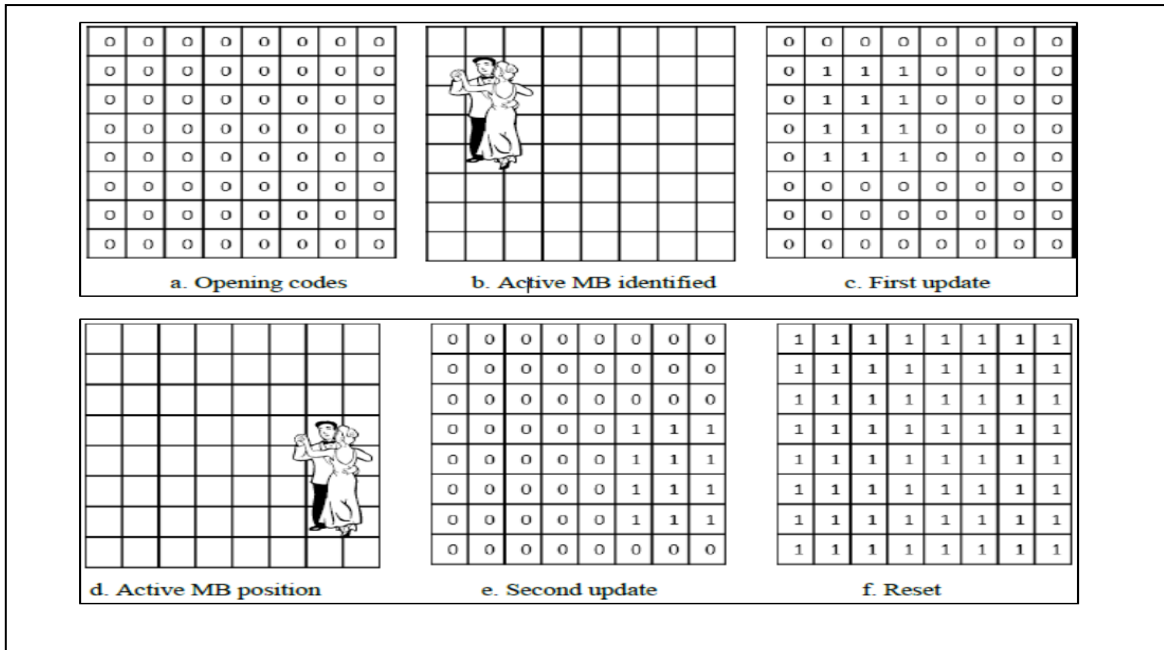


Figure 4.18 Example of MVV-AIR map Update for a single view

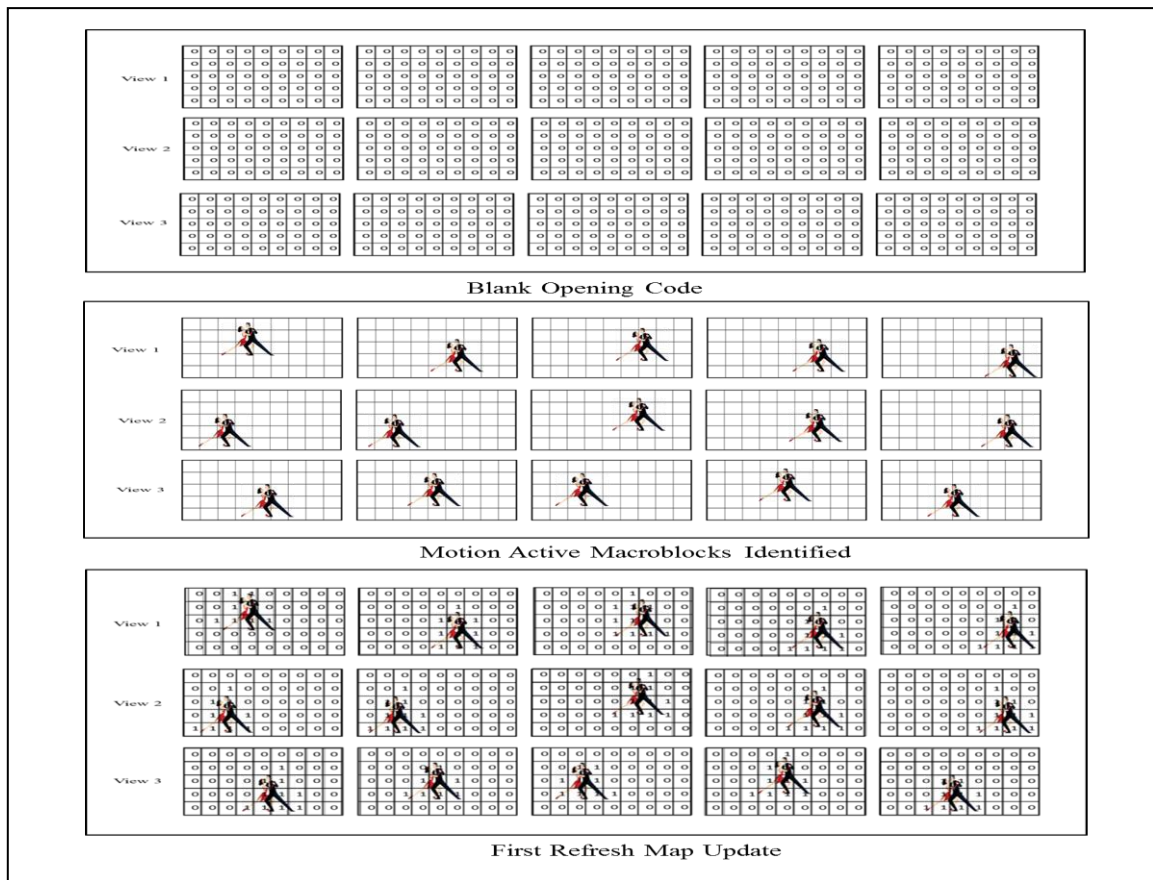


Figure 4.19: Example for MVV-AIR Map Update for three camera views

4.6 Periodic Insertion of Cyclic Line

The cyclic insertion of intra-coded lines of macroblocks within successive temporally predicted frames in GOP mitigates spatiotemporal error propagation. In our approach, a GOP is chosen from the sequence to be Intra refreshed. Figure 4-20 demonstrates how the cyclic Intra-coded macroblock are periodically inserted to refresh an erroneous GOP consisting of three camera views (view1, view2 and view3). In the example shown in Figure 4.20 the error is not confined to a particular frame in the GOP. Therefore, a cyclic pattern of refreshing the entire GOP is applied. The process involves moving the Intra-coded macroblocks in descending order pattern from top to bottom. The algorithm calculates macroblocks of each frame, for instance for Ballroom sequence (640 x 480), one (16 x 16) frame is equivalent to (40 x 30) macroblocks. Therefore, refreshing a (640 x 480) picture 30 times, the whole 1200 macroblocks of a frame can be clear from any error. Thus, the primary role of the cyclic Intra refresh is to erase temporal error propagation that arises from channel noise. The cyclic insertion of the Intra-coded macroblocks mitigates error in the GOP without introducing any additional bitrate and computation complexity.

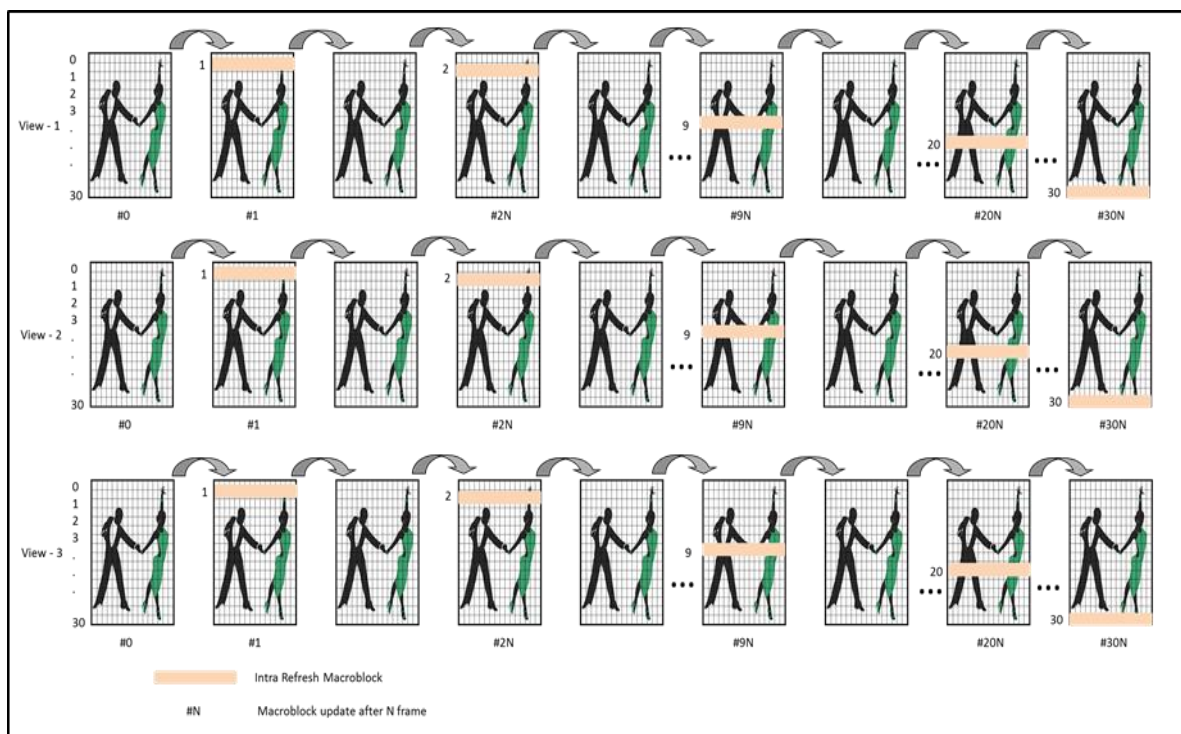


Figure 4.20: Cyclic Periodic Insertion of Intra Coded Macroblock Lines

4.7 Error Detection

Error in bitstream can be characterized as a contextual error, illegal code word error and error as a result of code being out of range. Error detection is a critical process in MVV-AIR error resilience technique. The ability of a MVV decoder to detect error can provide a passive MVV-AIR Intra- coding.

The error detection process is initiated from the encoder, because the encoder often adds extra redundant bits during the encoding process. As bitstream is received by the decoder, the error detection block verifies whether the received bitstream is correct or not. The decoder verify the correctness or otherwise of the received bitstream by subtracting the added redundant bits. This mathematical computation is simply carry out by error coding techniques such as parity check, cyclic redundancy check, checksum and repetition codes.

In some cases, a decoder can fail to detect error instantly. For example in Figure 4.21 the error slice contain at the position b can be described by three intervals. In the portion between (a - b), the slice is correctly decoded. An error occurs at the position b, hence, the error portion between b and c is undetected until the position c. This part is handled incorrectly by the decoder. Starting from the position c, until the end of the slice d, the decoder can conceal the detected error.

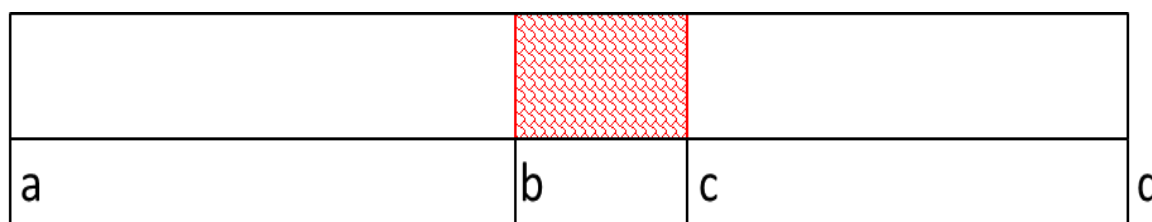


Figure 4.21: Error Detection

In a situation where the decoder cannot conceal the error, the decoder informs the encoder about the erroneous macroblock(s) via a feedback channel. Thus, erroneous packer can be completely dropped by the decoder or the decoder can take another action of further send the information of erroneous packets to the encoder. The encoder uses this information to update the MVV-AIR refresh map.

4.8 Experiments and Discussions

Having fitted a MVV-AIR error resilience scheme, this section presents the performance evaluation of the cutting edge algorithm. The algorithm was validated over error-free and

noisy channel environment. Subsection 4.8.1 presents results of the simulation conducted. Subsection 4.8.2 analyzes and discusses the results. Finally, Subsection 4.8.3 presents the subjective performance.

4.8.1 Simulations

The primary purpose of the proposed MVV-AIR error resilience algorithm is to win control of error propagation. We carried out simulations to test and validate the algorithm. The simulations were conducted with a H.264/AVC JMVC encoder and decoder system. The simulations framework is illustrated in Figure 4.22. In our experiments, three views of the sequences "Ballroom", "Exit" and "Vassar" were configured. The configuration files parameters in JMVC are employed.

The tests for three camera views were run sequentially in the JMVC encoder. The encoder consecutively treats each camera view. Furthermore, JMVC assembler tool accordingly sort the compressed bitstreams for transmission or storage. In our simulation, four error resilience methods are implemented and the result was compared. The four methods are namely: random Intra refresh (RIR), Flexible Macroblock Ordering (FMO), non-error resilience (NER) and MVV-AIR. We compared the performance of MVV-AIR map for Ballroom, Vassar, and Exit sequences for 300 frames at 30 frames/second frame rate.

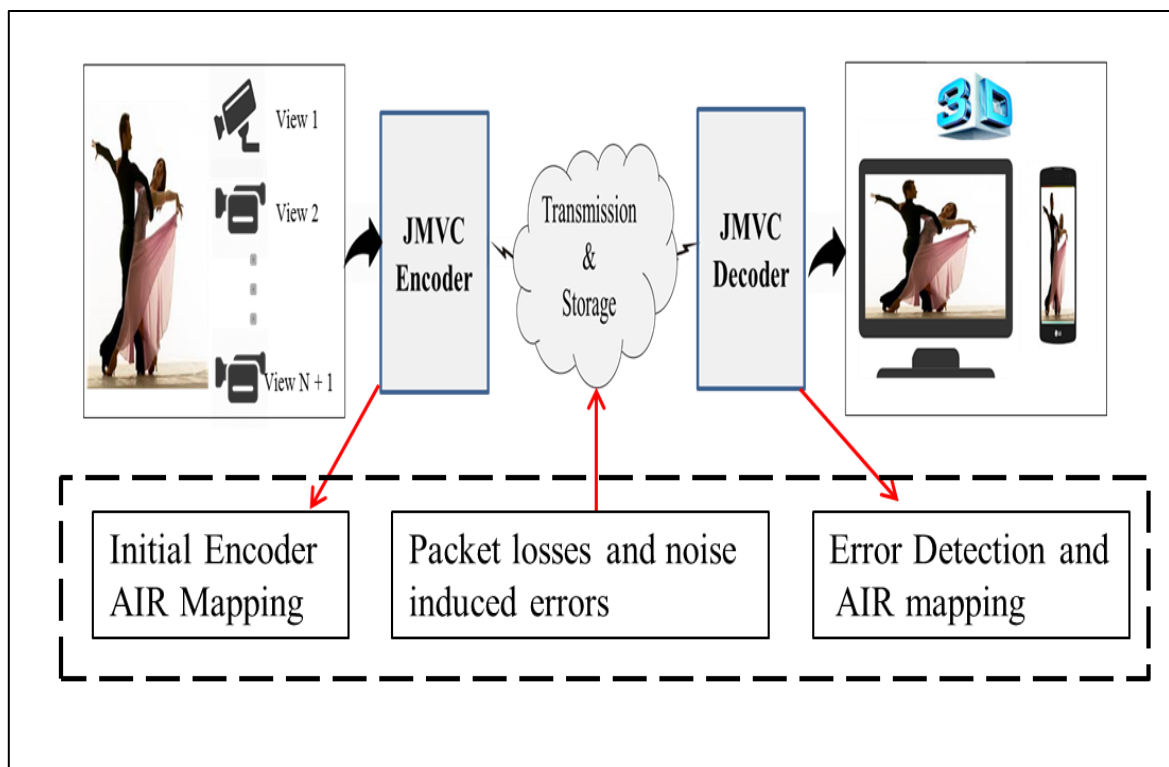


Figure 4.22: H.264/AVC video over Wireless Network Simulation Framework

It should be noted that all principles of a communication system from the source to the destination were applied in the simulation. However, the compressed bitstreams for the non-error resilience (NER) were directly transmitted to the channel without employing an error resilience scheme.

In testing the validity of MVV-AIR refresh algorithm, macroblocks with high motion were considered to be vulnerable to errors due to nature of MVC. Therefore, for the purpose of comparison other error resilience techniques such as random Intra refresh (RIR) [202], Flexible Macroblock Ordering (FMO) [234] and the H.264/AVC MVV-AIR were employed. Table 4.3 shows a summary of some relevant encoding parameters used.

Table 4.3: Configuration Coding Parameters of MVV-AIR

Serial No	Parameter	Specification	Remarks
1.	Input file	Ballroom, Exit ,and Vassar	640 x 480
2.	Resolution	640 x 480	
3.	Frame rate	30Hz	
4.	Frame encoded	200	
5.	Quantization parameter (QP)	25, 27,29, 31,32,33	
6.	Mean macroblocks	1	Adaptively selected
7.	GOP size	12	
8.	Intra period	12	
9.	Number of Reference frame	2	I and P
10.	Number of views	3	

4.8.2 Analysis and Discussions

The performance of MVV-AIR, NER, RIR and FMO are evaluated under noisy networking environment. The compressed bitstreams are transmitted over a noisy channel of 5%, 10%, 15% and 20% packet loss. Additionally, a packet loss in a GOP is viewed to be like loss of one complete video frame. Consequently, error control strategy in the form of concealment to

hide error is employed in FMO, NER and RIR techniques. The error concealment is in the form frame copy and motion interpolation methods aim to hide the error.

Figure 4.23 the illustrate performance of the sequence Ballroom under different network condition. The information given in the graph shows the performance of the four techniques for a percentage packet loss from 5% to 20%. NER outperforms the MVV-AIR under 5% PLR. But for above 5% PLR the MVV-AIR performs significantly better than the rest of the techniques.

Although the performance of NER starts with a higher PSNR value, performance sharply dropped to 22 dB at 20 percent PLR. This better performance of NER at zero packet loss is because the NER, unlike other techniques, does not employ error concealment coding schemes to hide errors.

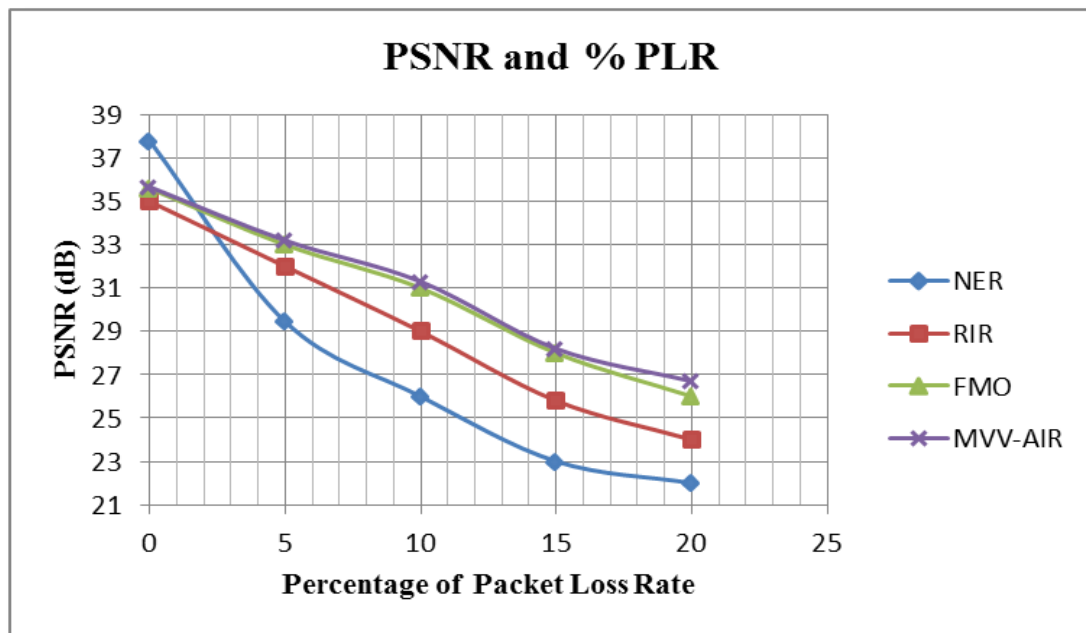


Figure 4.23: PSNR performance for the Ballroom

Figures 4.24 show the performance of the Ballroom sequence under free condition. From the diagram, the reconstructed luminance, depth and average PSNR for MVV-AIR, NER, RIR and FMO are plotted. It is evident from the figure that MVV-AIR has better performance compared to FMO. We find that the MVV-AIR method is better compression performance by more than 2dB PSNR.

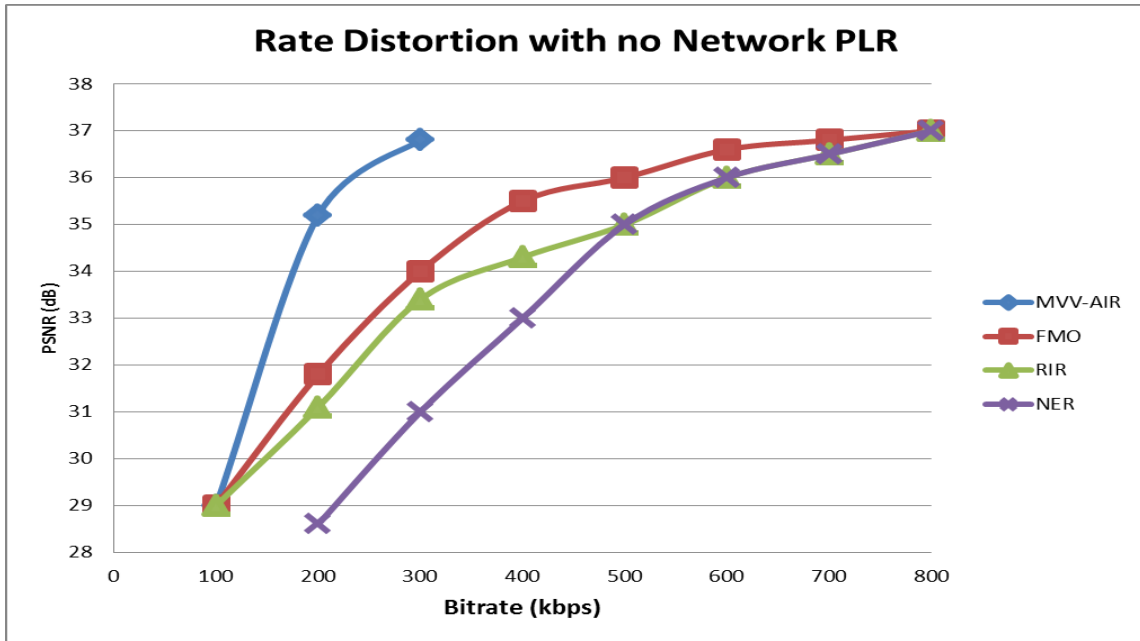


Figure 4.24: PSNR performance for Ballroom

Experiments conducted on “Exit” and “Vassar,” video sequences presented similar results as shown in Figures 4.25 and Figure 4-26 respectively.

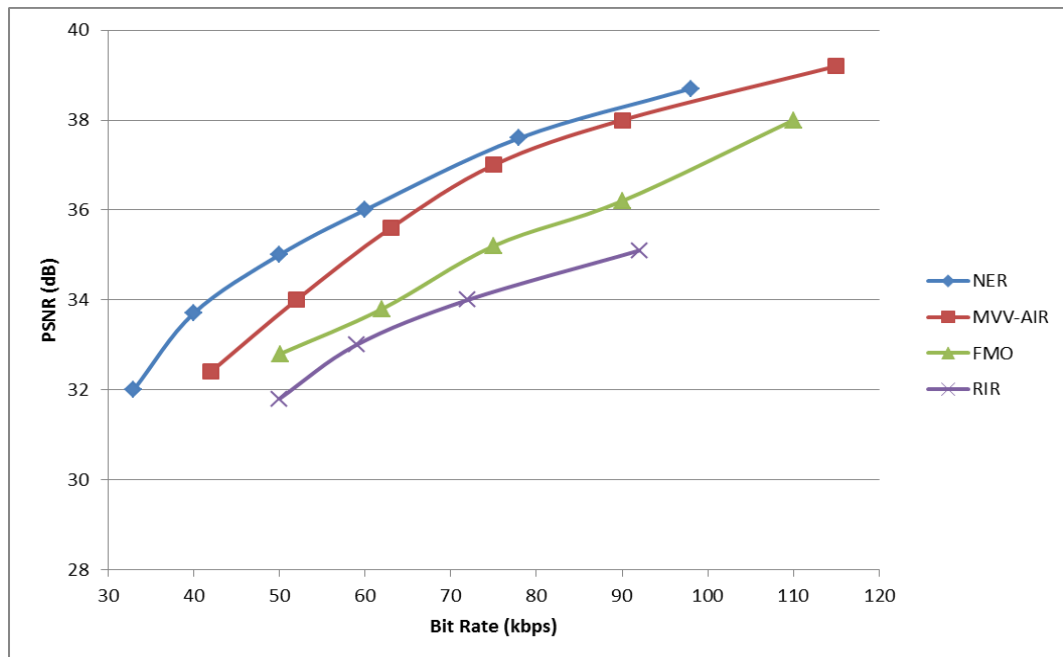


Figure 4.25: PSNR performance for Exit

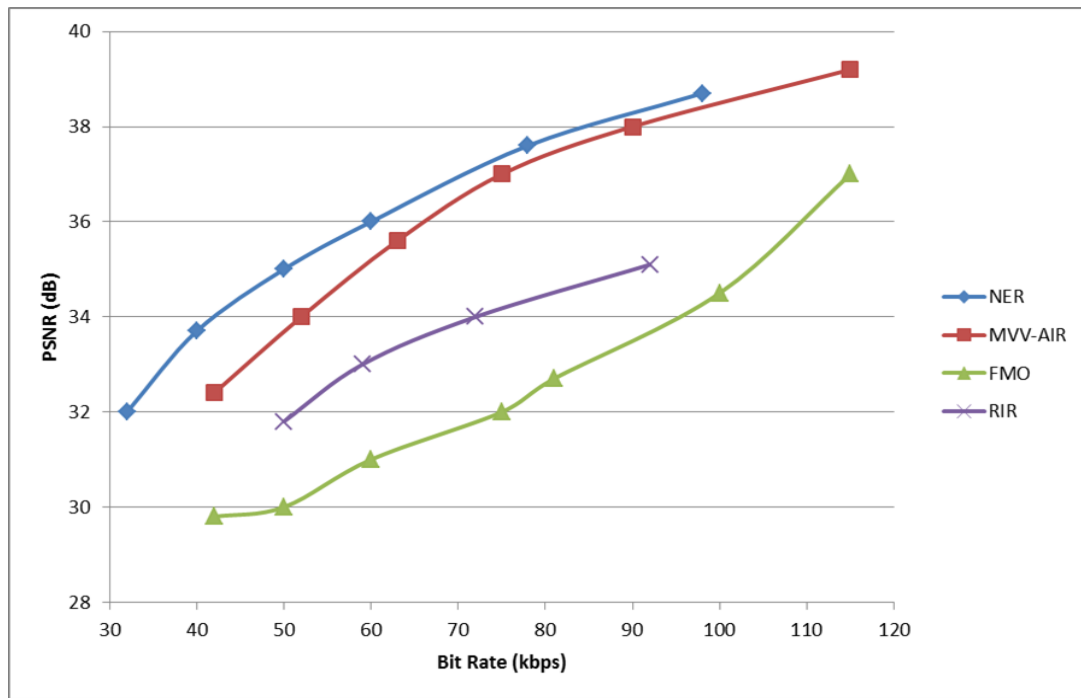


Figure 4.26: PSNR performance for Vassa

The diagram in Figure 4.27 presents the performance of Ballroom sequence with error distortion of 20% packet loss. The graph shows that the MVV-AIR and FMO outperform the RIR and NER approaches. Clearly the MVV-AIR demonstrates a much higher PSNR in the highly active sequences than other error resilience techniques. Here, one can notice an efficient performance of about 4dB gain by MVV-AIR as compared to FMO. The video quality of the reconstructed data at the receiver is directly proportional to the compression. The higher the compression, the less the quality since compression exposed the bitstream to channel errors. Some bit are employed to overcome data loss to the detriment of overall PSNR level.

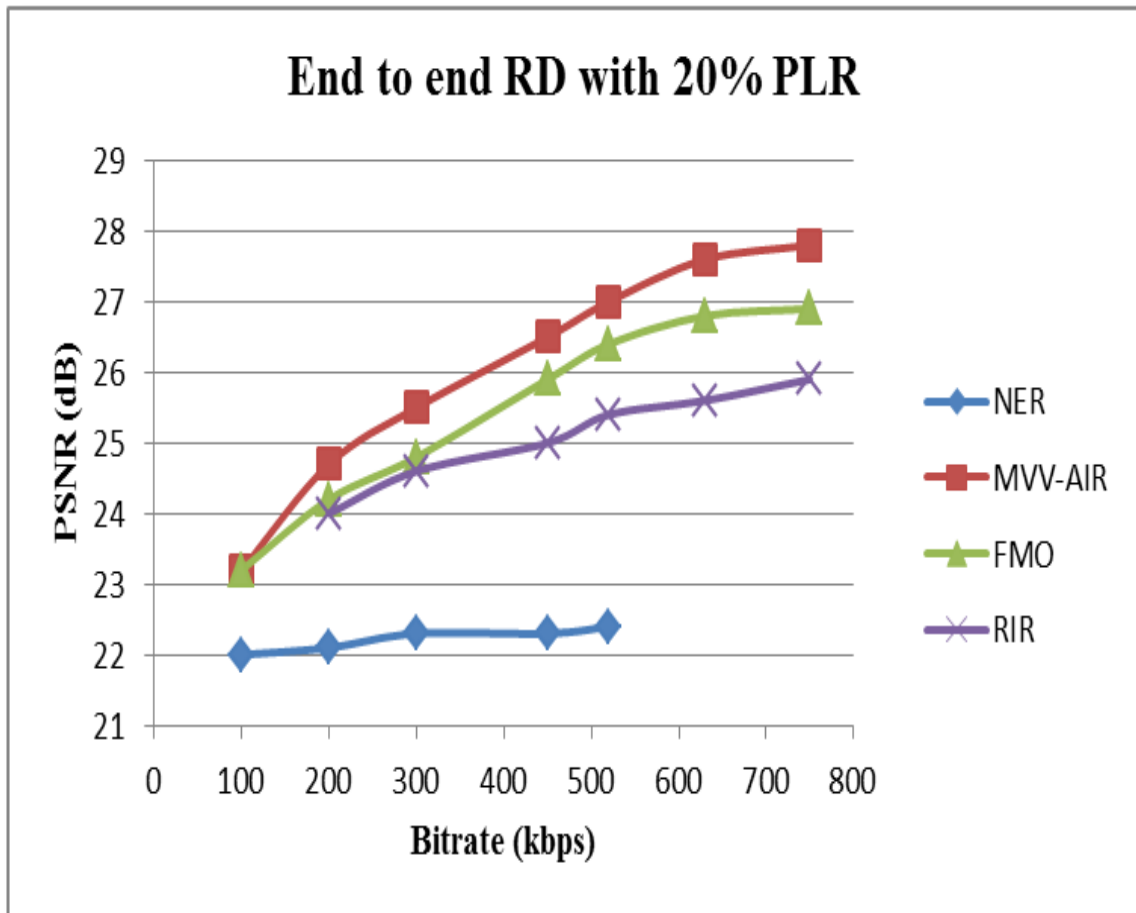


Figure 4.27: End to end RD with 20% PLR Ballroom Sequence

4.8.3 Subjective Performance

While objective assessment is a useful method of evaluating compression performance, it will particularly be effective when subjective assessment supports it. Figure 4.28 show the subjective performance of some selected decoded frames from Ballroom, Exit and Vassar sequences under noise free environment. Furthermore, to ensure balance judgment same number of packets is contained in each of the video frame.

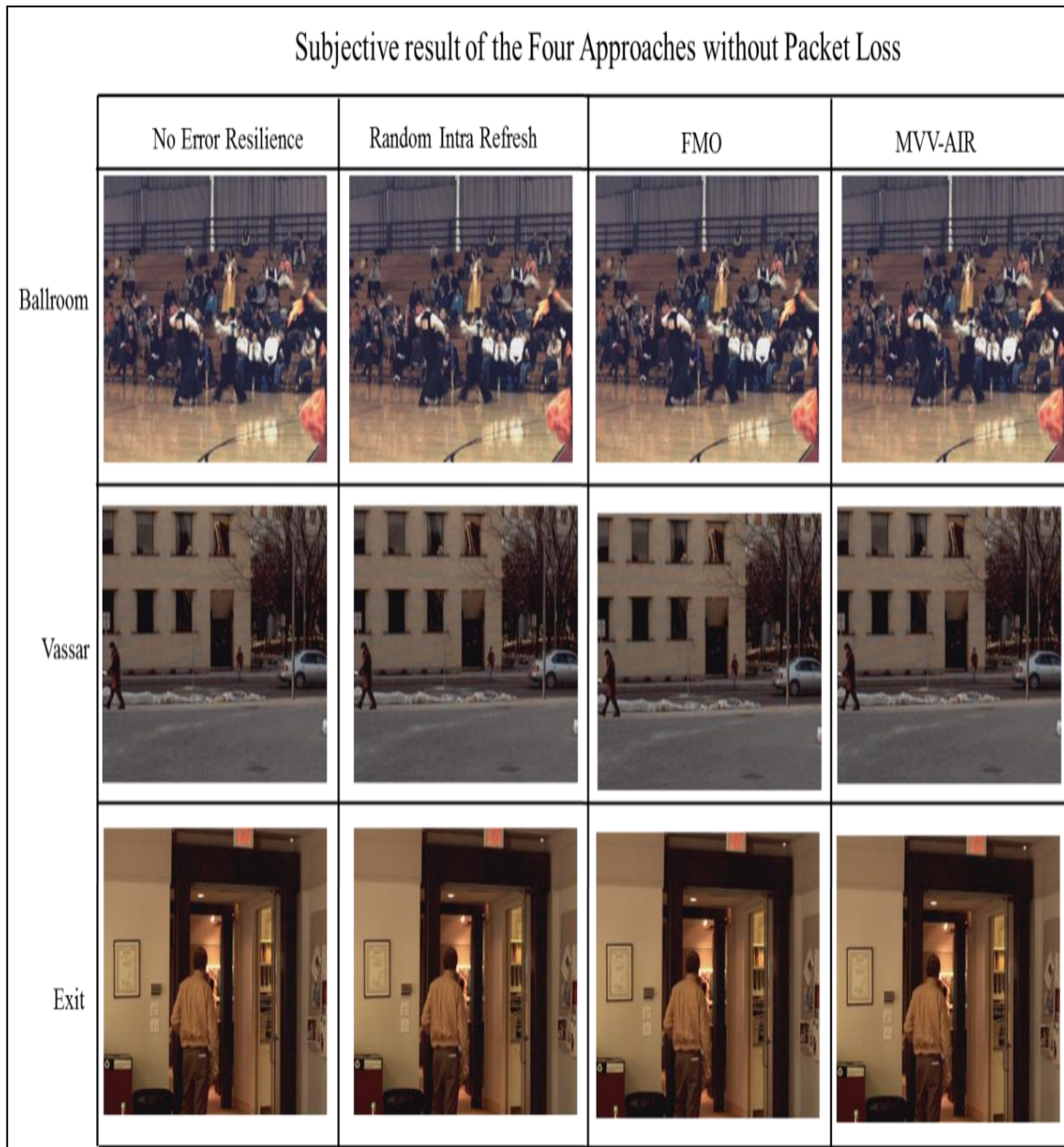


Figure 4.28: Subjective Performance of Selected Decoded Frames

Figure 4-29 show the subjective performance of Ballroom, Exit and Vassar sequences under 20%. From the pictures in Figure 4.29, it can easily be seen that in the MVV-AIR the diffusion of error arising from 20% error pattern to the video luminance and depth is rather slow. The subjective result indicates that the MVV-AIR algorithm is very efficient in handling the transmission error propagation.

Subjective result of the Four Approaches with 20% Packet Loss

	No Error Resilience	Random Intra Refresh	FMO	MVV-AIR
Ballroom				
Vassar				
Exit				

Figure 4.29: Subjective Results with 20% Packet Loss

4.9 Summary

In this chapter, we discuss error resilience MVV-AIR technique that is designed to enhance the delivery of 3D video over noisy channel environment. The chapter briefly describes error resilience compression techniques and presented an overview on H.264/AVC. Furthermore, we explain in a descriptive way the challenges associated with the impact of transmission error to compressed 3D video. We then presented MVV-AIR strategies for mitigating

transmission error propagation in a 3D video communication. We start by describing the architectural design of generating MVV-AIR map. In the MVV-AIR method, the high motion macroblocks are identified, and information about the condition of the transmission channel are obtained. MVV-AIR refresh map is generated by using the predetermined threshold value to compute the variations of high motion macroblock and channel state. The MVV-AIR map is used to insert cyclic line pattern of Intra-coded macroblocks to halt transmission error propagation. We then explained a robust and efficient cyclic AIR algorithm that is used to Intra refresh a GOP. At the same time, we highlight the need to establish a balance between subjective visual quality and the bit rate.

Finally, the chapter demonstrated that the proposed MVV-AIR algorithm can efficiently contribute in robust transport of multi-view video data over wireless networks. Above all, the objective and subjective rate-distortion performance evaluations of our algorithm outperform that of FMO, RIR and NER under noise-free and error-prone environment.

Chapter 5

Multi-view Video Transcoding

In this chapter, we describe a multi-view video Adaptive Intra Refresh (MVV-AIR) transcoding technique that we have developed. After the introduction in Section 5.1, we examine error resilience video transcoding methods in Sections 5.2. Then, in Section 5.3, we outline the video transcoding architecture. Proposed multi-view video transcoder is described in Section 5.4. Implantations strategies are discussed in Section 5.5. Then, roles of H.264/AVC in video transcoding are highlighted in Section 5.6. Section 5.7 covers experiment and simulation. The entire chapter is summarized in Section 5-8.

5.1 Introduction

The increasing use of mobile communication has raised concerns about 3D video communication using smartphones, laptop and PDAs. At the same time, failure of these portable communication devices to decode compressed multi-view video bitstream has dramatically reduced mobile 3D video communication. Furthermore, different content representation formats and network used by these mobile devices increases interoperability between different communications systems. Therefore, it is necessary to design a mechanism that can make 3D video viewable across different networking platforms and on all mobile devices. Multi-view video transcoding is the key technology that can affectedly convert the 3D video encoded bitstream to single view standard using H.264/AVC standard [34].

Primarily, transcoding in video communication perceptible is regarded as the act of converting one coded signal to another. However, a summary of definitions indicates that video transcoding is the process in which a compressed bitstream is converted from one format to another [197, 253]. Depending on the target destination requirement video transcoding take many forms. The most common transcoding processes are as follows:

- Different format (H.264/AVC to H.265/HEVC).
- Different frame resolution (spatial transcoding).
- Different frame rate (temporal transcoding).
- Different video quality (bit-rate transcoding).
- Additional feature (insertion of logo).

Thus, in a nutshell, the block diagram of Figure 5.1 illustrates a 3D video transcoder that operates differently from conventional video encoder.

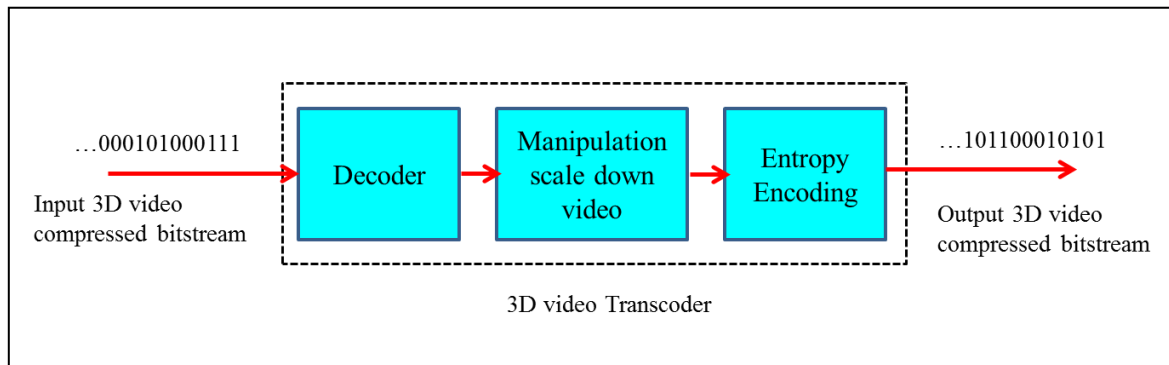


Figure 5.1: General Video Transcoder Block Diagram

Compressed multi-view video bitstreams are input to the decoder end of the 3D video transcoder. The transcoder extracts statistical parameters and re-encodes the bitstream based on the target device requirement. The transcoder scales down one or more of bit-rate, frame rate, spatial and temporal resolution to convert 3D video to a single view video.

Figure 5.2 shows that a variable or combinations of two or more variables can be manipulated to meet the requirements of the target devices. For example, a high bit-rate 3D TV program that is originally compressed for studio application can be transformed to 2D video with lower bit-rate. This is in order to meet the transmission bandwidth requirements of the 2D video devices. Also, the 3D video transcoder can also be used to insert logo, watermarks and add error resilience features.

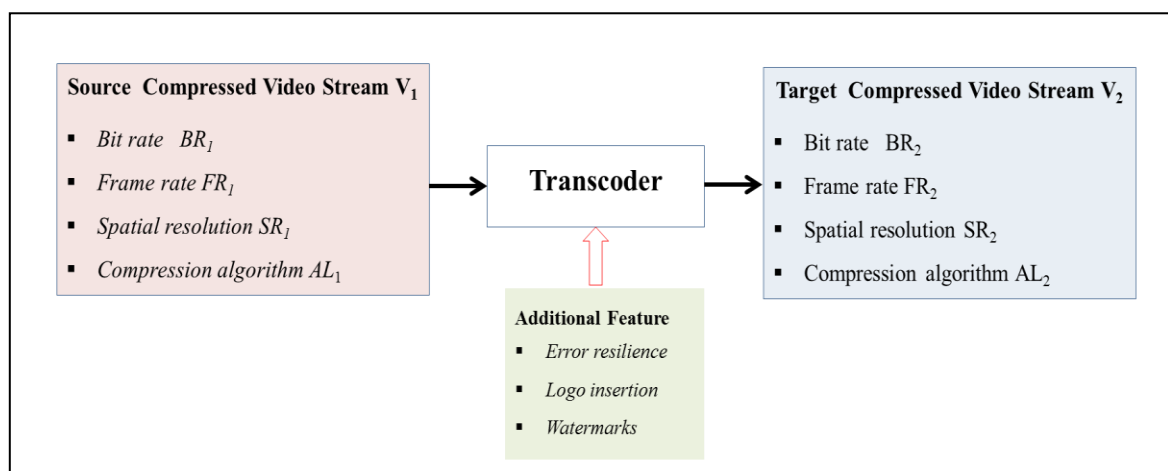


Figure 5.2: Conversion Element of Video Transcoder

3D video transcoding is essential for content adaptation and peer-to-peer (P-2-P) network over a shared communication medium [43, 283]. A straightforward 3D video transcoding method involves simultaneous decoding and re-encoding of the compressed bitstream. However, for real-time applications this process is computationally complex. Therefore, there is a need to exploit a mechanism such as motion information re-use that is already available through the compressed video bit-stream in order to speed-up the conversion and reduce computational complexity.

The purpose of this chapter therefore is to present MVV-AIR transcoding with a view to convert compressed 3D video bitstream to 2D video devices destination. The chapter will cover video transcoding architectures and proposed MVV-AIR transcoder. It will also discuss the error resilience video transcoding as well as the implementation strategy of MVV-AIR transcoder. The 3D video transcoding using same H.264/AVC format will also be highlighted. Finally, the experiment, simulation and data analysis of MVV-AIR transcoding would be discussed.

5.2 Robust Transcoding Methods

An appreciation of the role of error resilience transcoding technique is presented in this section. We also review existing literature on robust video transcoding techniques. The challenges and process involve in robust MVV transcoding are presented. A study of related on robust transcoding technique indicates that error resilience entropy coding (EREC) was among the earliest methods [284]. In this technique incoming bitstream is rearranged in MPEG-2 standard without adding redundancy. The method exploits synchronization units to reduce the bit-rate of VLC codes. The synchronization markers decide if corrupted frame due to transmission errors should be dropped. However, the major pitfall is the issue of computational complexity. Furthermore, the performance of the technique degrades with a decrease of PSNR.

According to Reyes et al. [175], a robust transcoder was proposed that employed rate-distortion framework. However, this error resilience transcoding method does not directly consider periodic insertion of the intra-coded macroblock. As a result, the performance of the video quality of the transcoder degrades with significant random noise effect. Dogan et al. [31] demonstrated that AIR error resilience developed for feedback control signaling (FCS) can improve the robustness of video transcoding operation. Adaptive Intra Refresh technique was employed in this study to mitigate error propagation.

In [10] Cote et al. presented a transcoder with optimal error resilience insertion subject to optimal macroblock mode selection and resynchronization marker. Zhang et al. [285] pointed out that adding error resilience using pixel-level precision can increase the robustness of video transcoding. The method is accomplished without adding additional computational constraints.

Wang et al. [286] considering a transcoder that focus on networking-level mechanisms. Their study proposed an ARQ proxy error resilience transcoder that operates at the gateway of a wireless network. The error resilience transcoder handles ARQ requests and mitigates errors thereby reducing retransmission delays. The transcoder process involves the use of ARQ proxy to resend vital information such as motion vectors. Furthermore, the technique uses to drop less critical packets information that contained DCT coefficients in order to enhance bandwidth efficiency. The missing information is detected through the request of retransmission via feedback channel.

Figure 5.3 illustrates the block diagram of the proposed MVV-AIR transcoder. The newest technology is comprised of reconstruction motion vector block, flow control block, buffer, AIR error resilience and the transcoder. Before the entry of the incoming signal to the transcoder the noise channel might induce error into the bitstream. The flow control block identifies the noise distortion variation in the channel. It further analyses the data variation as a result of motion active in the frame. The transcoder block operation in line with AIR error resilience. In order to ensure robustness, the AIR error resilience generates the MVV-AIR refresh map. The sets threshold values influence the generation of AIR refresh map. The shortest credible way to update the refresh map is to compare the predetermined threshold with a bit-rate variation of high motion frame. A buffer is also used to scale the motion information and facilitate re-used of reference motion vector.

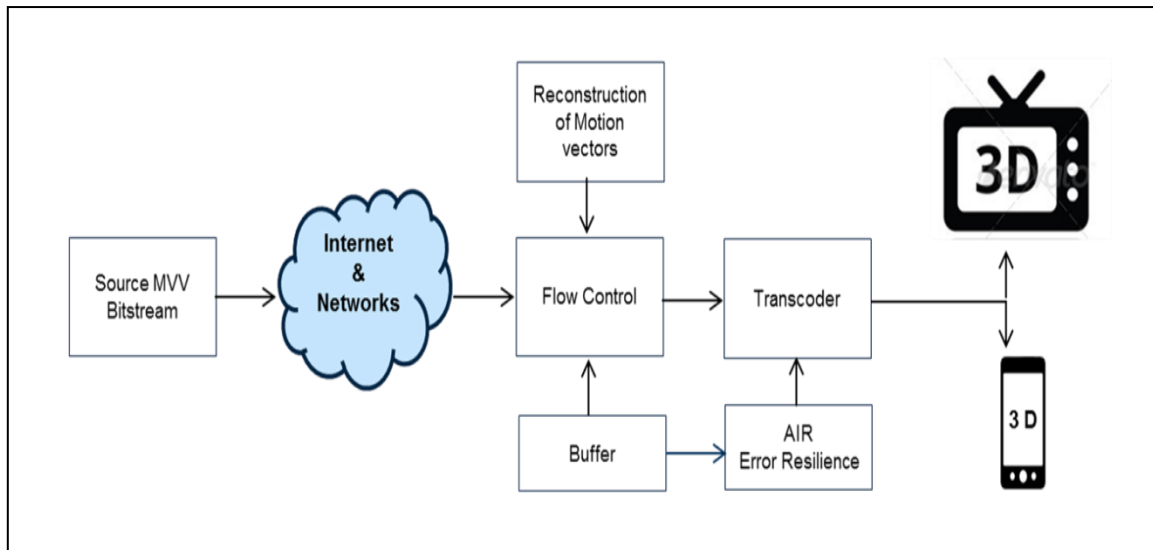


Figure 5.3: Block Diagram of MVV-AIR Transcoder

5.3 Video Transcoding Architectures

There are essentially, three types of video transcoding architectures [17], these are:

- Open-Loop Transcoder
- Close-Loop (DCT Domain) Transcoder
- Cascaded (Pixel Domain) Transcoder

Figure 5.4 depicts the simple transcoder architecture. The transcoder block is divided into decoder parts and encoder parts. The incoming compressed bitstream to the transcoder is first decoded by the transcoder. Then the encoder part of the transcoder re-encodes the video sequence to match the target device requirement.

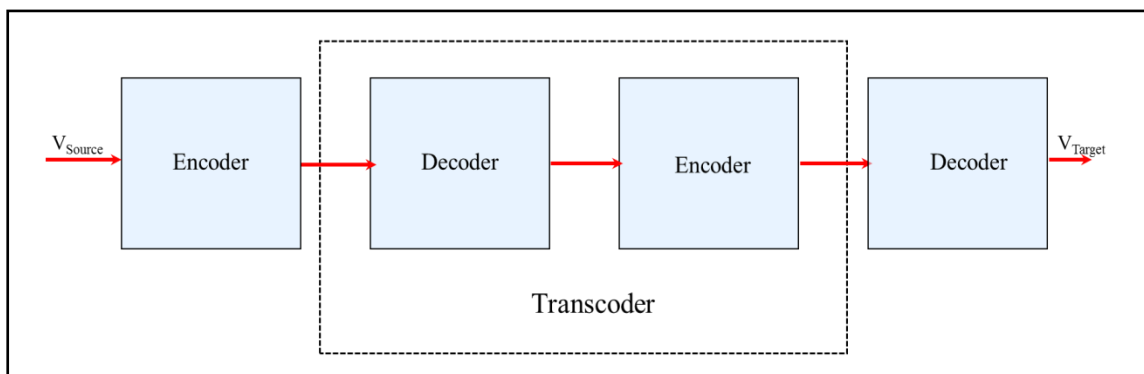


Figure 5.4: Simple Transcoder Architecture

5.3.1 Open-Loop Transcoder

Figure 5.5 shows an open-loop transcoder system. The input bitstream is decoded by a variable-length decoder (VLD). The generated coefficients are inverse-quantized coefficients represented in the diagram as Q_1^{-1} . The Q_1^{-1} is added to DCT coefficients goes to the Q_2 . The VLD also obtain motion vectors information for each macroblock which is used to compute the target bitstream. Finally, the variable length coding (VLC) encodes the target bitstream which is generated with reference to the store motion vector information. The open-loop transcoder is suitable for bit-rate transcoding. The bit-rate transcoding consists of decreasing the video stream bit-rate. The bit-rate reduction mechanism can be achieved using specific Rate Control function.

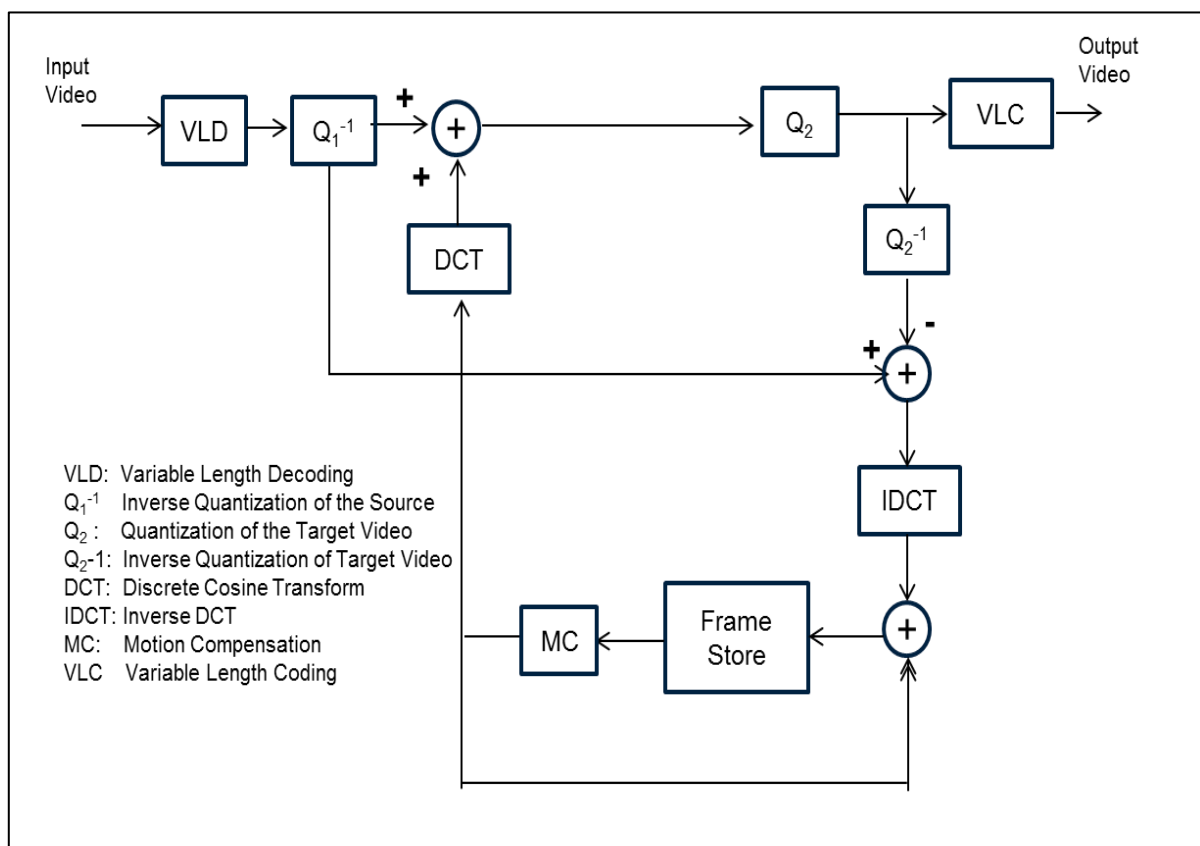


Figure 5.5: Open-loop Transcoding

5.3.2 Close-Loop - DCT Domain Transcoder

The DCT domain transcoder offer a simplest video transcoding process. Figure 5.6 shows the architectural design of the DCT domain transcoder. The information about macroblock level and the DCT prediction error is extracted by the VLD. A new DCT prediction value is constructed using DCT conversion factor. For example, conversion factors of 2 will only facilities 4×4 DCT coefficients of each 8×8 macroblocks to be retained. Consequently,

DCT coefficients with low-frequency from each block are exploited to generate the output video. The DCT domain transcoder is good for spatial transcoding as spatial transcoding involves reducing the frame resolution of the input video stream.

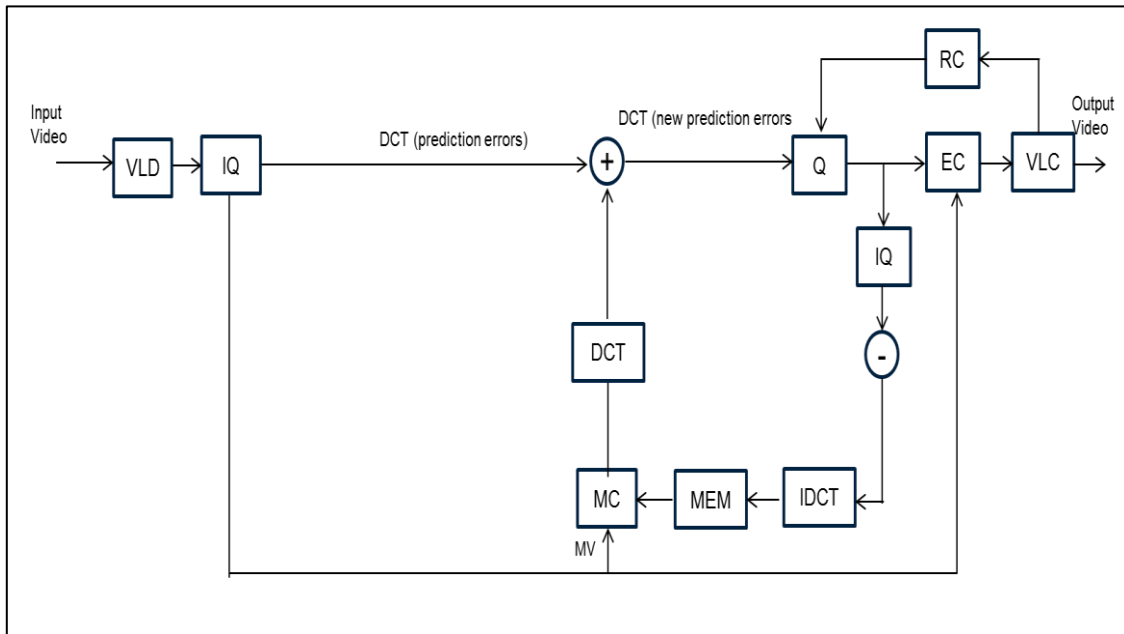


Figure 5.6: DCT Domain Transcoding

5.3.3 Cascade - Pixel Domain Transcoder

Figure 5.7 shows the pixel domain or cascaded transcoder. In the cascaded method, the transcoder decode and re-encode the input compressed bitstream in tandem operation. This technique includes decoding incoming bitstream fully and then scale down the entire data of the decoded sequence before re-encoding the same data again. The pixel domain technique involve complex frame down scaling and re-ordering of approximately 16 pixel motion re-estimation operation. Pixel transcoding is often use in temporal transcoding by dropping some frames and then re-compute using new motion vectors. The new motion vectors can be acquired by interpolating the motion vectors of all dropped frames. Consequently, the prediction errors must be computed according to the new motion vector.

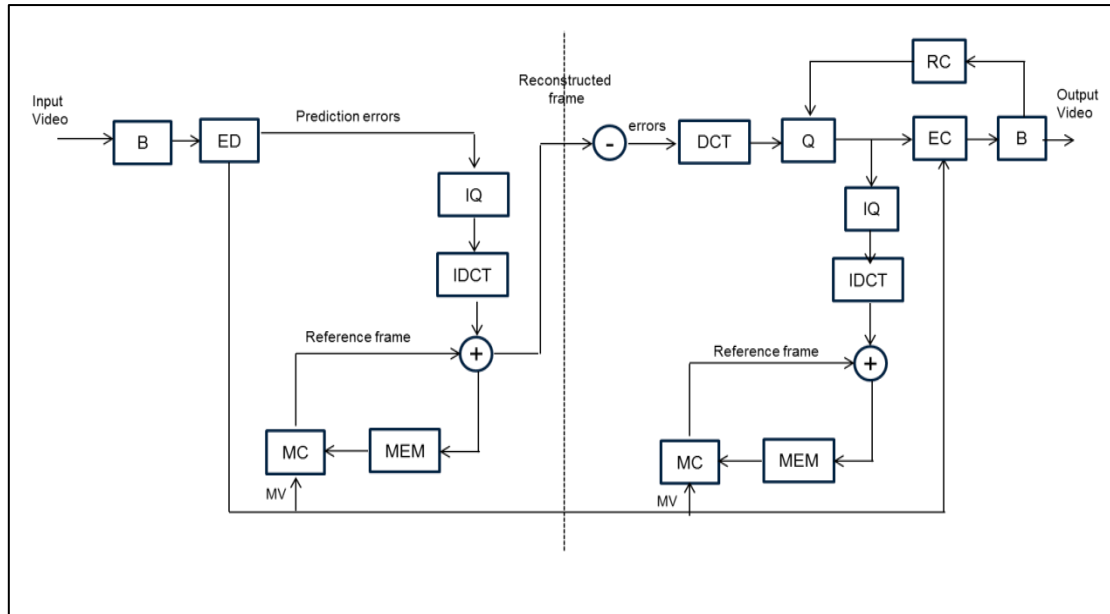


Figure 5.7: Pixel domain Transcoding

5.3.4 Proxy Transcoder

In practice, the most widely used video transcoder is the proxy type, where the transcoder is located at a central point known as the gateway. The transcoder can also be co-located with either a transmitter or receiver. In spite of the location, the purpose of a transcoder is to convert one coded signal to another with lower computational complexity and latency. According to [287] spatial and view downscaling algorithm is the most appropriate transcoding method from multi-view to a single view. This process extensively makes use of both reference frame and pictures motion information reuse. If the bit-rate distortion is indeed computed than highly compressed 3D video data should be transform into single view 2D video format.

In this research work, a proxy video transcoder is used to convert 3D video from multi-view video to single view video. Adaptive Intra refresh error resilience is added in order to mitigate transmission error propagation that might occur when conveying the bitstream over a wireless environment. Figure 5.8 depicts the block diagram of the distribution scenario of the MVV-AIR transcoder. The MVV-AIR proxy transcoder is sandwiched between low BER/high bandwidth network and high BER/low bandwidth networks.

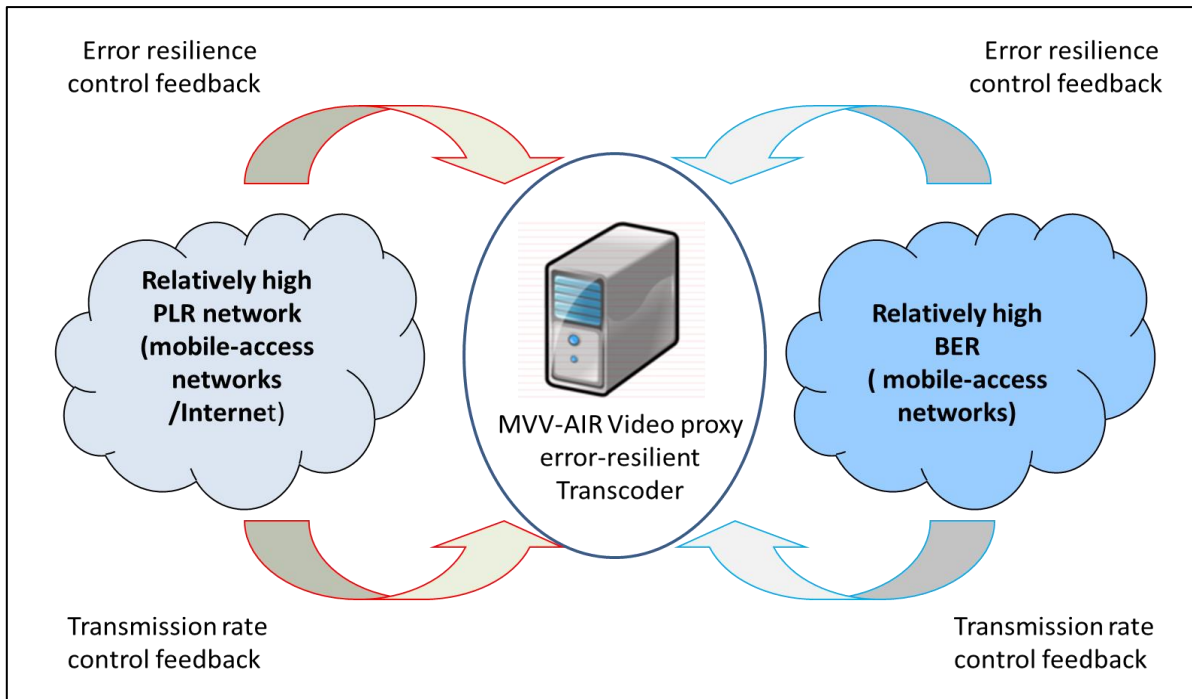


Figure 5.8: MVV-AIR Transcoding Scenario

5.4 Proposed MVV-AIR Transcoder

We proposed MVV-AIR transcoder that robustly convert compressed 3D video to single view video using H.264/AVC codec. In the design of the MVV-AIR transcoding algorithm, three camera views in a GOP setting are used. Figure 5.9 depicts the structural block diagram of the proposed cascaded MVV-AIR error resilience transcoder. The diagram illustrates the concept of video transcoding from multi-view to single view. The two rectangular areas represent the decoder and encoder sections of the transcoder. It is pertinent to stress that the decoding and encoding operation in a video transcoder follows the same decoding and encoding mechanism of a standard video codec. We, therefore, need only to emphasize on the suitable process of downscaling the data. The downscaling algorithm reduces the massive multi-view video data to single view by removing excess view data to form single view information. Similarly, vital information about the scaled data and motion vector information are stored in the reference picture memory (RPM) block.

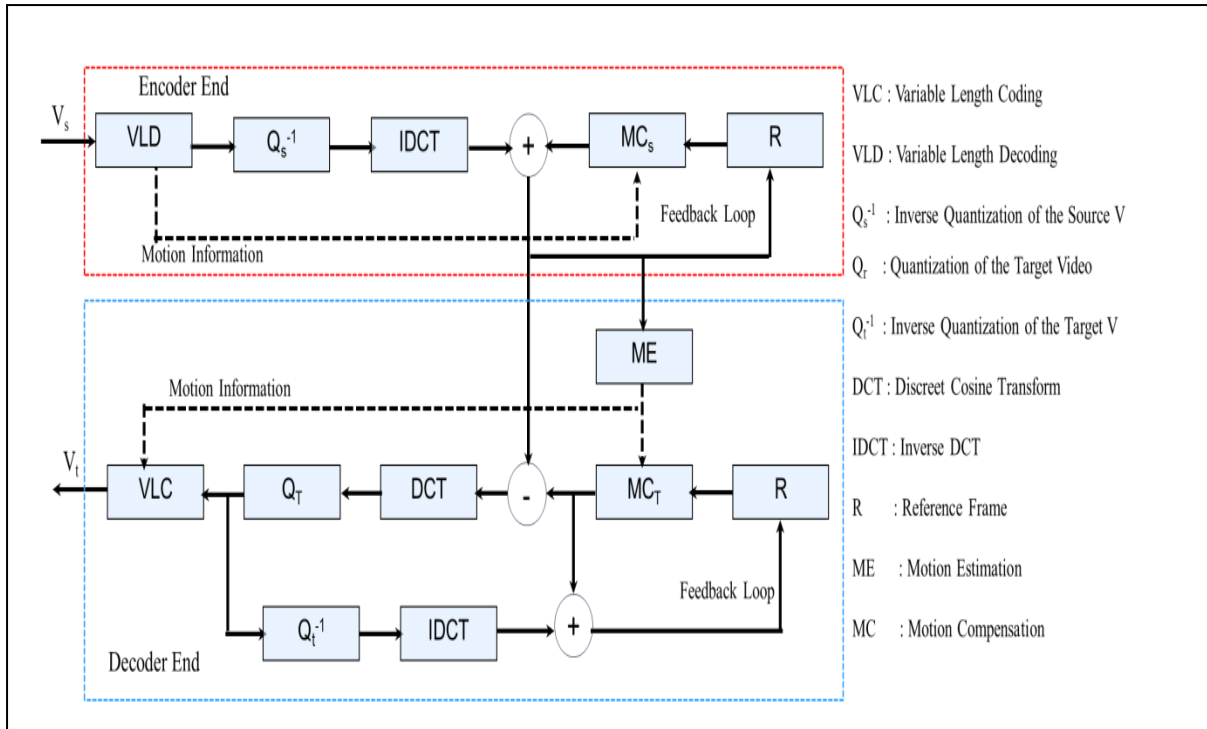


Figure 5.9: MVV-AIR Architecture

At robust encoder end of the transcoder, the information contained in the RPM and the motion compensation simultaneously re-encoded the decoded data in conformity with the requirement of the target device or network. For our proposed transcoder system it would seem reasonable to state that there is no picture drift and no additional computation complexity associated with conversion operation. The re-use of valuable statistical coding information parameters facilitates reduction of complexity and enhance the quality performance of the transcoded video. However, the dynamic nature of wireless channel which is characterised by interference, multipath and noise retransmission pattern. Random time variation due to mobility of communication devices also affects video communication. In most cases impulse noise due to transmission error severely affect compressed bitstream. Thus, video to support efficient multi-view video transcoding over wireless channel error control mechanism is essential.

In this design, AIR error resilience is added to mitigate error propagation. The operation of AIR depends on two issues namely changing channel condition and macroblock motion activity in GOP. In the first case, channel bit-rate varies over time as compressed bitstream path through a different level of free space noise environment error may affect the transmitted signal. In the second case, bit-rate variation due to random motion in the high active

macroblock is likely to cause larger drift error. Therefore, AIR error resilience method added to the design of this transcoder can effectively restrict the spread of this kind of error.

5.4.1 Design Objectives

The MVV-AIR transcoding design was done in order to achieve the following objectives:

- To provide uninterrupted flow of 3D video in real-time applications to 2D video mobile device.
- To provide quality transcoded bitstream that should be comparable to the one obtained by direct encoding and decoding of the target stream
- To make use of the information contained in the source bitream as much as possible so as to avoid introduction of additional distortion.
- To develop high quality, low cost and low complexity transcoder.

5.4.2 Application Requirement

There are three major applications that video transcoder can provides these are presented in Table 5.1. The choice of any of this video transcoding application depends on the function the transcoder is expected to perform. On the one hand, video transcoding is planned to adapt convert the bit-rate of a high compress bitstream into low bit-rate. On the other hand, video transcoding is developed to allow the target bitstream adapt to the dynamic changing channel condition and bandwidth availability.

Table 5.1: Video Transcoder Classification and Function

Serial	Transcoding Classification	Function
1.	Heterogeneous	<ul style="list-style-type: none"> ▪ Interlaced and Progressive ▪ Format changes between standards
2.	Homogeneous	<ul style="list-style-type: none"> ▪ Change of bit rate with changing resolution ▪ Adjustment of spatial resolution ▪ Temporal resolution adjustment ▪ Conversion from single to multi-layer ▪ VBR and CBR
3.	Special	<ul style="list-style-type: none"> ▪ Enhanced error resilience ▪ Insertion of logo and watermarking

5.4.3 Complexity Reduction

In the MVV-AIR transcoding methods described here, significant computational complexity is reduced. The reduction in computational complexity is achieved by re-using of vital information. The re-use of information such as coding parameters has prompted the high bit-rate speed performance and provides high-quality video resolution. Furthermore, re-use of motion vector information refinement overcome the loss of quality and drastically eliminate the complexity of using full motion re-estimation. According to Youn et al. [225, 258], reusing the motion vectors leads to imperfect transcoding results. They confirmed that reference information re-used eradicate disparity between prediction and residual components as well as minimize the use of resources. Consequently, in this research MVV-AIR error resilience is added to compliment the drawback that leads to imperfection introduced by reuse of motion vectors.

5.5 Implementation

As highlighted at the beginning of this thesis, implementing a robust video transcoding is a key technology that permits interoperability of multi-view video content among diverse networks. A wireless environment characterized by interference, additive noise and fading, is still the dominant medium of communication today. Therefore, successfully implementation of MVV-AIR transcoder application in the wireless environment requires a low delay, less sophisticated and robust system. Implementation of the MVV-AIR transcoder for wireless communication considers the use of motion information re-used in the H.264/AVC standard.

Figure 5.10 shows a cascaded MVV-AIR transcoder modified to use motion information re-used and provide the desired target result. The process involves decoding the incoming compressed 3D video bitstream as well as scaling it down to meet the characteristic of the target single view video. The technique exploits only variable length decoder (VLD) and inverse quantization to control the target output bit-rate dynamically. We assume that the MVV-AIR transcoder will operate with compressed bitstream that is transmitted over constant bit-rate (CBR) communication channel.

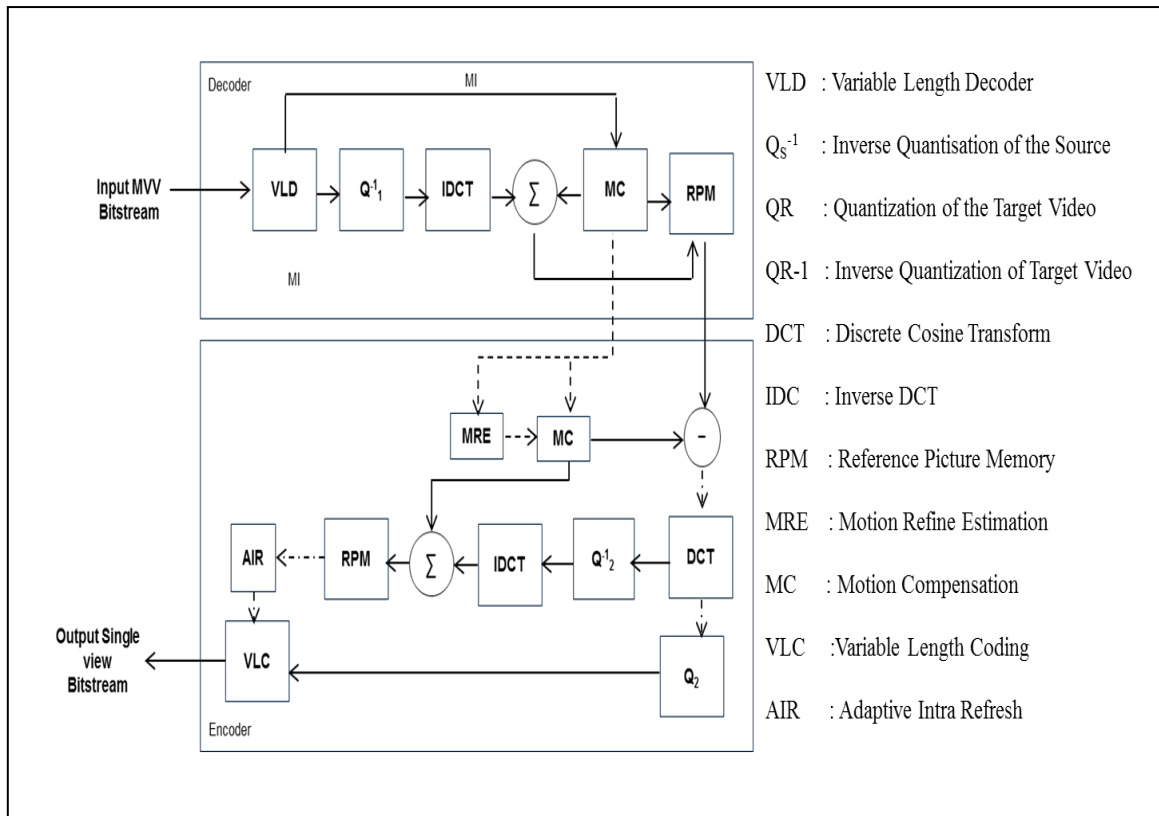


Figure 5.10: Proposed MVV-AIR transcoder scheme

The MVV-AIR transcoder is developed to robustly incorporate motion information re-use and offer full decoding and encoding operation with unattended processing of incoming bitstreams. Consequently, the encoder part of the MVV-AIR transcoder obtained information about motion vector from the data based stored in reference picture memory (RPM). Similarly, in determining the target output bitstream, it is important to factor in the DCT values and inverse quantization. Motion compensation of the frequency-domain module are used to reduce the drift error. Second quantization is required at this stage to checkmate the effect of drift error. The AIR error resilience periodically inserts Intra-coded macroblock to mitigate spatiotemporal error propagation. Figure 5.11 shows a flow chart of the MVV-AIR algorithm for the selection and insertion of intra-coded macroblocks to the target.

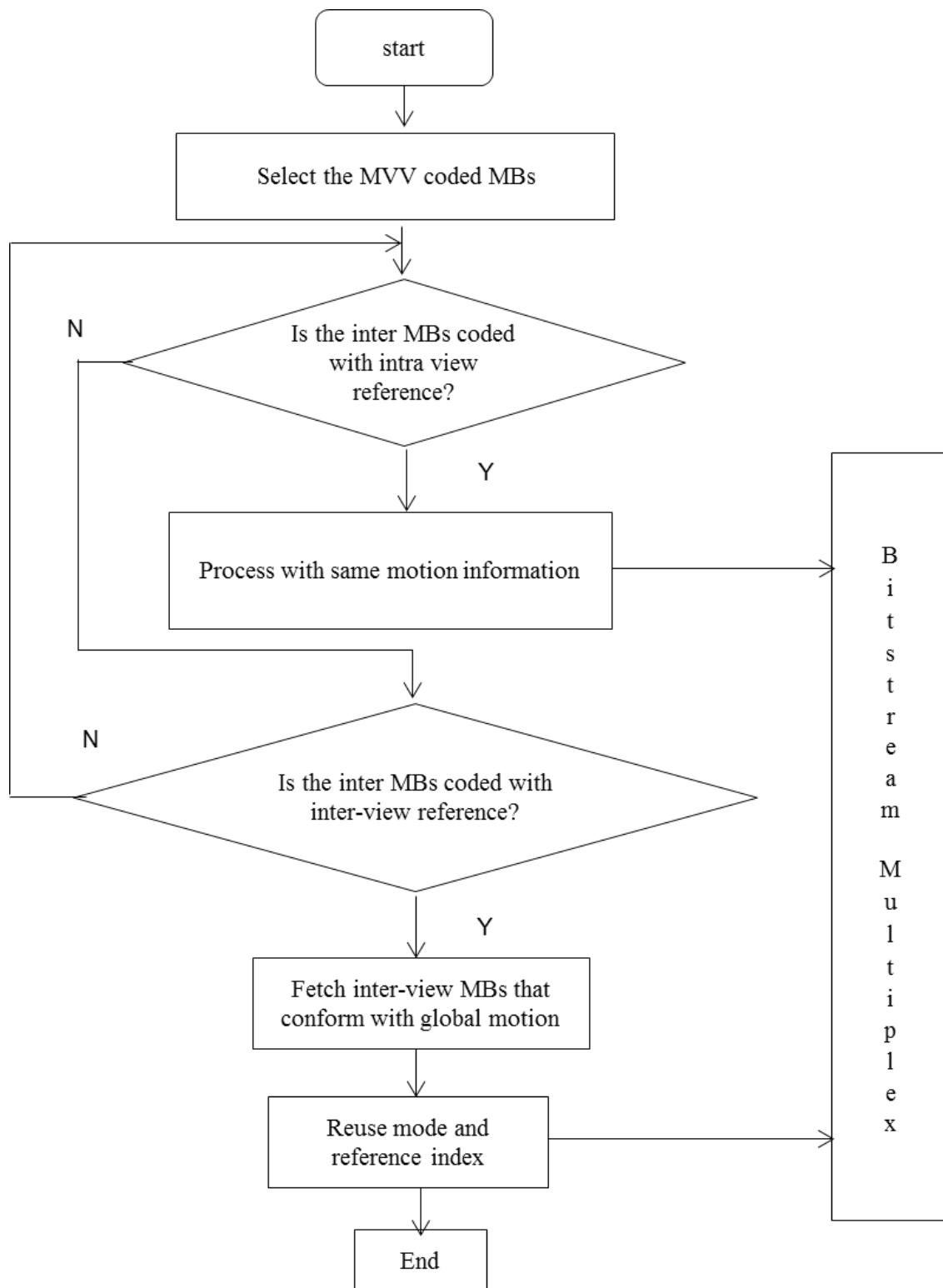


Figure 5.11: Flow Chart for MVV-AIR Transcoding

The H.264/AVC is universally recognized to be one of the leading video coding and conversion formats [288]. With the H.264/AVC an incoming compressed multi-view video can be converted into a single video bitstream with lower quality resolution. This is achieved

by exploiting re-quantization features to reduce bit-rates, frame rate, spatial and or temporal resolution.

5.6 Experiments and Simulations

In this Section, we present the MVV-AIR transcoding simulation carried out. For a fair comparison, we test our proposed MVV-AIR transcoder with existing approach namely Cascade and H.264 error resilience methods [288]. The implementation of the algorithm was based on H.264/AVC modified JMVC software version.

5.6.1 Experimental Set-Up

Three standard video sequences: Ballroom, Exit and Vassar (640 x 480) are used as the testing video. JMVC version 8 Reference Software is employed with QP 22, 27, 32 and 37. The simulation followed the common MVC test conditions standard that is defined in [38]. While noting the obvious vital role of the video transcoder, performance evaluation tests using the established standard related three camera views.

In our experiment, we use SIRANNON wireless network simulator platform [58]. To evaluate actual performance of MVV-AIR code, the platform specification employed in this thesis is given in Appendix D. Figure 5.12 depicts the Sirannon network modules. The Information Management Program Evaluation Group (Impeg) read the input bitstream data, and the video packetizer grouped the data into packets. The audio section is disabled. Finally, the data path through noise free and noisy channel environment in the real time protocol (RTP) and Hypertext Transfer Protocol (HTTP). In the simulation noise corrupted the video are by ratio varied from 5%, 10%, and 15% to 20%. The sink reconstructed the transmitted. Simulations were conducted 50 times and average values of bit-rate and PSNR were recorded for Ballroom, Vassar and Exit sequences.

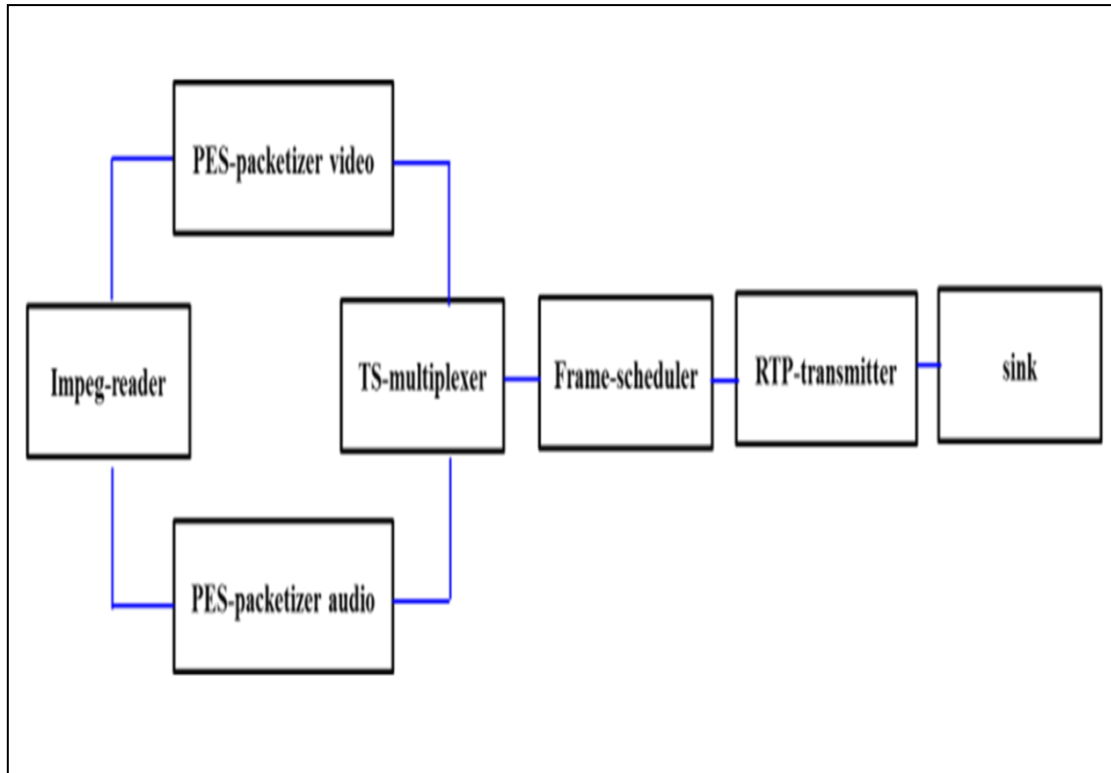


Figure 5.12: SIRANNON Network

5.6.2 The Ballroom Sequence

We employ PSNR to illustrate performance in terms of quantitative quality of the decoded video for various techniques using Ballroom sequence in the (640 x 480). Within different values of threshold, different PSNR and bit-rate results of the proposed transcoder were obtained. For comparison purpose, we used an anchor bit allocation method that insert intra-coded macroblocks and a fixed intra refresh rate of 20% cyclic refresh pattern. Figure 5.13 shows plots of the average PSNR performance comparisons of the rate-distortion (RD) for Ballroom sequences. In the plotted graph, the MVV-AIR scheme achieves similar PSNR performance to the cascaded and H.264. The MVV-AIR outperform and H.264 technique with approximately 0.4dB.

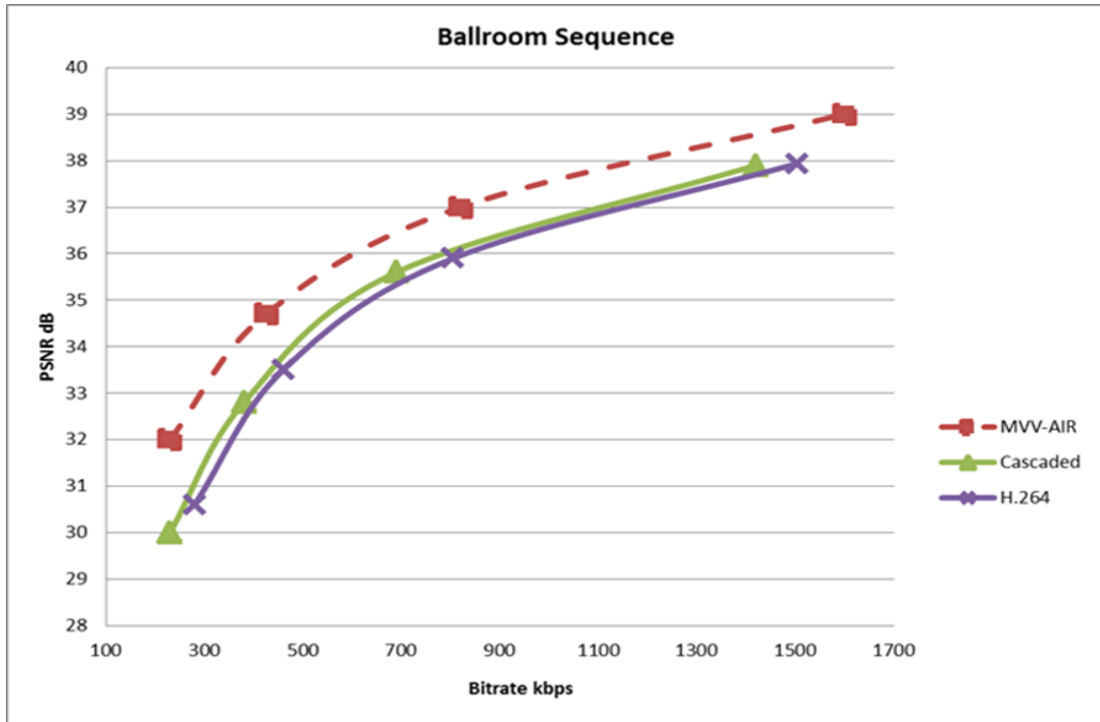


Figure 5.13: Ballroom Sequence

5.6.3 Exit Sequence

The MVV-AIR transcoder has about 0.2dB improved in rate distortion performance using Exit sequence as shown in Figure 5.14. The reason for this performance relates to the limited selection of inter-view predictions during encoding.

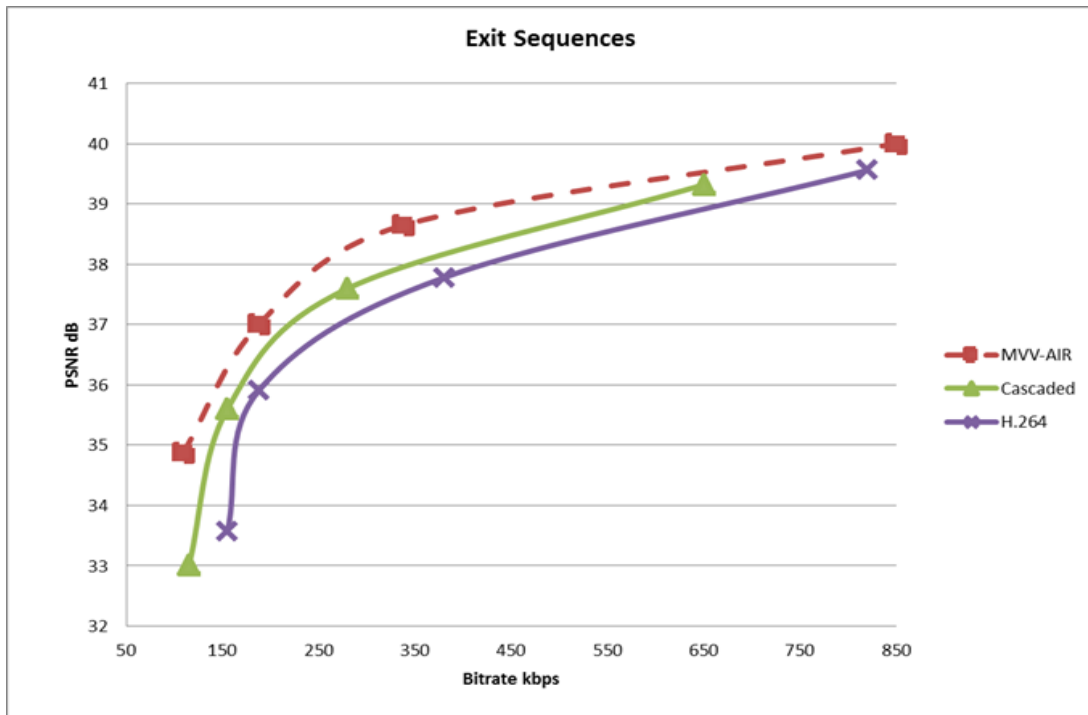


Figure 5.14: Rate Distortion Performance Exit

5.6.4 The Vassar Sequence

Using Vassar sequence, we also compared the quantitative quality performance of the MVV-AIR transcoders with Cascaded and H.264 at fixed value bit-rate using similar rate control method. Figure 5.15 show the rate-distortion performance for Vassar sequences. Apparently, MVV-AIR approach performs significantly better than the Cascaded and H.264 transcoder scheme. The comparison of reconstructed video in PNSR shows MVV-AIR has about 1.02dB improved performance regarding rate distortion. The highest improvements with Vassar sequence despite being the least motion video are due to lest insertion of intra refresh macroblock.

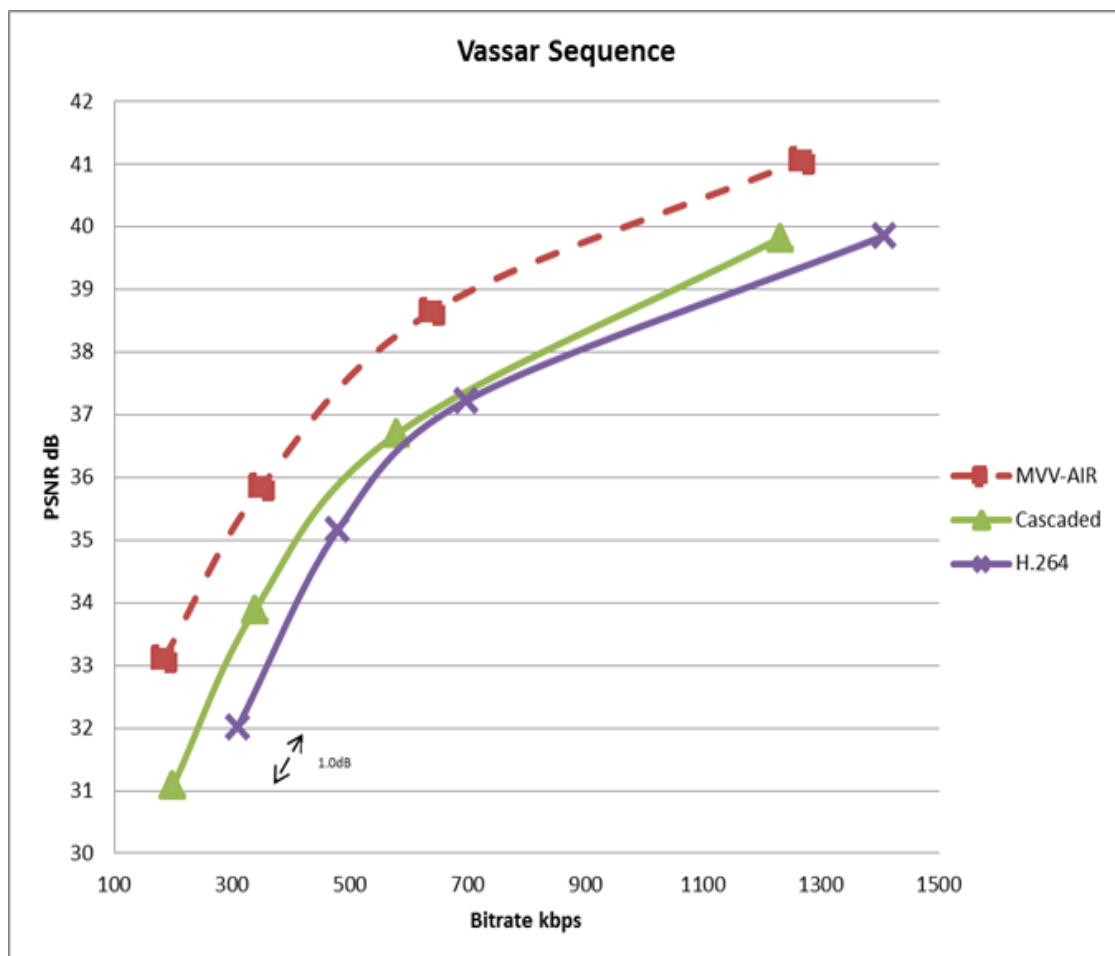


Figure 5.15: Rate Distortion Performance Vassar

Table 5.2 lists the average results in PSNR (dB) of MVV-AIR-C, Cascaded-B and H.264-A of different approaches for Ballroom, Exit and Vassar sequences. To explore the perceptual quality, we present the reconstructed video of difference packet loss rate corrupted video in 5%, 10%, 15% and 20%. Indeed, our method MVV-AIR-C scheme significantly perform better PSNR gain than H.264-A and the Cascaded-B scheme

Table 5.2: PSNR Comparison

Sequence	Scheme	PSNR (dB) Packet Loss Rate			
		5%	10%	15%	20%
Ballroom	H.264-A	31.28	31.18	30.80	30.07
	Cascaded-B	32.40	32.24	31.79	30.79
	MVV-AIR-C	33.90	33.04	32.34	31.05
Exit	H.264-A	30.68	30.38	30.12	30.02
	Cascaded-B	31.60	31.24	31.19	30.79
	MVV-AIR-C	32.90	32.64	31.34	31.05
Vassar	H.264-A	30.28	30.18	30.10	30.02
	Cascaded-B	31.57	31.23	31.09	30.79
	MVV-AIR-C	33.06	32.79	32.34	31.75

In contrast, Figure 5.16 shows the average PSNR performances comparison for HTTP transmission using Ballroom, Exit and Vassar sequences. The MVV-AIR transcoder is more robust than the Cascaded and H.264 methods.

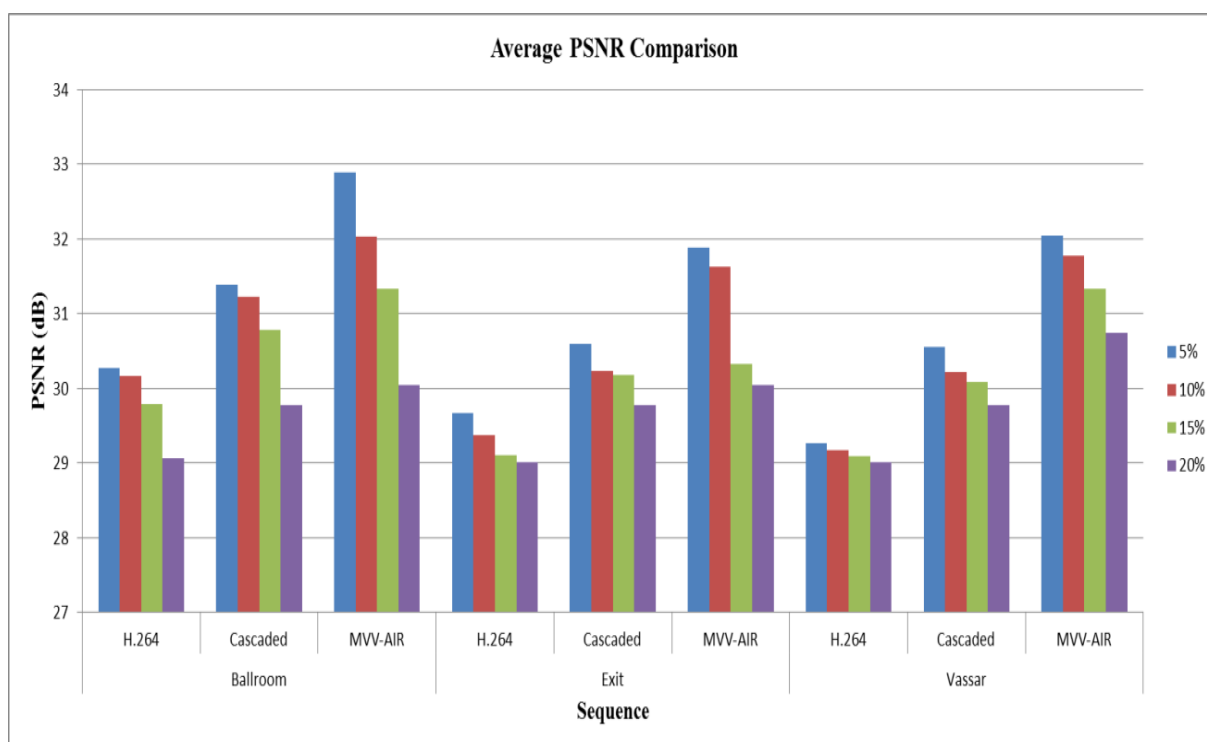


Figure 5.16: Hypertext Transfer Protocol Transmission

Figure 5.17 show the subjective result of selected decoded frames from Ballroom, Exit and Vassar sequences. The video depth and luminance are exposed to packet loss rate of 5%, 15% and 20%. The bitstream files that are corrupted are also decoded. Apparently, the subjective video quality of the H.264 methods the quality is worst at 10% and 20%. In contrast, the MVV-AIR method has better subjective quality result than the H.264 and Cascaded method. The MVV-AIR transcoder can remove noise efficiently by periodic insertion of a cyclic line of Intra refresh macroblocks. The subjective shows that MVV-AIR transcoder does indeed meet end users eceptations.

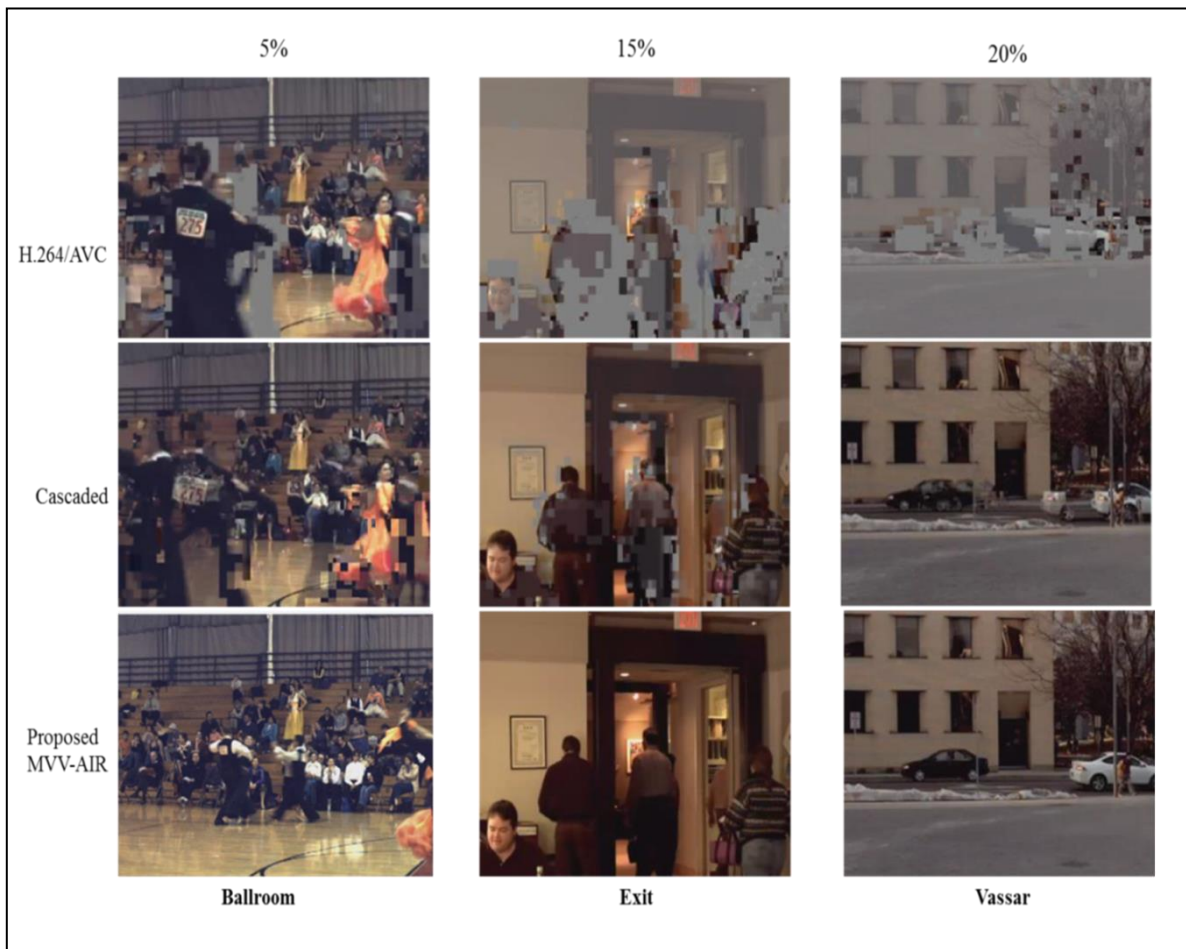


Figure 5.17: Subjective Result

Figure 5.18 shows how much operation time it takes the transcoder to deliver a packet of data from one selected point to another. From the figure, it is confirmed that the MVV-AIR technique achieves the best latency performance as compared with the Cascaded. Note that the MVV-AIR has less computational complexity than the Cascaded method.

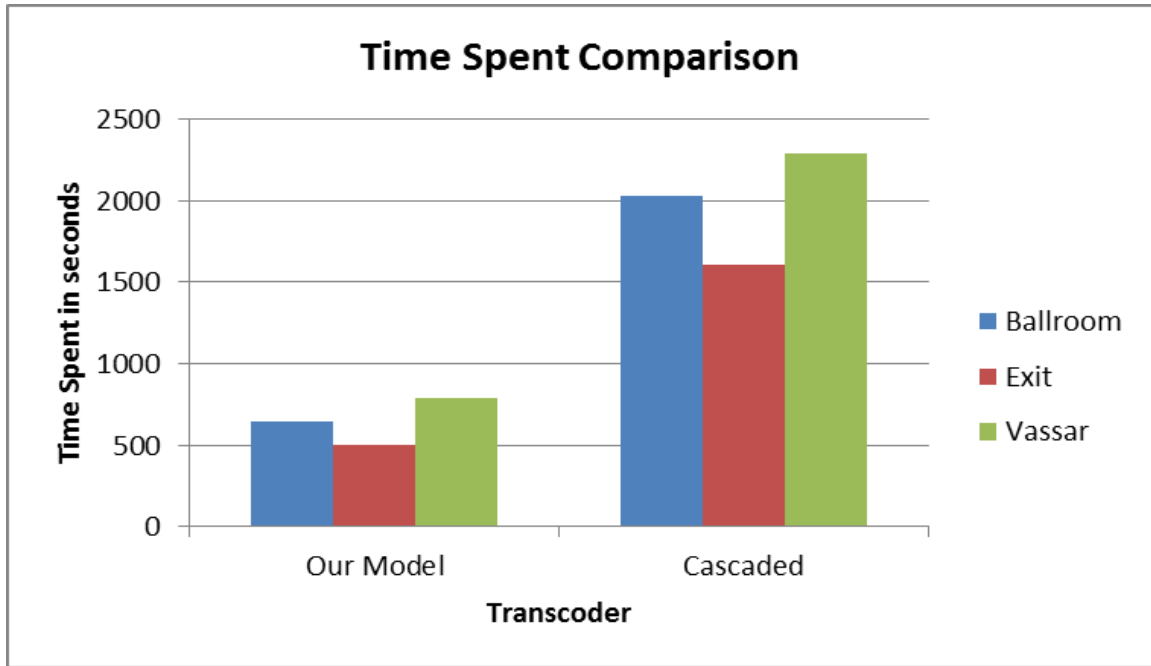


Figure 5.18: Latency Performance

Figure 5.19 shows the results of the error transmission and packet losses. According to this plotted graphs, the PSNR values for H.264 and Cascaded scheme dramatically decline with packet loss rate increases from 0% to 5%. However, the PSNR levels further gradually decrease from 5% to 20%. But, the pattern changes with the MVV-AIR because the added AIR error resilience mitigates the erroneous frames periodically. The PSNR of MVV-AIR scheme under packet loss of 5%, 10% and 20% are 3dB higher than Cascaded scheme.

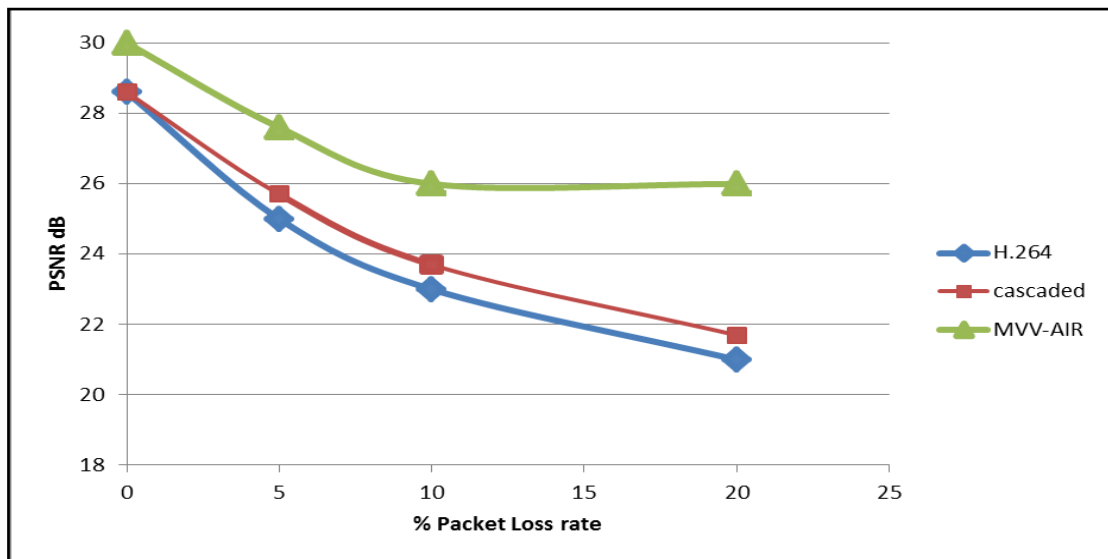


Figure 5.19: Internet Cascaded Test

5.7 Summary

In this chapter, we have presented robust multi-view video transcoding algorithms using Adaptive Intra Refresh error residence schemes. The Adaptive Intra Refresh periodically inserts Intra-code macroblock to mitigate error propagation in the target bitstream. The first two sections of the chapter covered an overview of error resilience video transcoding and transcoding architecture. Next, we described the proposed MVV-AIR transcoder that uses motion information re-use to convert compressed bitstream from multi-view video format to single view video format.

The experimental results demonstrated that proposed MVV-AIR transcoding schemes seeks out and suppress effect of noise interference on the transmission channel. Moreover, the MVV-AIR transcoder shows better performance over all the PLR ranges. The Cascaded transcoder requires more time to operate than the MVV-AIR transcoder. The proposed robust MVV-AIR transcoding structures can be easily applied to higher video standard such as H.265/HEVC.

Chapter 6

Conclusions and Future Work

This chapter summarizes the whole thesis and draws a conclusion. Section 6.1 covers a general summary. The general conclusion is presented in Section 6.2. Finally, Section 6.3 suggestions for further future work.

Adaptive Intra Refresh is a simple error resilience technique that allows robust transmission of video content over a wireless network. It is particularly useful for mobile 3D video communication which is a sensitive subject today. However, high level of burst and random bit error from wireless channel impacts on 3D video communication. The transmission error severely deteriorates the QoS affecting end user QoE. Therefore, an error resilience strategy is needed to protect the compressed bitstream from transmission errors. In particular, this thesis focuses on a traditional AIR error resilience scheme to make the compressed 3D video more robust against transmission error propagation. We introduced a simple cyclic AIR method in H.264/AVC to suppression spatiotemporal error propagation. The AIR algorithm developed takes into account each macroblock individual features to generated MVV-AIR map. To speed 3D video recovery from transmission error propagation high motion GOP is selected to be Intra-coded. We explore MVV-AIR transcoding scheme to validate the effectiveness of the developed MVV-AIR error resilience algorithm. The MVV-AIR transcoder employed motion vector information reuse to convert compressed bitstream from multi-view video format to a single view video. The 3D video transcoder algorithm developed has low computational complexity.

6.1 General Summary

After a brief introduction in chapter one, we presented background information by reviewing the three core issues that are central to this study in chapter two. The three key points are wireless communication, error resilience, and video transcoding. Various efforts have been made to write on the concept relating to wireless communication, error resilience and video transcoding. Most of the published research work and books reviewed covered these areas adequately. Some researcher also treated the relationship between error resilience and multi-view video transcoding. This study acknowledged the work already done in this field. However, it went a little further to evaluate the current state of the art of AIR, Data

Partitioning, Multiple Descriptive Coding, flexible macroblock ordering and Reversible Variable Length Coding error resilience capability over wireless networks. It then looked at the characteristics of 4G and future 5G networks. The 5G network would establish a better QoS for efficient transmission of compressed 3D video bitstream. The 5G Technology will offer enhanced connectivity for 3D video transmission.

In chapter three, we presented a subjective quality assessment to appraise the human perception with regards to QoS and QoE. The subject test was performed based on publicly available data collated on wireless transmission of 3D video clip. A total of 280 respondents from the Brunel University London UK and Nigerian Defence Academy, Kaduna, Nigeria were made to watch 3D video and complete questionnaires. Of the number respondents, 110 were male, and 170 were female. It was discovered that most respondents response correlated strongly with the overall perception of QoS significantly affect QoE. The chapter highlights the subjective video requirements and expectation of end user. We explore ITU-R recommendation subjective guidelines and Systems Analysis Technique to validate data collated. The data obtained were then used to answering the research question and testing of the hypotheses. The statistical results demonstrated the correlation of 3D video with human perception across contents. One major limitation is our in the ability to use structural similarity (SSIM) index to predict the perceived 3D video picture quality.

In chapter four, we designed an AIR error resilience technique for 3D video transmission over wireless networks. A robust and efficient cyclic AIR algorithm for GOP Intra refresh in H.264/AVC was presented. The objective is to mitigate the spatiotemporal error propagation and improve the perceptual video quality of 3D video over wireless networks. Experiments are conducted using H.264/AVC standard. The simulation was carried out with Sirranon software to validate the result obtained using H.264/AVC. Finally, the chapter demonstrated that the proposed MVV-AIR algorithm can efficiently contribute to the robust transport of multi-view video data over wireless networks. Above all, the objective and subjective rate-distortion performance evaluations of our algorithm outperform that of FMO, RIR and NER under noise-free and error-prone environment. However, the major weakness of the methodology is the undesired increase in the bit-rate incurred. This problem has been overcome by employing an adaptive Intra refresh scheme.

In chapter five, we presented the multi-view video Adaptive Intra Refresh (MVV-AIR) transcoding technique that we have developed. The MVV-AIR transcoder process involves

variable conversion using the H.264/AVC standard. The chapter states the technical issues relating to our proposed MVV-AIR transcoding. Then, outline the techniques for converting compressed bitstream from multi-view video to single view video. The experimental results demonstrated that proposed MVV-AIR transcoding schemes are more robust than the H.264 and Cascaded transcoder system at high PLR rate. Moreover, the MVV-AIR transcoder shows better performance over all the PLR ranges. The Cascaded transcoder requires more time to operate than the MVV-AIR transcoder. The proposed robust MVV-AIR transcoding structures can be easily applied to higher video standard such as H.265/HEVC.

6.2 General Conclusions

The thesis proposes Adaptive Intra Refresh error resilience method for multi-view video over a wireless channel. The algorithm was validated through the intensive simulations that were carried out in chapters three and four. The performance of AIR error resilience was significantly better compared with FMO, RIR and NER under noise-free and error-prone environment.

Similarly, the performance MVV-AIR transcoder was compared with Cascaded and H.264/AVC standard for both errors free and noisy environment. In spite of the significant performance improvement of the MVV-AIR transcoder, the simulation results indicate that the MVV-AIR transcoder requires much lower computational complexity than the Cascaded with slight loss of quality. These achievements have answers the questions this thesis set. The four detailed thesis questions are broken down as follows:

- a. What is the nature and state of error resilience and video transcoding over the wireless network?

Error resilience and video transcoding over the wireless network has evolved from a small research area to great sensitive subject in the telecommunication industry and academia. Robust mobile 3D video communication is now vital communication and entrainment platform for many people. Furthermore, the emergence of smartphones with a broad range of applications operating on 4G networking platforms is the key success for mobile wireless 3D video communication.

Moreover, video transcoding has managed to create an enabling environment for interoperability between diverse communication devices and network. To this end, through

multi-view video transcoding, mobile devices such as Laptop and PDAs can decode and display encoded multi-view video bitstreams.

The future 5G wireless concept will open platform for mobile 3D video communication in different ways. The 5G technology will bring stronger mobile communication links; create all pie networks that will facilitate mobile 3D video calls.

- b. What are the implications of the MVV-AIR transcoding algorithm over the quality and computational complexity of the 3D video communication?

Extensive simulation and experiments on the MVV-AIR transcoding algorithm testing showed that the quality of transcoded bitstream does indeed meet end user expectations. Similarly, analysis of the MVV-AIR transcoder showed that no much computational complexity is involved.

- c. How does H.264/AVC to H.264/AVC transcoder perform based on MVV-AIR motion vector information re-uses?

Our tests show that MVV-AIR using the same H.264/AVC at the both the transmitter/receiver and using motion vector information re-used does indeed meet viewer's expectations. The reduction in computational complexity is achieved by re-used of vital information. The re-used of information such as coding parameters has prompted the high bit-rate speed performance and provides high-quality video resolution. Furthermore, re-use of motion vector information refinement overcome the loss of quality and drastically eliminate the complexity of using full motion re-estimation. Thus, reusing the motion vectors leads to imperfect transcoding results. Also reduce the disparity between prediction and residual components as well as minimize the use of resources.

- d. What strategies should be applied to suppress the effects of the transmission error propagation and sustain MVV-AIR transcoding?

Yes, the MVV-AIR can provide robust and reliable 3D video communication over wireless networks. The MVV-AIR performs better regarding network QoS parameters and end users QoE. It is, therefore, safe to say that MVV-AIR transcoder can be used for wireless communication without having to worry about degraded quality.

6.3 Future Work

The mobile 3D video communication is rapidly becoming popular in all aspect of our daily life. Millions of people today carry a smartphone with myriad applications including 3D video. Thus, this research focused on robust mobile 3D video transmission using MVV-AIR error resilience scheme. However, there are still many issues on robust multi-view video transmission as well as multi-view video transcoding that have not been addressed. Some of the identified areas which will need continued improvements and further future researchers work is as follows:

6.3.1 Multi- view Video Coding for Wireless Communication

Mobile wireless communications are by any measure the most dynamic segment of the telecommunications industry. The existing multi-video coding (MVC) is observed to be lagging behind the pace of mobile 3D video communication. This is because the predictive nature of MVC turned to be the cause of error propagation. Therefore, there is the need to consider coding each of the view separately in the H.264/AVC codec and the newest H.265/HEVC standard. With this, only the view demanded would be transmitted as compared with the present system of MVC encoding and transmission methods.

6.3.2 3D video communication over Future Internet

We are now living in a ‘Networked Era’ where the Internet has profoundly changed every aspect of our daily life. Also, the popularity of the cloud computing is rapidly growing. We can be connected at anytime, anywhere and to anything. The Internet of Thing (IoT) will also afford to join all kind of virtual objects and software. With the future networking systems, we shall see person-to-person and person-to-group 3D video communication with acute high resolution. However, many challenges are facing the future network. This includes:

- Flexible and efficient use of radio access to enable ubiquitous access to broadband mobile services.
- Problem of managing real time communications and time-varying network topology.
- The issue of Internet of Things (IoT) sub-networks integration.
- Elimination of the barriers to broadband access.
- Seamless QoS and QoE end to end network and service.
- Support to high-quality media services.

With these problems the future 3D video transmission schemes may not work efficiently. Therefore, there is a need for future researches to address these problems.

6.3.3 Assessment of 3D Video Quality Metrics

Another suggestion for a future area of research is in the field assessment for 3D video quality metrics. As we can see in chapter three there are various types of methods to assess 3D video quality subjectively. Since the subjective test is connected to user perceived experience, it has some subjective feeling that can directly or indirectly affect the personal judgements. Furthermore, since mobile 3D video communication is getting more popular, a new dimension of 3D video display is created. The existing subjective video quality test standards are not entirely dedicated to the evaluation of mobile 3D video content quality. Therefore, there is the need for a subjective mobile 3D video quality assessment. Future studies should consider mobile display 3D video resolutions of the same test sequences in the subjective evaluation methodologies.

6.3.4 Transcoding H.264/AVC to H.264/AVC

Video transcoding has ensured interoperability among systems used by different standards in the last few years. The H.264/AVC to H.264 transcoding converts compressed bitstream in a variety of ways. However, with the rapid changes of coding parameters, there is a need for future research to be carried out on transcoding from H.264/AVC to other codecs using frequency domain and prediction block structures.

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