On The Standardization of Ultra-High-Definition (UHD) Video Transmission by Digital Video Broadcasting – Satellite Second Generation (DVB-S2)

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Doctor of Philosophy Declaration

"I, Urvashi Pal, declare that the PhD thesis entitled 'On The Standardization of Ultra-High-Definition (UHD) Video Transmission by Digital Video Broadcasting – Satellite Second Generation (DVB-S2)' is no more than 100,000 words in length including quotes and exclusive of tables, figures, appendices, bibliography, references and footnotes. This thesis contains no material that has been submitted previously, in whole or in part, for the award of any other academic degree or diploma. Except where otherwise indicated, this thesis is my own work".

Signature　　　　　　　　　　　　　　　　　　Date: 31st August 2016

ABSTRACT

Currently, the best quality video that can be viewed on our TV is at a resolution of 1920 x 1080 pixels, standardized as High-definition (HD). To view a video even bigger and better than HD, a new resolution has recently been standardized as Ultra-High-Definition (UHD) at a resolution of 3840 x 2160 pixels. However, to broadcast a UHD video using the standard broadcast method, Digital Video Broadcasting (DVB), an exclusive DVB-UHD broadcast profile is being developed, which defines parameters for the content being transmitted, the transmitter-receiver equipment, and the television displays. At present, we only have a broadcast profile for Standard-Definition (SD) and HD. Thus, the objective of this research work is to contribute towards the standardization of the DVB-UHD broadcast profile.

Since the future broadcast system needs to deal with multiple high frequencies of different video standards and a digital wireless communication is prone to noise or bit errors, it is crucial to study the end-to-end signal performance of different video standards being transmitted over-the-air. Bit Error Rate (BER) v/s Signal to Noise Ratio (SNR) simulations provide an ideal way to determine the effects on the quality of signal transmission. Therefore, in this thesis, methodologies have been developed and applied on signal performance of UHD and HD video transmission using the future broadcast scenario of multiple resolution, frame rates and video compression methods. Sixteen different video samples are transmitted through the MATLAB built DVB-S2 model with different modulation and coding schemes, in the presence of Additive White Gaussian Noise (AWGN), Rician Fading Channel and a Correlated Phase Noise.

Channel estimation is also performed on the received bits with the help of known pilot bits to reduce the noise.

The results show that BER varies with different video parameters, under the same amount of noise. The impact of signal performance is then observed for Shannon Channel Capacity, Spectral Efficiency, Coverage Area and Transmission Cost. An adaptive video quality system using the Principle of Inclusion has also been proposed. This study is significant for broadcasters since the choice from these video parameters is linked to the way broadcasting will be delivered in the future. Therefore, this investigation will help the broadcasters take an optimum decision towards their future production, migration and distribution strategies including general broadcasting specifications.

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Contents

List of Figures

List of Tables

List of Abbreviations

ACM	Adaptive Coding and Modulation
APSK	Amplitude Phase Shift Keying
AVC	Adaptive Video Coding
BCH	Bose, Chaudhuri, and Hocquenghem
BER	Bit Error Rate
BSS	Broadcast Satellite Services
CB	Coding block
CCFL	Cold-Cathode Fluorescent Lamps
CI	Common Interface
CTB	Coding Tree Block
CTU	Coding Tree Unit
DASH	Dynamic Adaptive Streaming Over HTTP
DSNG	Digital Satellite News Gathering
DTH	Direct-To-Home
DVB-S2	Digital Video Broadcast-Satellite Second Generation
DVB-S2X	Digital Video Broadcast-Satellite Second Generation Extension
EBU	European Broadcasting Union
ECC	Error Correction Codes
FEC	Forwards Error Correction
FFT	Fast Fourier Transform

FSS	Fixed Satellite Services
HbbTV	Hybrid Television
HD	High Definition
HDMI	High Definition Motion Interface
HDR	Higher Dynamic Range
HEVC	High Efficiency Video Coding
HFR	Higher Frame Rate
IPTV	Internet Protocol Television
ITU	International Telecommunication Union
LCD	Liquid Crystal Display
LDPC	Low Density Parity Check
LED	Light Emitting Diodes
MPEG-4	Moving Pictures Expert Group
OFDM	Orthogonal Frequency Division Multiplexing
OLED	Organic Light-Emitting Diode
PB	Prediction block
PLP	Physical Layer Pipe
PSK	Phase Shift Keying
QPSK	Quadrature Phase Shift Keying
RS	Reed-Solomon coding
SD	Standard Definition
SDI	Serial Digital Interface

SFN	Single Frequency Network
SMPTE	Society of Motion Picture & Television Engineers
SNR	Signal to Noise Ratio
STB	Set Top Box
SVC	Scalable Video Coding
TB	Transform Block
TCM	Trellis Coded Modulation
TFT	Thin Film Transistors
TS	Transport Stream
UHD	Ultra High Definition
VCM	Variable coding and modulation
WCG	Wide Colour Gamut

Chapter 1

Introduction

1.1 Background

In the past the only video format available to view programs or movies on our television screen, was at a resolution of 720 x 576 pixels, known as Standard Definition (SD). This was followed by High-Definition (HD) video resolution of 1920 x 1080 pixels, which had a better picture quality and bigger size than SD, but consumed more bandwidth. In 2013, the International Telecommunication Union (ITU), standardized a new digital video format known as Ultra-High Definition (UHD), having two resolutions [1]:

- 3840 x 2160 pixels: UHD-1 or 4K
- 7680 x 4320 pixels: UHD-2 or 8K

However, by just listing programs and movie content under UHD standard, does not mean that it is ready to be delivered. Nevertheless, Digital Video Broadcasting (DVB) is the broadcast standard for digital television, adopted by Europe, Africa, India and Australia (USA uses ATSC) [2]. For a complete ecosystem of UHD broadcast by DVB, we need appropriate content for the general public, such as an efficient and affordable video compression format to compress the heavy UHD content before transmission; compatible transmitter and receiver hardware, TV displays supporting the rich content and other features that would make it commercially successful. Therefore, there is a need to define the parameters of a UHD broadcast profile, just like we have for HD and SD. Since 2013, European Broadcasting Union (EBU) has been working with partners such as DVB, ITU and the Society of Motion Picture and Television Engineers (SMPTE) to enhance the best UHDTV production and distribution technologies [3], and migration strategies, from HD to UHD (by 2017 for UHD-1 and by 2020 for UHD-2) [4]. Thus, the objective of this research work is to contribute towards the standardization of a UHD broadcast profile, to be defined by DVB in the coming years.

1.2 Problem statement

> *"Will UHD perform differently to HD over the air? Will it be more susceptible to noise? Will this result in a higher transmission power cost?*
> *Does High Frame Rate (HFR) require more bandwidth?*
> *Will upscaling or downscaling solve all these problems?"*

With the introduction of UHDTV, also known as '4K' TV, the number of digital video standards varying in spatial and temporal resolution continues to expand [5]. Till now, Standard Definition TV (SDTV) and HDTV have been using frame rates of 25 frames per second (fps), but for UHDTV, we will be dealing with High Frame Rates (HFR) of 50 frames per second or fps, 100fps and more. A new frame rate of 50-full-frames has also been added to HDTV standard i.e. 1080/50i (50 interlaced frames) has been upgraded to 1080/50p (50 progressive frames) and is known as HD+ [6]. The high resolution of UHDTV favors the use of HFRs mostly in progressive mode, as this will help in delivering an improved colour rendition and image depth required for an ultra-HD video quality, as shown in Figure 1.1.

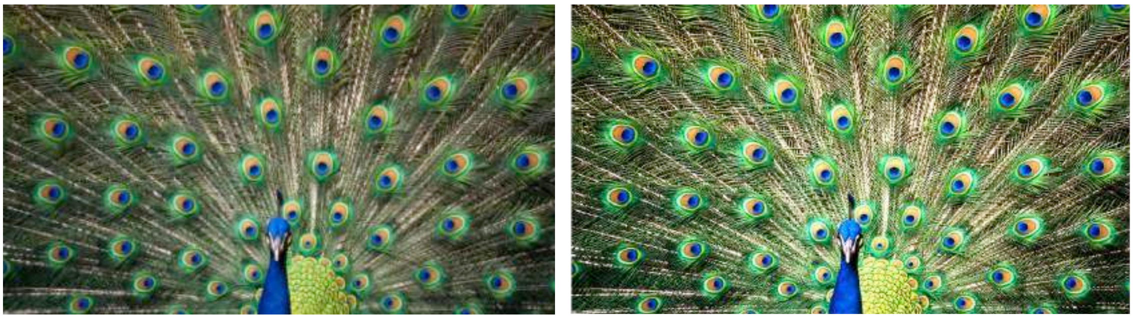


Figure 1.1: HD (Left) vs. UHD (Right) [7]

However, due to the lack of resources and technology in the end-to-end broadcast chain, it will be difficult for broadcasters to transmit complete UHD content at the moment [8]. Unless the entire chain is upgraded (which is going to cost the broadcasters a lot), the original UHD content will be downscaled to a lower resolution and the original HD content will be upscaled to a higher resolution [9]. This process can happen at any point in the broadcast chain depending upon the operator's preference. Future-ready UHDTV and HDTV will require upscaling and downscaling capabilities to comply with the user demands. Broadcasters will be forced to transmit Moving Picture Experts Group-4 (MPEG-4) compressed videos until a majority of the customers own a High Efficiency Video Coding (HEVC) compatible Set-Top-Box (STB) and UHDTV, currently unavailable. Therefore, many video standards with varying resolutions, frame rates and compression, as depicted in Figure 1.2, will have to support future transmissions [10][11].

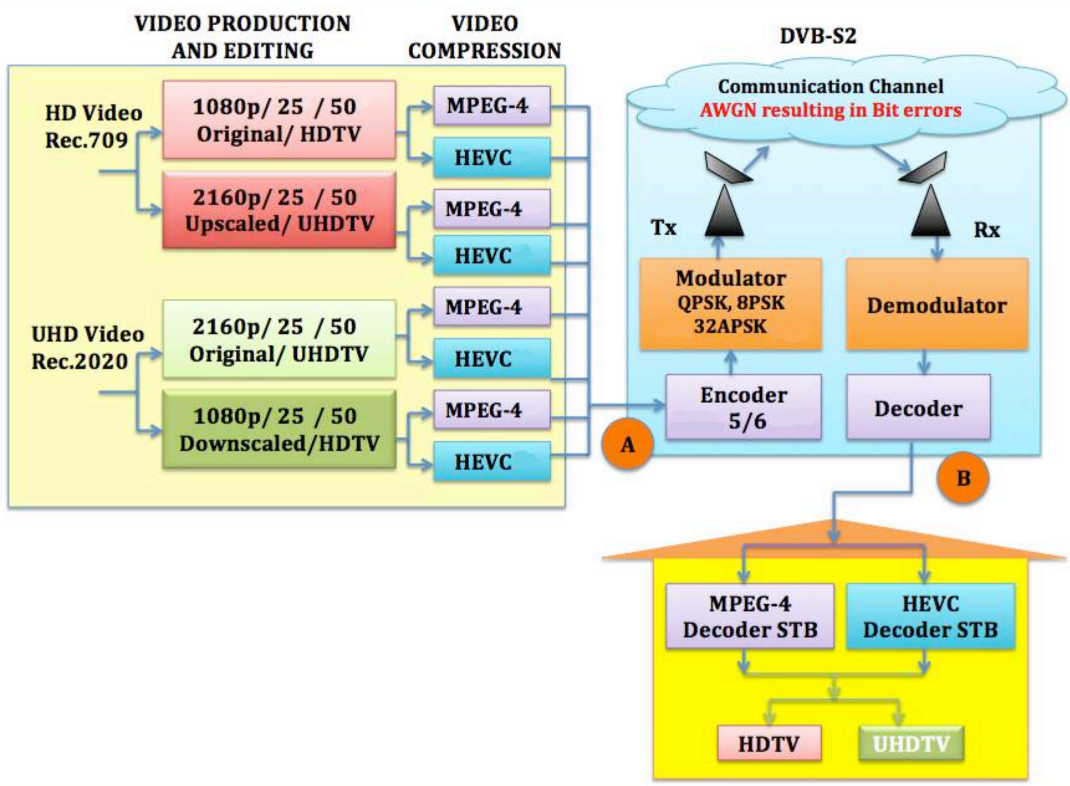


Figure 1.2: Co-existence of multiple video standards [10][11]

UHD video delivery has become possible with the help of supporting technologies such as HEVC and High Definition Multimedia Interface 2.0 (HDMI). The trials for UHD broadcast by DVB-S2 (Satellite Second Generation) have already started and a new broadcast standard, DVB-S2X (S2-Extensions), has been developed to support high data volume and picture quality requirements of UHD [12][13]. In addition to UHD video transmission, SMPTE is developing high-speed 6G/ 12G/ 24G - Serial Digital Interface (SDI) cables [14]. As a result, UHD video transmission creates many new hardware design challenges since it is important to ensure low jitter in the broadcast system to maintain the integrity of the network. Therefore, the future broadcast system needs to deal with multiple high frequencies of different video standards and since, a digital wireless communication is prone to noise or bit errors, it is crucial to study the end-to-end signal performance of different video standards being transmitted over-the-air. Bit Error Rate (BER) v/s Signal to Noise Ratio (SNR) simulations provides an ideal way to determine the effects on the quality of signal transmission [15].

While research work on UHD video quality assessment like Peak-SNR (PSNR) calculation has been carried out and, subjective and objective assessments have become quite common [16], there are very few research papers calculating the effect of noise on UHD and HD videos with varying parameters, in a wireless transmission. The video quality assessment is done mostly at the production level before video transmission is done. Once the signal is transmitted over air, the video quality is bound to deteriorate and hence, the study of noise channels on different types of videos is equally important. Unlike many other forms of analysis, BER v/s SNR determines the full end-to-end performance of a system at the given signal power, including the transmitter, receiver and the medium between the two. By calculating BER, the bit errors caused by disturbance on the transmission path can be corrected by using error correction methods at the receiver [17].

1.3 Scope

In this research project,

- Signal performance (BER v/s SNR) of a UHD video transmission by DVB-S2, will be observed and characterized by varying the codec (video compression method), resolution and frame rate, in the presence of different kinds of interferences, for different modulation and coding schemes.

- Interference experienced by the transmitted video signal, in a wireless communication channel of DVB-S2, deteriorates the signal quality and thus, a method to improve the signal recovery is also proposed.

The impact of signal performance is observed for the following:

- Shannon Channel Capacity
- Spectral Efficiency
- Coverage area: Distance between Transmitter and Receiver
- Service Area Separation Distance
- An adaptive video quality system using the proposed and developed Principle of Inclusion
- Transmission Cost

This study is significant for broadcasters since the choice from varying performance options is linked to the way broadcast will be delivered [18]. For example, HD video should be aired at its standard resolution of 1080p (‘*p*’ means progressive mode or full scanning), after being compressed by MPEG-4 video compression format; however, to avoid investing on upgraded infrastructure, some broadcasters still transmit it at 720p or 1080i (‘*i*’ means interlacing or half scanning) with MPEG-2 (old video compression format, recommended for SD). UHD has an advanced feature of a faster frame rate of 50fps and 100fps in progressive mode, however, in the initial phase of UHD broadcast, the content might have to be broadcasted in interlaced form or 25fps and users have to rely on expensive television sets to artificially generate frames by software algorithms, which will still have inevitable artifacts [19]. This quality cannot be assumed to be equivalent to an original video of 50fps in progressive mode. Similarly, it is most likely for broadcasters to transmit UHD content using MPEG-4 (recommended for HD) video compression, instead of HEVC (latest video compression format, recommended for UHD), and at 1080p resolution, instead of 2160p. Some might just upscale the HD video to view them on UHDTV due to the lack of content or downscale UHD videos to view them on HDTV due to the lack of infrastructure [20].

This dilemma of broadcasters and consumers has prevented the complete roll-out of the real HDTV till now, and the same reason might prevent the complete roll-out of the real UHDTV. Therefore, it is entirely the broadcaster's decision, which video compression and MODCOD (modulation-coding) scheme will be adopted for transmitting a UHD video. There is a trade off between quality and cost in every option, and this research will explore every aspect of these scenarios from which the broadcasters can take an optimum decision towards their future planning of a UHD-DVB broadcast profile [4][5]. Other than movies and TV programs, UHD video broadcast will be useful in other applications where minute pixel data plays an important role [21], applications include the following:

- Medical imaging
- Weather forecasting
- Disaster Recovery
- Education and security

1.4 Research Objective and Contribution

The objective of this research work is to define the requirement of a UHD broadcast profile and contribute towards its standardization [22]. The investigation will help members of EBU, SMPTE, DVB and ITU-R, to make strategic decisions for future production and distribution technologies, by identifying the market demand per service type, commercial requirements and the backward compatibility of the UHD content with HDTV applications.

At the moment, many of the technical aspects of UHD broadcasting are yet to be agreed upon at a global level. To make UHD broadcasting a reality, we need a complete ecosystem, with content being made that the public wants, transmitters, receivers, and displays that are readily available. The specification should also consider features that the system would need to make it commercially successful. Some DVB Members think that displays for UHD-2 are too far away to be considered now, while others argue that UHD-2 is inevitable [23]. Therefore, we need to understand the requirements based on the trends of UHD-1 and when we can expect UHD-2 on the market. We also need to consider whether we can use DVB-S2 for UHD or not. Therefore, this research will analyze the performance of UHD video signals, with varying parameters as compared to HD, when transmitted by DVB-S2.

To analyze the UHD video performance in the future broadcast scenario, we first need to understand the existing scenario. Hence, we need to study the performance of HD and compare it with UHD. HD should only be viewed at a resolution of 1920x1080 pixels in 25fps progressive mode, and ideally on a TV screen above 42″. However, not many consumers will buy an expensive television of 42″ and not every broadcaster will have enough bandwidth, to air every channel in full resolution, thereby, resulting in non-ideal standard adoption. UHD has many parameters defining its video quality and the broadcaster needs to decide, which set of parameter they need to choose for a particular program and channel [24].

A news channel, where the anchor is mostly sitting in one place, talking to others, is a low bandwidth broadcasting requirement. While, a sports channel showing F1 race, where video graphics change every second, requires a higher frame rate and higher bandwidth. This thesis contributes towards a detailed study of the parameters in every combination of a UHD channel, which will help the broadcasters in the migration phase from HD to UHD, as explained in the following tables:

Table 1.1: Contribution Towards Modulation and Coding Scheme	
What is known [25]	DVB-S2 Modulation and coding schemes
Fact [26]	UHD content will be transmitted over the air, along with HD simulcasting. Hence, a detailed signal performance comparison between HD and UHD is required.
What is not known	Are UHD and HD videos going to perform similarly under every MODCOD scheme and Noise?
Thesis Contribution	Proposed experiments to determine whether: 1) UHD BER is higher or lower than HD in QPSK and 8PSK, 3/4 and 5/6 scheme, in the presence of AWGN 2) UHD BER is higher or lower than HD in QPSK and 16APSK, 3/4 and 5/6, in a Rician Fading Channel (K=5). 3) For all other cases, the BER of UHD and HD are almost the same

Table 1.2: Contribution Towards Resolution	
What is known [27]	HDTV: 1920 x 1080p Should be viewed on an HDTV above 42″ UHD: 3840 x 2160p Should be viewed on a UHDTV above 55″
Fact [18]	The size of an HDTV that most of the consumers have is below 40″. If the ideal standard of UHD is followed, consumers will have to buy new expensive UHDTV to view an ideal UHD channel. But due to cost and resource constraints, original UHD content will be downscaled or HD content will be upscaled, therefore, there is a need to study the non-ideal combinations
What is not known	Signal performance (BER v/s SNR) of UHD and HD videos in its original and upscaled or downscaled version. Will downscaling a UHD video from 2160p to 1080p result in a similar BER as HD 1080p?
Thesis Contribution	Using Experiment 2 to determine whether UHD videos have a higher or lower BER than HD in 8PSK-5/6 scheme or UHD downscaled video i.e. UHD original content of 2160p, downscaled to 1080p, results in a higher BER than HD 1080p and HD upscaled to 2160p.

Table 1.3: Contribution Towards Frame Rate	
What is known [28]	UHD: 25, 50, 100fps (only progressive) HD: 25 fps (progressive and interlaced)
Facts [29][30]	Lower frame rates should be used for movie channels. Higher frame rates should be used for sports channel. Interlaced videos save bandwidth and cost. Wrong notion that HFR will result in an increased bandwidth and BER.
What is not known	Will HFR result in an increased BER or bandwidth? Will 1080p/50 HD video be the same as 2160p/25 UHD? Will upscaling and downscaling solve the problem?
Thesis Contribution	Using Experiment 2, in 8PSK-5/6 scheme to determine whether, 50fps video BER is lower than 25fps videos.

Table 1.4: Contribution Towards Video Compression	
What is known [31][32]	MPEG-4: Currently being used for HD HEVC: 50% more efficient than MPEG-4 and is to be used for UHD
Facts [33]	HEVC is still being improved and its compatible hardware is still not widely available. Therefore, in the initial UHD broadcast phase, MPEG-4 will be used for UHD compression. If broadcasters use HEVC for UHD video compression, consumers cannot view UHD on their HDTVs. If broadcasters use MPEG-4, it will consume high bandwidth as one UHD channel will consume the bandwidth of four HD channels.
What is not known	Will MPEG-4 and HEVC compressed video, result in the same BER?
Thesis Contribution	Using Experiment 2, in 8PSK-5/6 to determine whether, HEVC compressed BER is lower than MPEG-4 due to a lower bit rate resulting in a lower BER. Observe HD and UHD and hence, determine if HEVC compression should be adopted for HD.

1.5 List of Publications

A number of peer-reviewed publications have been generated from the research accomplished in this thesis.

- 1) Horace King, **Urvashi Pal**, "A Statistical Approach to Determine Handover Success Using the Principle of Inclusion and Load Variation on Links in Wireless Networks", International Journal of Information, Communication Technology and Applications (IJICTA), Vol. 1, No. 1 (2015), pp. 143-151, December 2015.
- 2) **Urvashi Pal**, Horace King, "Bit Error Rate (BER) analysis of UHD High Frame Rate (HFR) videos through different modulation schemes", International Broadcasting Convention (IBC) - 2015, Future Zone, RAI Amsterdam, September 2015.
- 3) **Urvashi Pal**, Horace King, "Effect of Ultra High Definition (UHD) High Frame Rates (HFR) on Video Transmission", Society of Motion Pictures and Television Engineers, Sydney (SMPTE), Australia, July 2015.
- 4) **Urvashi pal**, Horace King, "Effect of Modulation Scheme on Ultra-High Definition (UHD) Video Transmission", accepted for IEEE Wireless Telecommunication symposium (WTS), New York City, USA, April 2015.
- 5) **Urvashi Pal**, Horace King, "DVB-S2 Channel Estimation and Decoding in The Presence of Phase Noise for Non-Linear Channels", International Journal of Information, Communication Technology and Applications (IJICTA), Vol. 1, No. 1 (2015), pp. 112-127, March 2015.

1.6 Thesis Organization

This research is devoted to the standardization of UHD video transmission by DVB-S2. Chapter 1 lays the foundation by analyzing the background literature, establish the problem statement and provide the research objectives and contributions.

Chapter 2 analyzes UHD ecosystem and discusses the features added to the UHD ecosystem such as 4K resolution, Higher Frame Rate, Wide Colour Gamut, Higher Dynamic Range and the new advanced and highly efficient video codec HEVC. It also discusses the different methods to broadcast this enormous video content. Further, it describes the infrastructure required for UHD delivery through DVB-S2. In addition. the latest television receivers available on the market today are discussed. The chapter is summarized by setting the UHD roadmap of the future.

Chapter 3 analyzes and explains Encoding-Modulation and Decoding-Demodulation in the DVB-S2 system. It also reviews effects on a signal in a wireless communication channel due to Rician Fading, correlated phase noise and AWGN.

Chapter 4 analyzes the scenario of UHD video broadcasting through DVB-S2. Since many organizations are working towards the standardization of DVB-UHD standard, the problem of BER in this scenario is explored. The Importance of BER vs. SNR calculation is explained and a method to reduce the error rate, known as Channel Estimation using pilot bits, is proposed.

Chapter 5 proposes video performance evaluation method to calculate BER vs. SNR graphs using MATLAB simulations. The scenario of multiple video standards in the future is considered and video quality assessment is done. Following that, three experiments are performed. In Experiment 1, two videos (HEVC HD 1080p/25 and HEVC UHD 2160p/25) and transmitted through DVB-S2 model in the presence of AWGN for different modulation schemes and code rates (QPSK, 8PSK, 16APSK and 32APSK & 3/4, 5/6 and 9/10 rate). In Experiment 2, sixteen different videos varying in original content (HD, UHD) resolution (1080p, 2160p), frame rate (25fps, 50fps), codec (MPEG-4, HEVC) are transmitted through DVB-S2 model in the presence of AWGN only, for 8PSK-5/6 scheme. In Experiment 3, two videos of Experiment 1 are transmitted through DVB-S2 in the presence of Rayleigh Fading Channel (K=0) and Rician Fading Channel (K=5), correlated phase noise and AWGN. The same experiment is repeated after applying channel estimation method using pilot bits, to reduce the BER.

In Chapter 6, results of chapter 5 are used to calculate the Channel Capacity, Coverage area (Distance between Transmitter and Receiver), Service area Separation Distance. Using these parameters, the Principle of Inclusion is developed and implemented and, a UHD parameter adaptive scenario is explained. It is shown that there is an increase in the cost of transmission power to broadcast a UHD video, as compared to HD using the developed formulations.

This thesis is concluded with a summary and future work possibilities in Chapter 7.

Chapter 2

Literature Review of UHD Ecosystem

2.1 Introduction

"The colours are breathtaking.

The clarity is flawless.

The definition is so sharp that viewers feel truly immersed in the action." [19]

With a wealth of benefits including four times higher resolution than HD, faster frame rate, higher dynamic range and a wider colour gamut, television and media industry is on the cusp of a revolutionary transformation in video transmission. UHD's advanced technology promises to surpass consumer's expectations. By region, its household penetration will reach 33% in North America, 22% in Western Europe and 18% in Asia Pacific by 2020 [19]. Hence, the following features have been introduced or modified to provide users with an 'Ultra'-HD experience.

2.2 Video Production

2.2.1 4K Resolution

The human vision is one of the most complex parts of the human body. The eye perceives movement, senses depth, and sees a range of colours greater than any current existing video technology is able to display. UHDTV has a resolution of 3840 x 2160 pixels, which is four times the resolution of HDTV. This means that there is four times more information displayed on screen, which is one of the factors to enhance the video quality. The ideal size of a UHDTV is supposed to be around 55″ to 80″. Based on the size of television, viewing distance is calculated to maintain the maximum perceived angular resolution because there are limits to what an eye can perceive [34]. If you sit too close to the TV, you will be seeing the unwanted individual pixels and if you sit too far, you won't be able to observe all the details in the video. That means, if you sit too far away from a UHDTV, the UHD content will look like HD. As a result, the viewing distance for a UHDTV is half of what is required for HDTV.

2.2.2 High Frame Rates (HFR)

Ultra HD changes the way moving images are displayed, stored, and transmitted. To ensure a smooth viewing experience, HFRs will be used for UHD and HD videos in the future [2]. Until now, interlaced scanning (odd and even lines transmitted in turn) was being used to save bandwidth. However, there was a trade off with quality. Although, most recent HDTVs have the technology to de-interlace the frames, the artifacts could never be eliminated completely. Hence for UHD, the signal will mostly be transmitted in progressive mode, since it offers higher vertical resolution, better picture quality and easier frame conversion to other formats.

Frame rate used till now is 25fps for HD but for UHD, we will be dealing with 50fps, 100fps or even higher. Increasing the frame rate increases the smoothness of a video, especially for high motion contents [35]. Increased information per second of the video with more frames enhances the smoothness and colour rendition.

HFR technology was first introduced for 3D movies and has now been adopted for UHD videos [35]. “The Hobbit: An unexpected journey” (2012) in 3D, was the first movie to be shot at an HFR of 48fps (double of 24fps). Simultaneously, a new frame rate for HDTV at 50 fps (progressive) has also been standardized, keeping in mind that UHDTV will take time to penetrate the market and there is already a demand for increased video quality among the users [6]. DVB has included 1080p/50 format in its DVB specification TS 101 154 V1.9.1, for Advanced Video Coding (AVC) and Scalable Video Coding (SVC). Broadcasting in 1080/50p will be possible when new UHD STB arrive in the market (with HEVC encoding), offering progressive mode in the channels, not yet available.

2.2.3 Wide Colour Gamut (WCG)

UHD technology allows for a greater array of colours to be perceived by viewers. Rec.709 gives HD’s colour space, while for UHD, Rec.2020 has been standardized, as shown in Figure 2.1. Rec.709 covers 1.6 million colours while Rec.2020 covers 1 billion. In other words, Rec.709 captures 35% of the natural view, while Rec.2020 captures 75%. Hence, watching a UHD video will be similar to watching a 3D video without the glasses. Rendering a particular colour in a pixel is given by a video’s colour depth or bit depth, as it is the number of bits required to define the colour of a pixel. UHD includes a richer colour depth of 10-bit or 12-bit as compared to 8-bit used by HD. 8-bit consists of (8 x 8 x 8) values, ranging from 0 - 255 colours for RGB, while 10-bit consists of (10 x 10 x 10) values, each ranging from 0 - 1023 colours. The wide range of colours is going to radically enhance the picture quality of a UHD video. This improvement in display technology will enable the human eye to use more of its potential and foster viewing experience that will appear more and more lifelike [36].

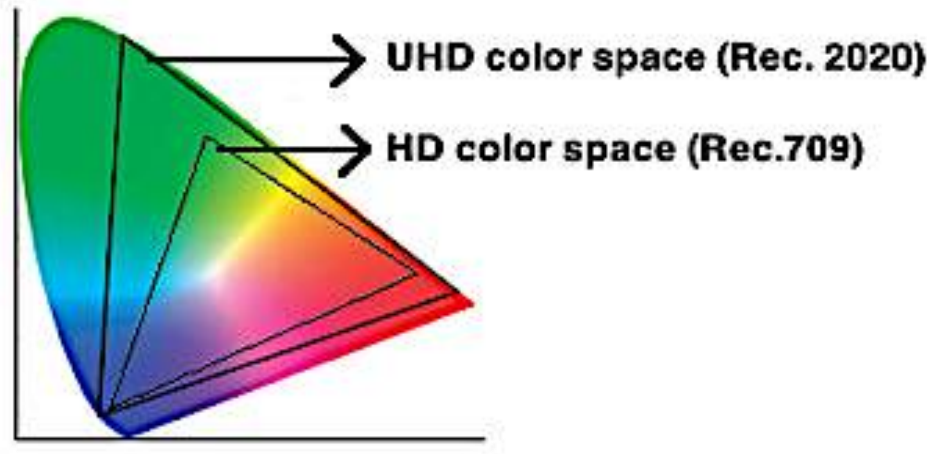


Figure 2.1: HD and UHD Colour Space [37]

2.2.4 High Dynamic Range (HDR)

One more feature that will improve the video quality, is allowing a High Dynamic Range (HDR) that will help produce a greater dynamic range of luminosity [38]. With current technology, details in the dark are often not easily perceptible and important information displayed onscreen can be lost. With HDR, these details will be displayed more clearly, even when there is unfavorable lighting. As HDR technology adds greater depth and detail at both ends of the light level spectrum, it has been shown to create an increase in subjective quality for viewers, regardless of screen size and viewing distance [39][40].

2.3 Video Compression: MPEG-4 vs. HEVC

At present, MPEG-4 video compression format is being used to watch HD channels on our HDTVs. HEVC is the new video compression method, developed especially to compress the huge data of UHD and has been adopted for its transmission by DVB [41].

2.3.1 Advantages of HEVC compared to MPEG-4 [42][43]:

- HEVC offers 50% higher video compression and quality as compared to MPEG-4 and therefore, will make the transmission of UHD content more efficient by saving the bandwidth significantly. Example: Using MPEG-4, 1 UHD channel will be available, and using HEVC, 4 UHD channels will be available using the same bandwidth.
- With the high performance of HEVC, about the same bit-rate used for 1080i/50 broadcast will be required for 1080p/50, and a better image quality will be delivered to the home. This is because compression avoids transmitting the entire frame whose information has already been transmitted in the previous frames. It only transmits the residual information between the referenced frame and current frame. Hence, the total bit rate is reduced and bandwidth is saved [15].

2.3.2 Disadvantages of HEVC compared to MPEG-4 [42][43]:

- HEVC encoder and decoder is at its early stage of development and not much has been finalized yet.
- To use HEVC, broadcasters will have to invest in upgraded infrastructure, which will take time and cost a lot of money.

- If the broadcasters start using HEVC to transmit UHD, consumers will be forced to dump their existing HDTVs and buy expensive HEVC compatible UHDTVs, and this will take time.
- UHD HEVC channels TV package will be costlier than what the consumer is paying at present for HD MPEG-4 channels, hence, HEVC-UHD will take time to successfully hit the market.

Due to the disadvantages of HEVC, in the early migration phase of UHD the broadcasters will be left with no other choice, but to broadcast UHD channels in MPEG-4 format, compromising quality and bandwidth. HEVC was previously being developed for only-progressive mode, however, most of the producers and broadcasters still use the legacy interlaced format and cannot be abandoned at once and migrated to progressive format so soon; leading to HEVC introducing interlaced video compression. The introduction of new video formats (1080p/50, 2160p/ 25, 2160p/50) in addition to an existing one (720p or 1080i) may require simulcasting the same service at different formats. In such a scenario, the combination of MPEG-4 or AVC, SVC and HEVC will be used for different video formats [10][44].

HEVC Working:

HEVC video codec divides a frame into Coding Tree Units (CTU), which consist of Coding Tree Blocks (CTB) i.e. one Luma (Y), two Chroma samples (C_b, C_r) and associated syntax elements [42]. Each CTB is of the same size as a CTU. These CTBs are further split up into variable Coding Blocks (CB) for inter-picture or intra-picture prediction. HEVC handles Coding Blocks of length (64 x 64), (32 x 32), (16x16) and

(8 x 8) pixels, by changing the size according to texture (MPEG-4 uses macro-block sizes maximum of (16 x 16) pixels). Different Prediction Blocks (PB) are introduced for precise prediction of the moving images. A Coding Block (CB) is further split into Transform Blocks (TB) to code the difference between the predicted image and the actual image. The complete process is explained in Figure 2.2. Figure 2.3 shows a comparison of HEVC and MPEG-4 compression technique [42].

Step 1:

CTU	CTU	CTU	CTU	CTU
CTU	CTU	CTU	CTU	CTU
CTU	CTU	CTU	CTU	CTU
CTU	CTU	CTU	CTU	CTU

Image Frame Divided into CTUs

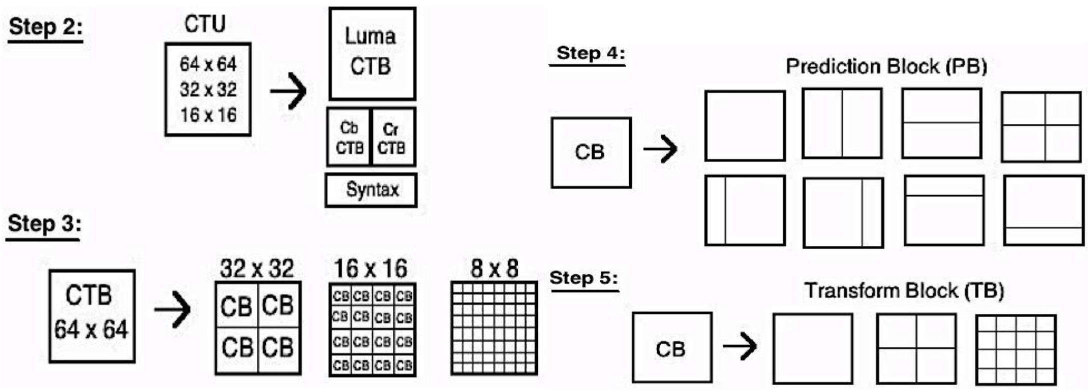


Figure 2.2: HEVC Compression Technique [31]

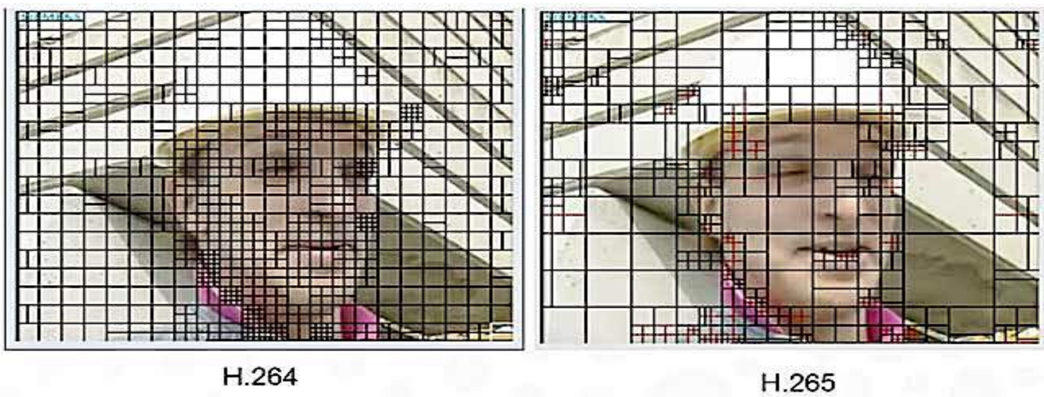


Figure 2.3: Comparison of MPEG-4/H.264 and HEVC/H.265 Compression [45]

2.4 Video Broadcasting

2.4.1 Using DVB-S2/S2X

DVB-S2 is the technique for Direct-to-Home (DTH) services. It uses Bose-Chaudhuri-Hocquenghem (BCH) + Low Density Parity Check (LDPC) encoder-decoder and interleaver (except for QPSK), combined with a variety of modulation schemes and code rates, along with Adaptive Coding Modulation (ACM), resulting in an improved efficiency of 30-35% as compared to DVB-S [46]. The adoption of new S2 Extension (S2X) will further improve the efficiency by 20% (for DTH) and 51% for other professional applications, by providing more speed, mobility and robustness. DVB-S2X target is to support the rising demand for higher quality images with the rise of UHDTV and HEVC [47].

New features of S2 Extensions include bonding of TV streams (Channel Bonding) for DTH by sending one big Transport Stream (TS) over many transponders at the same time and merging their spare capacities. Stat-mux provides only 12% gain, therefore, more channels cannot be added, however, by using Channel bonding, 12% extra gain is achievable. More modulation schemes have been adopted for S2X, such as 64, 128 and 256 APSK and more Forward Error Correction (FEC) code rates have been added for each modulation scheme, as given in Table 2.1. Hence, ACM provides full efficiency, closer to the theoretical Shannon Limit, as compared to DVB-S2. Very low SNR Modulation-Coding rates (MODCODs) for BPSK and QPSK to support small antenna mobile (land, sea, air) applications are also added. More granularity with low roll offs

(5%, 10% and 15%), wideband implementation, and additional scrambling sequences are added, resulting in an increased bandwidth [48].

Table 2.1: Code rates comparison between DVB-S2 and DVB-S2X [46][14]

	DVB-S2	DVB-S2X
QPSK	1/2, 1/4, 1/3, 2/5, 3/5, 2/3, 3/4, 4/5, 5/6, 8/9, 9/10	13/45, 9/20, 11/20
8PSK	3/5, 2/3, 3/4, 5/6, 8/9, 9/10	23/36, 25/36, 13/18
16APSK	2/3, 3/4, 4/5, 5/6, 8/9, 9/10	26/45, 3/5, 28/45, 23/36,25/36, 13/18, 7/9, 77/90
32APSK	3/4, 4/5, 5/6, 8/9, 9/10	32/45, 11/15, 7/9

2.4.2 Using Other Methods

2.4.2.1 *DVB-T2/T2-Lite*

Digital Video Broadcasting through Terrestrial Network Second Generation (DVB-T2) has been primarily designed for fixed reception; however, in recent years there has been a noteworthy growth in the demand for wireless communication [2]. Its advanced version has recently been standardized i.e. DVB-T2-Lite for mobile and portable reception to reduce implementation costs. This technology uses a combination of satellite transmission link for long distance communication and terrestrial network link to reach the end user. It uses the concept of Single Frequency Network (SFN) and Orthogonal Frequency Division Multiplexing (OFDM) and involves LDPC encoders with Multiple Physical Layer Pipes (PLP) for different applications [49][50]. This mechanism allows T2-Lite and T2-base to be transmitted in one RF channel, even when the two profiles use different Fast Fourier Transform (FFT) sizes or guard intervals. The PLP transmission parameters for the mobile service are compliant to the T2-Lite parameter set. However, the disadvantage of this technology is that it is not possible to broadcast throughout the year due to adverse weather conditions and the available bandwidth is also low, as compared to DVB-S2. DVB-T2 system model, given in Figure 2.4 [49].

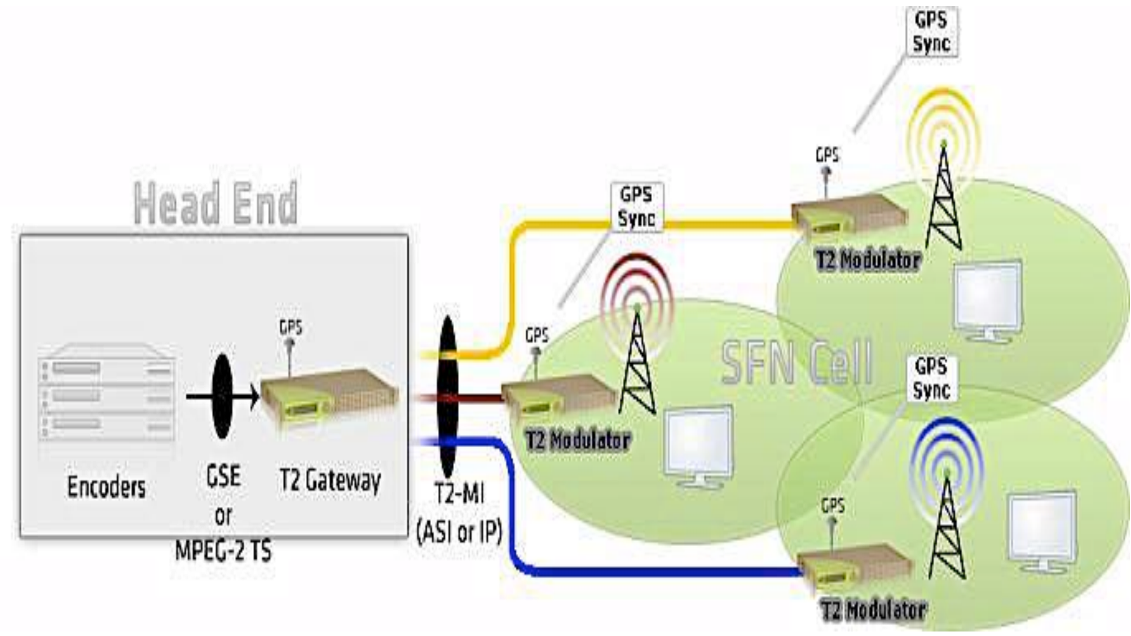


Figure 2.4: DVB-T2 System Architecture [49]

2.4.2.2 *IPTV: HbbTV and MPEG-DASH*

Another technology supporting 4K video delivery through Internet Protocol-TV (IPTV) has recently been standardized and involves MPEG-Dynamic Adaptive Streaming Over HTTP (DASH) and Hybrid Television (HbbTV) [51]. MPEG-DASH is the protocol that allows a smooth conversion of various video formats on the Internet. It also has an adaptive bit rate technology to adjust the video parameters (resolution, frame rate, etc.) as per the available bandwidth [52]. Other features on which the industry is working on are for improving the buffer speed, cache management and video-parameter transition behavior so that the user is not distracted during parameter change [53][54]. HbbTV is the hybrid of IPTV and DVB-S2, as shown in Figure 2.5 [55]. Its disadvantage is the lack of coverage in most regions on the globe; lower picture quality and available bandwidth as compared to DVB-S2 [10]. Therefore, DVB-S2 is the best possible broadcast method available, out of all the other methods. A comparison with other technologies is given in Table 2.2.

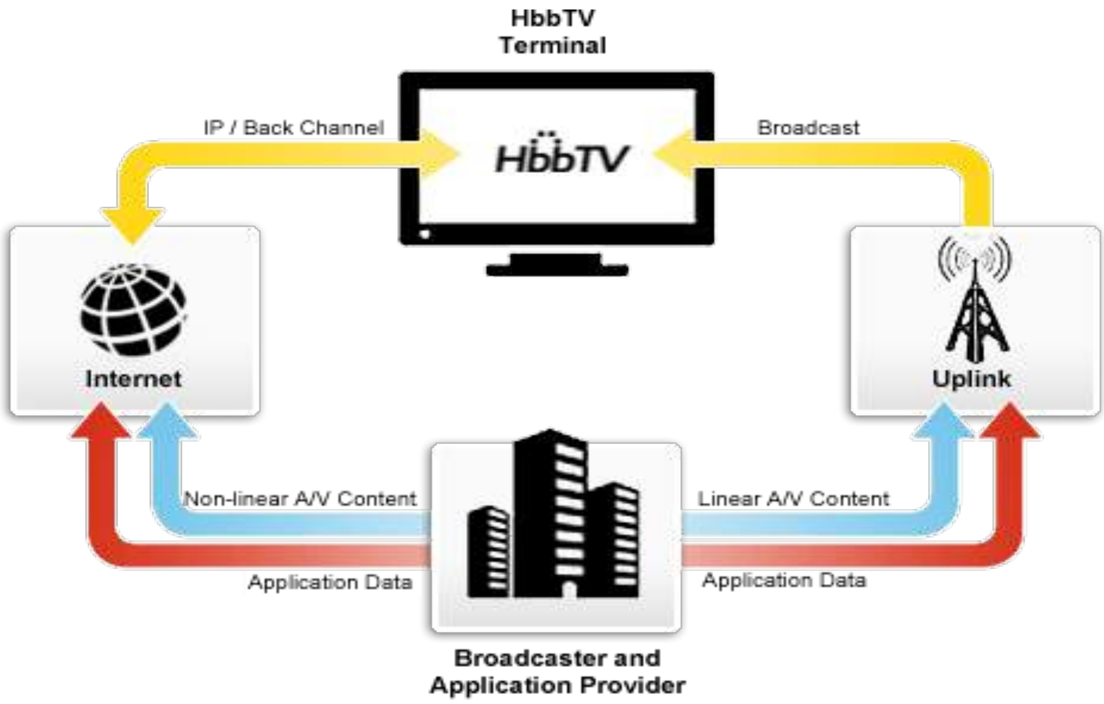


Figure 2.5: Hybrid television system architecture [55]

Table 2.2: Comparison of different broadcast models [10]

Method	Coverage	Picture Quality	Calendar	Bandwidth Availability
DVB-S2	Good	Good	Average	Good
DVB-T2	Average	Good	Limited	Limited
IPTV	Limited	Average	Good	Limited

2.5 Video Delivery Mechanisms

2.5.1 DVB-S2 UHD Satellites

At the present time, UHDTV channels are being trialed and tested with the help of demo channels via DVB-S2 supported satellites, which are inline with the DVB-UHDTV phase-1 specifications [56]. Table 2.3. describes the technical parameters for satellite reception of a UHDTV channel by DVB-S2 satellites.

Table 2.3: Technical parameters for satellite reception of a UHD channel [57][58]

UHD Satellite	Frequency (MHz)	Modulation-Coding
Hot Bird 4K1, 13°East	11296	8PSK, 3/4
Eutelsat 10A, 10°East	11429	8PSK, 5/6
Eutelsat 10A, 10°East	11346	8PSK, 5/6
SES Astra, 19.2°East	10994	8PSK, 5/6

2.5.2 Serial Digital Interface (SDI) Cables and STBs

Table 2.4 enlists current and future SDI cables standardized for supporting UHDTV. Due to the high demand for UHD video standard, video equipment suppliers are already working on future technologies to support faster data rates.

Table 2.4: SMPTE SDI cables supporting PAL videos [14][15]

Cable	Supported Video upto	Data rate
SD-SDI	480i/25	270 Mbps
HD-SDI	270p/50, 1080i/50	1.585 Gbps
3G-SDI	1080p/50	2.97 Gbps
6G-SDI	2160p/25 (upcoming)	5.97 Gbps
12-SDI	2160p/50 (unofficial)	11.8 Gbps
24-SDI	Next-gen tech (unofficial)	23.xx Gbps

From Table 2.4, it is evident that future SDI cables take into account the increase in the number of pixels and frame rates and in concert with the increase in data rates into higher Gbps.

2.5.3 High Definition Multimedia Interface (HDMI)

HDMI 2.0 can transmit 12-bit per sample RGB at 2160p (progressive) and 24/25/30 fps or it can transmit 12-bits per sample 4:2:2/4:2:0 YC_bC_r at 2160p and 50/60 fps. UHDTVs released before HDMI 2.0, support the current HDMI 1.4 version, which limits UHD content to 24-30 fps [59]. Even after the launch of 6G-SDI cables, viewers will only be able to receive UHD channels on their television sets, if they have a compatible 4K STB supporting the latest HDMI 2.0 standard.

Till now, most of the TVs and STBs use HDMI 1.4a (6.05 Gbps usable bandwidth), which supports videos for 1080p/60 (1920 x 1080 resolution, 60 frames per second in progressive mode) and 2160p/30. However, to support 2160p/60 and other enhanced features of UHD video and audio, we need HDMI 2.0 (14.4 usable bandwidth out of 18 Gbps), This upgrade can either be a firmware update or a hardware update depending on different TV and STB manufacturers [60]. Table 2.5 highlights its features.

Table 2.5: HDMI 1.4a vs. HDMI 2.0 [59]

Format/ HDMI version	**1080p/ 25fps**	**1080p/ 50fps**	**2160p/ 25fps**	**2160p/ 50fps**	**8-bit**	**10-bit 12-bit**	**4:4:4 Sampling**
1.4a	Yes	Yes	Yes	**NO**	Yes	**NO**	**NO**
2.0	Yes	Yes	Yes	Yes	Yes	Yes	Yes

2.6 Display and Backlight Technology

The colour accuracy of a Liquid Crystal Display (LCD) TV screen depends on the backlight technology used to produce the white light. The various backlight technologies available today are:

Cold-Cathode Fluorescent Lamps (CCFL) is the old backlight technology that produces light strongest in greens and not exactly white and therefore, are not suitable for UHDTVs.

Light Emitting Diodes (LED) backlight with LCD display is the perfect choice for UHDTV as they produce whiter whites than CCFL since they use a non-coloured light source to illuminate the screen.

Quantum Dots (QD) is the same LED backlight technology for LCD display; however, the method to create colours is new. Quantum Dots directly convert light from blue LEDs into primary colours, rather than using the existing white LEDs. A QD emits light in a specific Gaussian distribution resulting in more accurate colours with improved brightness, that are not colour filtered and thus require low power.

Organic Light-Emitting Diode (OLED) display is an alternative to LCD Thin Film Transistor (TFT) display that offers higher brightness and contrast ratio since it is a light emitter and creates Lambertian light. It can be seen uniformly at all angles and gives a very pleasing effect. It does not require any backlight and can be made thinner (at 2mm) than LED (3mm). OLEDs are expensive and require a glass-covered screen.

Curved and Flexible Displays can be for both, OLEDs and LCDs. This new innovative display technology improves the image quality and readability by eliminating the reflections from ambient lights sources. Curved displays are suitable for TVs as well as for mobiles, as it allows the displays to run at lower brightness, thus, increasing the power efficiency and battery running time.

2.7 UHD Roadmap

Figure 2.6 and 2.7 depict the development roadmap of the UHD industry. A lot of planning has been done towards the roll-out of UHD technology [61][62]. The entire infrastructure upgrade has been divided into two parts: UHD-1 and UHD-2. The UHD-1 roll out is further divided into two phases. A small list of famous companies working towards UHD implementation is also given in Table 2.6 [10].

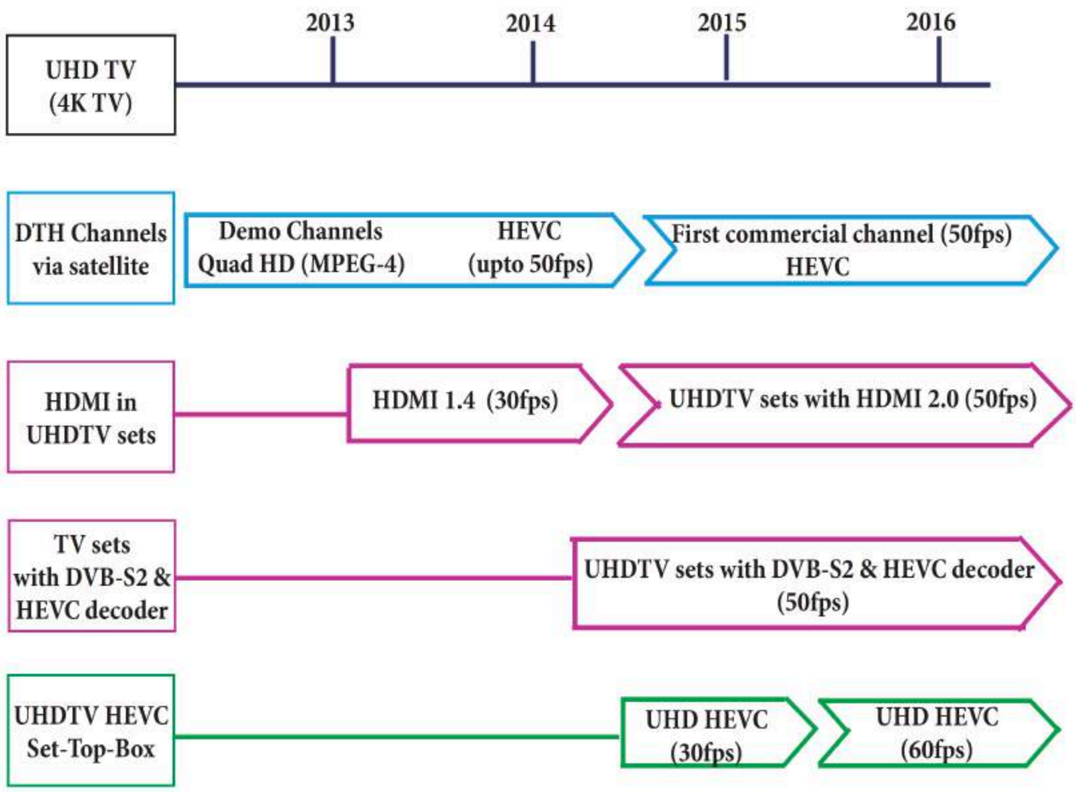


Figure 2.6: UHD development stages till now [10][62]

Table 2.6: List of some companies working towards UHD [10]

Professional 4K Cameras	HEVC	4K-UHDTV
Blackmagic Design, Canon, Panasonic, Red Epic, Sony	ATEME, Elemental, Envivo, Ericsson, Harmonic, Rohde & Schwarz	Sony, Samsung, Panasonic, LG

Figure 2.7: UHD future roadmap [10][62]

2.8 Summary

In this chapter, a detailed analysis of Ultra-High-Definition video parameters and requirements has been carried out. For a successful transmission and reception of a UHD video, it is important that every block in the broadcast chain must be upgraded. This will lead to an overall increase in the cost of production and broadcasting but the enhanced video quality with richer colours and dynamic motion range makes the effort totally worth it. Still, at the moment, the broadcasters will opt for a trade off in quality by artificially upscaling a lower resolution content rather than using the original high resolution content in the initial phase of broadcasting [63]. The availability of numerous options to select from for a UHD video will itself create confusion in the future broadcast scenario for the DTH operators. It is important that advanced hardwares support interoperability at every stage, which will take time, is supported and enhanced as the technology advances.

Chapter 3

Performance Analysis of DVB-S2

3.1 Introduction

Digital Video Broadcast-Satellite Second Generation (DVB-S2) is an audio and video broadcast standard for DTH, HDTV and MPEG-4 related services in Fixed Satellite Services (FSS) and Broadcast Satellite Services (BSS) bands. It is a successor to DVB-S (first generation), and follows a QPSK modulation scheme and Forward Error Correction (FEC), along with Reed–Solomon (RS) coding. For professional end-to-end transmission of audio and video signals and Digital Satellite News Gathering (DSNG), DVB proposed the next generation standard for video broadcasting i.e. DVB-S2 [25].

DVB-S2 uses Low Density Parity Check (LDPC) coding, Variable Coding and Modulation (VCM), and Adaptive Coding and Modulation (ACM) to minimize bandwidth wastage. It uses QPSK, 8PSK, 16PSK, and 32APSK modulation schemes along with various code rates and also supports backward compatibility. As a result of these characteristic, the satellite transmission capacity increases by 30-35 % for a given symbol rate and SNR as compared to DVB-S [46].

In a Pay-TV DTH system, video is recorded and sent to the relevant teleport and TV studio, where post-production/editing is done. Here the video is processed in the form of binary bits. It is then encrypted (encoded and modulated) and transmitted over the air in the form of RF signals. DVB-S2 satellite receives it and downlinks it back to the earth. The signal is received, converted back to digital and decrypted (decoded and demodulated) by an STB of the particular broadcaster. The user can only view the video after subscribing/paying to that broadcaster [63]. This procedure is depicted in Figure 3.1 and its technical block schematic is given in Figure 3.2.

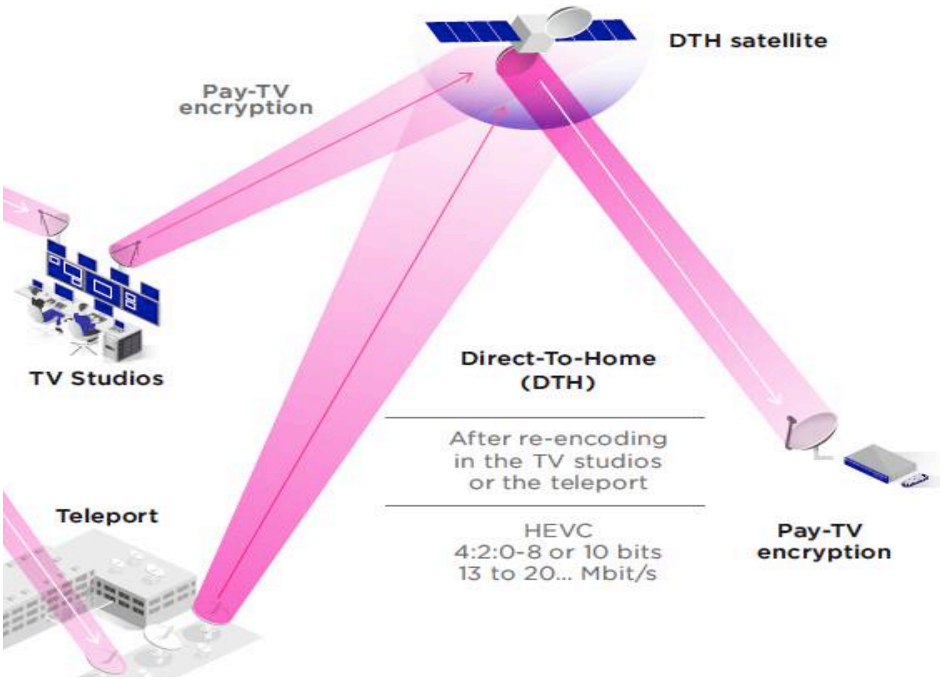


Figure 3.1: Direct-To-Home Pay-TV system model [10]

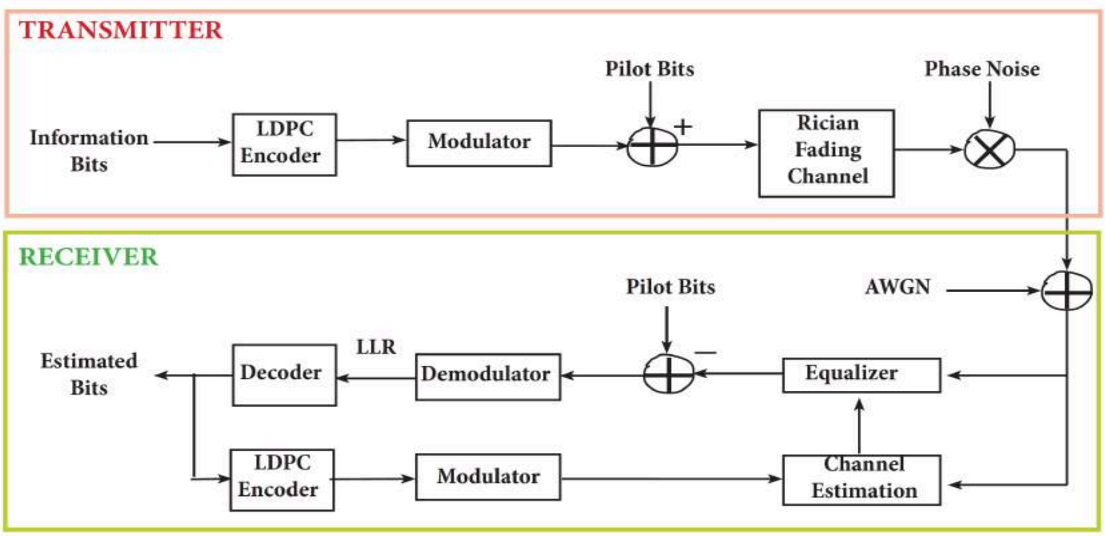


Figure 3.2: DVB-S2 block schematic [46]

3.2 Transmitter

It works on the message to deliver a suitable signal for transmission over the communication channel. In 1982, Ungerbôeck released his landmark paper on Trellis Coded Modulation (TCM), which states that Modulation and Coding together give an improved performance and help to achieve a power and bandwidth efficient wireless communication system. DVB-S2 transmitter consists of an LDPC encoder and a modulator to achieve performance close to the channel capacity [64]. In this report, study of an LDPC-coded modulation in the midst of Additive White Gaussian Noise (AWGN), correlated phase noise and a Rician Fading Channel is done. For a bandwidth-limited system, the higher the modulation scheme, the higher the spectral efficiency. However, there is a trade off between bandwidth and the required signal power. This is compromised with a loss of error performance.

3.2.1 Modulator Selection

3.2.1.1 *Quadrature Phase Shift Keying (QPSK) Modulator*

QPSK is a highly robust modulation scheme, as its states are far apart for the receiver to detect and decode the channel properly, even in the presence of noise. The normalized average energy per symbol shall be equal to one. Two bits are mapped to a QPSK symbol i.e. bits 2_i and 2_{i+1} determines the ith QPSK symbol, where i = 0, 1, 2,., (N/2)-1 and N is the coded LDPC block size. Gray coding is used to minimize the BER by keeping the transition between two continuous bits equal to one bit. When this property is followed, the receiver knows that the next code is different from the present one by only one bit and this helps in a better decoding technique with low probability of incorrect detection. However, its disadvantage is that its information rate per symbol is very low i.e. only 2 bits per symbol, as shown in Figure 3.3 and it is sensitive to phase variations, a phenomenon highly undesirable by DVB-S2.

3.2.1.2 ***8-Phase Shift Keying (8PSK) Modulator***

This is the most commonly used modulation scheme for satellite video broadcasting, other than QPSK, and transmits 8 symbols at a time and 3 bits per symbol. This increases the efficiency of the system as compared to QPSK. However, its hardware complexity is higher than QPSK and it requires high transmission power. Its BER is also higher than QPSK. The bit-mapping diagram to achieve 8PSK constellation is shown in Figure 3.3. The bit mapping uses gray coding for signal recovery. The normalized average energy per symbol is equal to one. After the bits are encoded and interleaved, the 3_i, 3_{i+1} and 3_{i+2} bit of the interleaver output determine the i^{th} 8PSK symbol, where i = 0, 1, 2, ...(N/3)-1 and N is the coded LDPC block size.

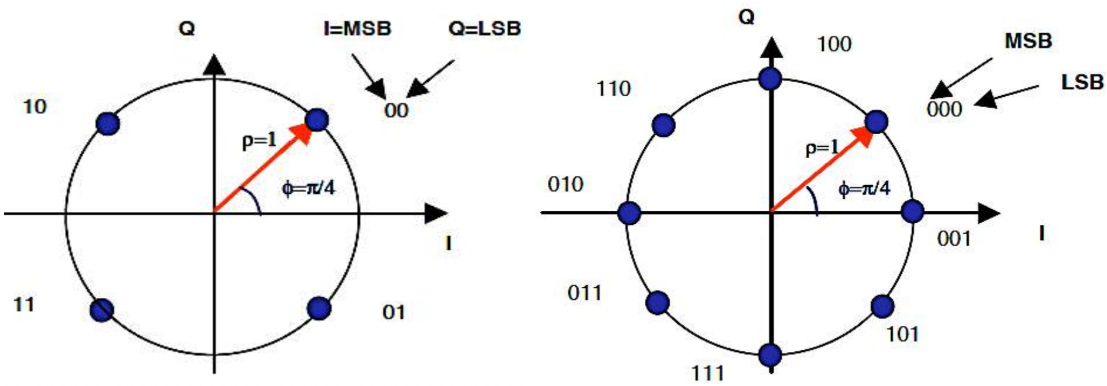


Figure 3.3: Constellation Diagram of QPSK (left) and 8PSK (right) [25]

3.2.1.3 ***16-Amplitude Phase Shift Keying (16APSK) Modulator***

The 16APSK modulation constellation, as shown in Figure 3.4, is composed of two concentric rings of uniformly spaced 4 and 12 PSK points, respectively in the inner ring of radius R_1 and outer ring of radius R_2. The ratio of the outer circle radius to the inner circle radius ($\gamma = R_2 / R_1$) is given in Table 3.1. Two are the admitted values for the constellation amplitudes, allowing performance optimization according to the channel characteristics

- E=1 (E=unit average symbol energy) corresponding to $[R_1]2 + 3[R_2]2 = 4$
- $R_2 = 1$

which means that the normalized energy of the bits in each radius is equal to 1 and bits 4_i, 4_{i+1}, 4_{i+2} and 4_{i+3} of the interleaver output determine the i^{th} 16APSK symbol, where i = 0, 1, 2, …, (N/4)-1 and N is the coded LDPC block size.

Table 3.1: Optimum Constellation Radius Ratio for 16APSK [25]

Code Rate	Efficiency	γ
2/3	2,66	3,15
3/4	2,99	2,85
4/5	3,19	2,75
5/6	3,32	2,70
8/9	3,55	2,60
9/10	3,59	2,57

3.2.1.4 ***32-Amplitude Phase Shift Keying (32APSK) Modulator***

32APSK has better spectral efficiency i.e. highest bits per symbol than QPSK and 8PSK. 32APSK points are optimized by placing them in concentric circles of constant amplitude, with uniformly spaced 4,12, and 16 PSK points, respectively in R_1 (innermost), R_2 and R_3, as shown in Figure 3.4, ensuring that the states in a particular ring will react to distortion in the same manner. Signal compression does not significantly change the spacing between the states (Euclidean distance), resulting in a better signal recovery. However, 32APSK requires higher Carrier-to-Noise ratio and pre-distortion methods (varying space between rings) before transmission, so that it cancels the non-linear distortion experienced during transmission and this is done using constellation amplitudes, γ_1 and γ_2, as explained in Table 3.2.

- E = 1 (E=unit average symbol energy)
- $[R_1]2 + 3[R_2]2 + 4[R_3]2 = 8$
- $R_3 = 1$

Bits 5_i, 5_{i+1}, 5_{i+2}, 5_{i+3} and 5_{i+4} of the interleaver output determine the i[th] 32APSK symbol, where i = 0, 1, 2, (N/5)-1.

Table 3.2: Optimum Constellation Radius Ratios for 32APSK [25]

Code Rate	**Efficiency**	**$\gamma_1 = R_2/R_1$**	**$\gamma_2 = R_3/R_1$**
3/4	3,74	2,84	5,27
4/5	3,99	2,72	4,87
5/6	4,15	2,64	4,64
8/9	4,43	2,65	4,33
9/10	4,49	2,53	4,30

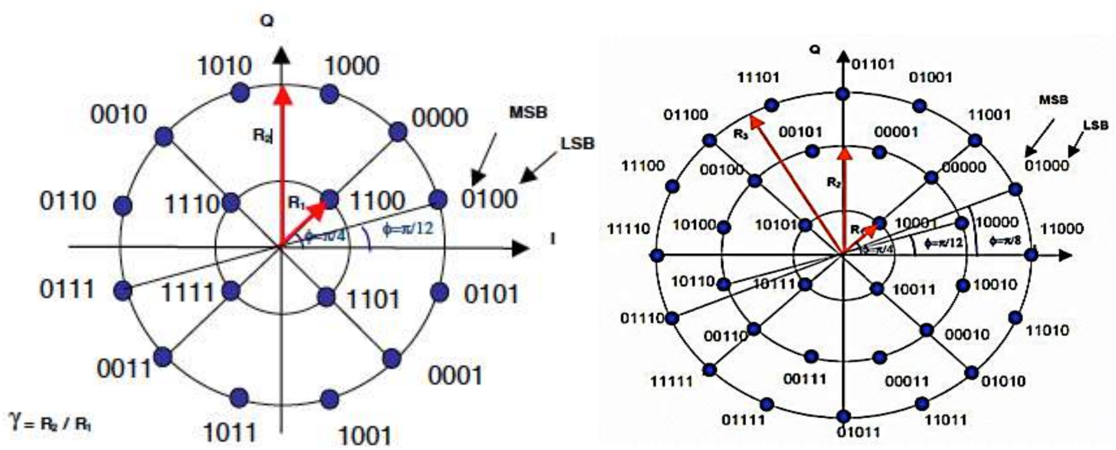


Figure 3.4: Constellation Diagram of 16APSK and 32APSK [25]

3.3 Analysis of The Transmission Channel

3.3.1 Rician Fading Channel

A channel acts as a medium for transmitting signal from the transmitter to the receiver. The transmission path keeps varying as the Line Of Sight (LOS) keeps changing according to the obstructions faced between the transmitter and receiver. In addition to multipath reflection from obstructing objects, the transmission path of the signal may increase. If the transmission path keeps increasing, the signal strength keeps decreasing. For this reason, radio channel modeling has been the most difficult task in communication systems. Therefore, modeling is done based on physical measurements made on the intended communication system.

In a radio communication system, the instantaneous signal received keeps fluctuating over time. This is because the received signal is the sum of many contributions coming from different directions due to multipath. Therefore, the phase is always varying with time. Two types of fading are considered here: Small Scale Fading and Large Scale Fading. When there is a LOS between the transmitter and receiver, the received signal is the sum of a complex exponential and a narrowband Gaussian process, which are known as the LOS component and the diffuse component respectively. The relative strength of the direct and scattered components of the received signal is expressed by the Rician factor. The Rice Fading Distribution models the variations in the signal envelope in a narrow-band multipath fading channel for a direct LOS path between transmitter and receiver.

Suppose, $g_I(t)$ and $g_Q(t)$ are Gaussian random processes with non-zero means $m_I(t)$ and $m_Q(t)$, respectively and b_0 represents the variance of $g_I(t_1)$ and $g_Q(t_1)$ [65]. The magnitude of the received complex envelope at time 't_l' has a Rician distribution as:

$$f(x) = \frac{x}{b_o} exp\left\{-\frac{x^2+s^2}{2b_o}\right\} I_o\left(\frac{xs}{b_o}\right); \quad x \geq 0, \tag{3.5}$$

$$s^2 = m_I^2(t) + m_Q^2(t) \tag{3.6}$$

where,

f(x): Received Signal Envelope

s^2 = specular power (LOS component)

$2b_0$ = scattered power (non-LOS component)

K is defined as the ratio of the specular power to scattered power, i.e.

$$K = \frac{s^2}{2b_0} \tag{3.7}$$

Equation (3.7) can be rewritten in terms of Rice Factor and average envelope power

$$E[\alpha^2] = \Omega = s^2 + 2b_o \tag{3.8}$$

where, K and Ω are shape and scale parameters, respectively. Therefore,

$$s^2 = \frac{K\Omega}{K+1} \tag{3.9}$$

$$2b_o = \frac{\Omega}{K+1} \tag{3.10}$$

Rice Probability Density function (PDF) of the received signal envelope is given by

$$f(x) = \frac{2(K+1)x}{\Omega} \exp\left(-K - \frac{(K+1)x^2}{\Omega}\right) I_o\left(2\sqrt{\frac{K(K+1)x}{\Omega}}\right) \tag{3.11}$$

Where:

I_o: O^{th}-order modified Bessel function

‘K’ is described as the ratio of the power received via the LOS path to the power contribution of the non-LOS paths, and is a measure of fading whose estimate is important in link budget calculations. Therefore, for higher ‘K’ factor i.e. a better LOS, the correlation is lower and signal performance is higher. Similarly, for low LOS, the correlation between signal samples is higher and the estimator’s performance deteriorates as the number of independent samples reduces. In this thesis, analysis is done for various modulation schemes and code rates for different ‘K’ factors. ‘K = 0’ is the case of Rayleigh Fading Channel where there is no LOS and ‘K > 0’ which is the case of Rician Fading Channel. Higher ‘K’ is due to lower noise. The following equation describes the magnitude of the received envelope for several values of ‘m’ (the Nakagami shape factor) by the distribution:

$$f(x) = \frac{2m^m x^{2m-1}}{\Gamma(m)\Omega^m} exp\left\{-\frac{mx^2}{\Omega}\right\} \quad m \geq \frac{1}{2} \tag{3.12}$$

Where,

m = 1, the distribution becomes Rayleigh distribution

m = 1/2, it becomes a one-sided Gaussian distribution

m → ∞, means no fading

$$K = \frac{\sqrt{m^2-m}}{m-\sqrt{m^2-m}} \qquad m > 1 \tag{3.13}$$

$$m = \frac{(K+1)^2}{(2K+1)} \tag{3.14}$$

3.3.2 Phase Noise

The output signal of an oscillator will always have some unwanted noise, which is basically spurious frequencies from the surroundings, harmonics and sub-harmonics [66].

Ideal Signal: $V(t) = A_0 \sin(2\pi f_0 t)$ (3.15)

$V(t)$: Variance

A_0: nominal peak voltage

f_0: nominal fundamental frequency

t: time

After adding Amplitude (AM) noise to (3.15):

$$V(t) = [A_0 + e(t)] \sin(2\pi f_0 t) \quad (3.16)$$

$e(t)$: Random deviation of amplitude from nominal "AM noise"

After adding random phase component to (3.16):

$$V(t) = [A_0 + e(t)] \sin[2\pi f_0 t + \Delta\phi(t)] \quad (3.17)$$

$\Delta\phi(t)$: Random deviation of phase from nominal "phase noise"

At amplitude level, oscillators get saturated; therefore, AM noise can be neglected.

$$V(t) = A_0 \sin[2\pi f_0 t + \Delta\phi(t)] \quad (3.18)$$

Now add a deterministic component to the phase in (3.18):

$$V(t) = A_0 \sin[2\pi f_0 t + \Delta\phi(t) + m_d \sin(2\pi f_d t)] \quad (3.19)$$

m_d: Amplitude of deterministic signal, phase modulating the carrier

f_d: Frequency of the deterministic signal

More detailed explanation is given in section 5.5.

3.3.3 Additive White Gaussian Noise (AWGN) Channel

Additive White Gaussian Noise (AWGN) is the channel in which noise is linearly added in wideband and white noise with constant spectral density and a Gaussian distribution of amplitude at the receiver [67].

Suppose,

$$Y_i = X_i + Z_i \tag{3.20}$$

Where,

Y_i = Channel Output

X_i = Channel Input

Z_i = Zero-mean Gaussian with variance N: $Z_i \sim \aleph\ (0,N)$

For an input codeword ($x_1, x_2, ..., x_n$), the average power is constrained so that

$$\frac{1}{n}\sum_{i=1}^{n} x_i^2 \ \leq P \tag{3.21}$$

Suppose + √P or - √P is sent over the channel.

The receiver looks at the received signal amplitude and determines the signal transmitted using a threshold test.

Therefore,

$$P_e \ = \frac{1}{2}\ P\left(Y < 0 \middle| X = +\sqrt{P}\right) + \frac{1}{2} P\left(Y > 0 \middle| X = -\sqrt{P}\right) \tag{3.22}$$

$$= \frac{1}{2} P\left(Z < -\sqrt{P} \middle| X = +\sqrt{P}\right) + \frac{1}{2} P(Z > \sqrt{P} | X = -\sqrt{P})$$

$$= P(Z > \sqrt{P})$$

Normal Cumulative Probability Function = $\int_{\sqrt{P}}^{\infty} \frac{1}{\sqrt{2\pi N}} e^{-x^2/2N} dx$ (3.23)

$$\text{Probability of error} = Q\left(\sqrt{\frac{P}{N}}\right) = 1 - \Phi\left(\sqrt{\frac{P}{N}}\right) \quad (3.24)$$

Where

$$Q(x) = \frac{1}{\sqrt{2\pi}} \int_{x}^{\infty} e^{-x^2/2} dx \quad (3.25)$$

$$\Phi(\mathrm{x}) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{x} e^{-x^2/t} dx \quad (3.26)$$

The information capacity of the Gaussian channel with power constraint is

$$C = \max_{f(x): EX^2 \leq P} I(X;Y) \quad (3.27)$$

A rate R is achievable for Gaussian channel with power constraint P, if there exists a (2^{nR}, n) codes with maximum probability of error

$$\lambda^n = max_{i=1}^{2^{nR}} \quad \lambda_i \rightarrow 0 \text{ as } n \rightarrow \infty$$

Consider codeword length as n and received vector as N, With power constraint, with high probability the space of received vector is a sphere with radius $\sqrt{n\,(P+N)}$.

Volume of n-dimensional sphere = $C_n r^n$ for constant C_n and radius r_n, total codewords can be given as:

$$\frac{C_n(n(P+N))^{\frac{n}{2}}}{C_n(nN)^{\frac{n}{2}}} = \left(1 + \frac{P}{N}\right)^{\frac{n}{2}} \quad (3.28)$$

Rate of the codebook or in other words, the capacity of a Gaussian channel with power constraint ‘P’ and noise variance ‘N’ is given by:

$$C = \frac{1}{2} \log\left(1 + \frac{P}{N}\right) \text{ bits per transmission.} \quad (3.29)$$

3.3.4 Error Correction Due To Channel Anomalies

Due to the multipath channel fading effect, the received signal contains noise, which makes signal reconstruction difficult. To detect the errors, we use the fact that any valid codeword gives: $CH^T = 0$. Error-detection mechanism is based on: $s = rH^T$, where $s = (s_1; s_2, \ldots, s_n)$ = syndrome vector. When 'S' = 0 vector, received vector is a valid codeword. Else, there are errors. The syndrome array is checked to find the corresponding error pattern e_j, for j = 1,2,..,n, and the decoded message is obtained by $m' = r + e_j$. There are two characteristics for LDPC codes:

- Parity-check: LDPC codes are represented by a parity-check matrix H, where H is a binary matrix that, must satisfy $CH^T = 0$, where c is a codeword.
- Low-density: H is a sparse matrix (i.e. the number of '1's is much lower than the number of '0's). The sparseness of H, which gives low computing complexity.

3.3.4.1 *Tanner Graph*

LDPC codes can also be comprised by the bipartite (Tanner) graph [18]. This graph connects check nodes with its participating nodes. Bit nodes correspond 'n' and check nodes to (n - k) i.e. 'm'. Coordinates of '1' within H determined node set connections. Parity check constraints proving to be a valid codeword are chosen by the Tanner graph. Suppose H is given as:

$$\begin{matrix} & n_1 & n_2 & n_3 & n_4 & n_5 & n_6 & n_7 & n_8 & \end{matrix}$$

$$H = \begin{bmatrix} 1 & 0 & 0 & 1 & 1 & 0 & 0 & 1 \\ 0 & 1 & 1 & 0 & 1 & 0 & 1 & 0 \\ 1 & 0 & 1 & 0 & 0 & 1 & 0 & 1 \\ 0 & 1 & 0 & 1 & 0 & 1 & 1 & 0 \end{bmatrix} \begin{matrix} m_1 \\ m_2 \\ m_3 \\ m_4 \end{matrix}$$

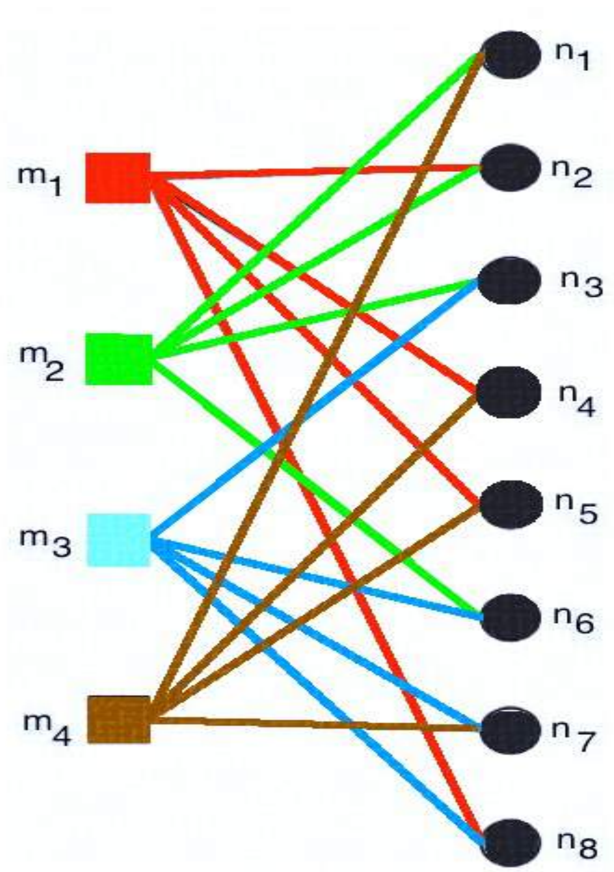


Figure 3.5: Tanner Graph

3.3.4.2 ***Iterative LDPC decoding: Belief Propagation (BP) Decoding:***

In LDPC Decoding, its representing bit node receives the channel value for each bit. This value is forwarded to check nodes by bit nodes. Upon receiving the values, parity check equations are used by checked nodes to update bit information. These messages are sent back, having two state probabilities: 0 or 1. Check node messages have a probability of being satisfied by parity check equations upon reception of input messages by bit nodes. Bit nodes follow soft decision. When all the conditions are satisfied by parity check equations using hard decision, we know that the correct codeword is obtained [21].

3.4 Summary

In this section, detailed analysis of DVB-S2 system performance has been carried out. A video is recorded and sent to TV studios for postproduction. From here, the video is uplinked to DVB-S2 satellite after encryption. The satellite downlinks video directly to home to the end user. The video is encoded using an LDPC encoder at different code rates, and modulated using QPSK, 8PSK, 16APSK or 32APSK. When the signal is transmitted through the wireless communication channel, it experiences interference or noise due to Rician Fading Channel, Correlated Phase Noise and AWGN. Error correction techniques are employed at reception and the signal is regenerated by the STB to be finally viewed on television as per the Pay-TV subscription.

Chapter 4

Analysis of UHD Video Broadcasting by DVB-S2

4.1 Introduction

UHD video delivery has become possible with the help of HEVC, HDMI 2.0, 6G-SDI and more [1]. In addition, DVB-S2X has been developed especially to support UHD video features. The trials for UHD video broadcast by DVB-S2 have also started using UHD specific satellites [12]. Since UHD features consist of different specifications, simulcasting of different video standards for UHD and HD will have to be adopted. Hence, there is a need to investigate the scenario of UHD broadcasting by DVB-S2.

4.2 Problems in DVB-S2

A DVB-S2 receiver working in Adaptive Coding and Modulation (ACM) mode, in the future 2nd Generation of video broadcasting is required to estimate an unknown residual gain before decoding the received signal using a LDPC code. In a mobile communication system, the satellite link can undergo many transmission impairments in uplink and downlink where the radio channel is usually a multipath-fading channel causing Inter-Symbol-Interference (ISI). In addition, the received signal can be affected by atmospheric noise and noise from the receiver [68].

In DVB-S2 systems, a time varying and correlated phase noise affects the signal. Due to multipath fading, the Channel Impulse Response (CIR) of the signal keeps changing continuously. Phase noise is undesirable and makes the estimation of CIR at the receiver difficult. This becomes a challenge for the demodulator to acquire and track the received signal with noise. Hence, as a result the signal is not detected and decoded properly, leading to noise or an increase in bit errors [25].

To counterbalance this problem, a pilot-aided joint channel estimation and data detection technique is proposed, in Section 4.4, to obtain the initial state of the channel. Channel estimation in a coded system is important for coherent detection and demodulation to estimate the complex impulse response of the transmitted message, so that the original message can be regenerated from the corrupt message. This improves the signal quality of DVB-S2 transmission and reduces the BER [69].

4.3 Importance of BER vs. SNR Calculation

Interference affects the signal quality and can result in the loss of information. In telecommunication, interference is called noise. BER estimates the Probability of Error (POE), which helps in predicting the signal performance in an end-to-end transmission chain. By calculating the POE, an appropriate method is applied to improve the signal performance at the receiver.

BER varies with SNR. In simple words, SNR is the ratio of useful data to irrelevant data. 1:1 ratio means SNR = 0 dB i.e. Signal = Noise. This scenario is not good and will result in high BER. SNR should be a positive figure, like 20dB, giving low BER. Therefore, BER v/s SNR graph is plotted in a logarithmic scale, as a measure of digital communication performance. BER cannot be reduced to zero because noise can only be reduced to a certain level in a fixed amount of bandwidth. The information bits contain noise. If noise is entirely removed, certain amount of information data will also be lost. The acceptable BER for a video signal is $\mathbf{10^{-6}}$ i.e. 1 bit error in 1,000,000 bits [70]. Therefore, we need to calculate at the SNR at which we will achieve this figure, for different types of signals. In specific scenarios a lower BER value is acceptable, depending on defined parameters.

BER vs. SNR graph simulation is important because it varies with the change in parameters and needs to be calculated separately, to know every aspect of the signal performance. Critical parameters have been defined to support BER vs. SNR correlation:

4.3.1 ***Noise Channel***

Distortion/ interference deteriorates video quality and is experienced in a wireless communication due to:

- Rayleigh Fading (When Line of Sight is Zero, K = 0)
- Rician Fading (When Line of Sigh is not Zero, K > 0)
- Correlated Phase Noise (Which adds in the wireless communication channel)
- AWGN (gets added to the signal at the receiver)

4.3.2 ***MOD-COD*** (Modulation and Coding) scheme:

- QPSK, 8PSK, 16APSK and 32APSK
- with Code Rates of: 1/2, 3/4, 5/6, 9/10, and more

4.3.3 ***Type of Video***

Till now there were not many types of video signals, but now we want to determine if different video standards can result in different error rates. Parameters given to differentiate video standards include:

- Resolution: (1920 x 1080), (3840 x 2160)
- Frame scan: Progressive (p) or interlaced (i)
- Frame Rate: 25, 50, 100 frames per second
- Colour profile: Rec.709 and Rec.2020
- Bit-depth: 8,10,12-bit
- Compression: MPEG-4 and HEVC

4.4 Proposed Error Reduction Method: Channel Estimation

Due to the effects of Fading, Phase Noise and AWGN, BER of the received signal can be very high causing the Channel Impulse Response (CIR) of the signal to keep varying; therefore, proper estimation or detection of the signal by the receiver becomes difficult [71][72]. To help the receiver detect CIR, a method known as Channel Estimation is used, where CIR is estimated with the help of known or pilot bits.

In this method, pilot bits are transmitted along with the information bits. These pilot bits experience same amount of noise, as experienced by the information bits. At the decoder, when corrupt bits are received, original channel is estimated by characterizing known bits, which assists signal recovery. In first iteration, known bits are used to estimate the channel.

Another iteration can be performed where the decoded bits can be treated as ‘known bits’, which will still be having some error/noise information and therefore, noise can again be characterized and information can be used for further improving the signal performance [72][73]. By comparing the BER achieved before and after applying

Channel Estimation, we can compare the BER reduction or performance gain of the proposed method. Figure 4.1 gives a block schematic of Channel Estimation method.

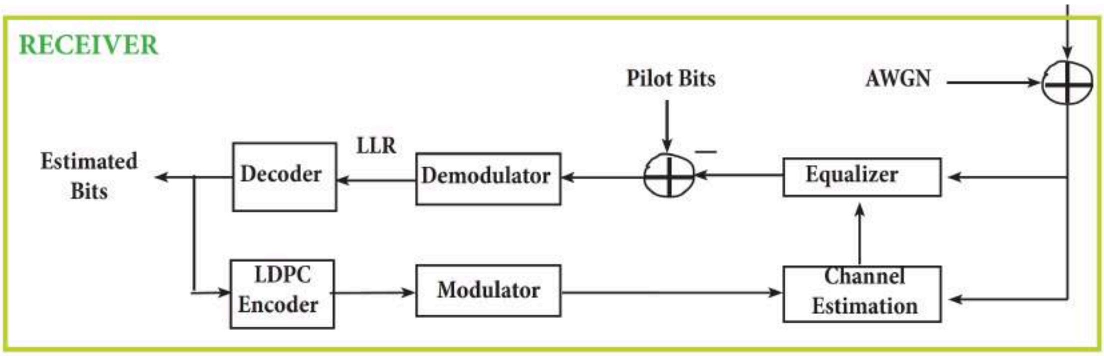


Figure 4.1 Channel Estimation Block Schematic

4.5 Effect of Symbol Rate on BER

Different modulation schemes have different symbol rates. Therefore, videos are bound to perform differently under different symbol rates, in the wireless channel.

AWGN channel passes the sum of the modulated signal and an uncorrelated 'white' Gaussian noise to the output. It gets added to the signal randomly, bit by bit [74]. In the analysis of the Noise (N_o) and bit energy (E_b) correlation,

Let N_o be a normally distributed random variable:

$$N_o = \sigma^2, \sigma = \sqrt{N_0} \tag{4.1}$$

$$\frac{E_S}{N_o}(dB) = \frac{E_b}{N_o}(dB) + 10log_{10}(k) \tag{4.2}$$

$$k = \log_2 M \tag{4.3}$$

Where,

k = number of bits per symbol

M = M-ary modulation scheme

E_s = Symbol energy

E_b = bit energy

For a modulated signal, therefore

$$\sigma = \sqrt{\frac{E_S}{\frac{E_S}{N_O}}} = \sqrt{\frac{E_S}{\frac{kE_b}{N_O}}} \tag{4.4}$$

For a coded signal, as the number of bits increases after coding, Energy per symbol decreases. So we have,

$$E_s = r * k * E_b, \tag{4.5}$$

Where, *r* is the Euclidean distance.

$$\sigma = \sqrt{\frac{E_S}{\frac{rkE_b}{N_O}}} \tag{4.6}$$

Usually, E_s=1; Therefore, Noise Power:

$$\sigma^2 = \frac{1}{rk\left(\frac{E_b}{N_O}\right)} \tag{4.7}$$

Where, $\sigma_I = \sigma_Q = \frac{1}{2}\sigma^2$, Quadrature and In-phase component.

In a digital transmission, SNR of a signal depends on the symbol rate, not on the bit rate. Noise effect is dependent on the bandwidth, which is influenced by the symbol clock rate. This can be understood by equation 4.8 and 4.9, where E is the signal power and D is period of the pulse interval.

$$SNR = \frac{P_r}{N_r} = \frac{Input\ Signal\ Power}{Noise\ Power} \quad (4.8)$$

$$P_r = \frac{E}{D} = \frac{1}{D}\int_0^D |s(t)|^2 dt \quad (4.9)$$

The signal is non-zero for 'D' seconds only and the mean power over an infinite time interval is zero. As a result, the mean power during one symbol period is taken as a measure of the signal strength. Symbol clock represents the frequency and exact timing of the transmission of the individual symbols. At the symbol clock transitions, the transmitted carrier is at the correct I/Q (or magnitude/phase) value to represent a specific symbol (a specific point in the constellation). Then the values (I/Q or magnitude/phase) of the transmitted carrier are changed to represent another symbol.

The interval between these two times is the symbol clock period, as shown in Figure 4.2, which shows the impulse or time-domain response of a raised cosine filter. Adjacent symbols do not interfere with each other at the symbol times because the response equals zero at all symbol times except the center (desired) one [75][76]. Therefore, signal performance over a wireless communication channel is highly dependent on the symbol rate or modulation scheme used, because that determines the quality (or quantity) of information bits being transmitted/received at a time. Noise power can be expressed in terms of the pulse interval, where

$$N_r = \frac{N_o}{2D} \tag{4.10}$$

Such that,

$$SNR = \frac{P_r}{N_r} = \frac{E}{D}\frac{2D}{N_o} = \frac{2E}{N_o} = \frac{2E_b log_2 M}{N_o} \tag{4.11}$$

Where E_b is Energy per bit, if each transmitted symbol consists of M possible characters. Shorter symbol time requires larger bandwidth and gives higher noise power [19].

The Nyquist's sampling theorem states that if channel is strictly band limited to 'B' Hz, it is sufficient to use the sampling frequency, $f_s = 2B$. This gives a connection between bandwidth of a channel and symbols per period of a discrete channel [67][77].

$$\frac{E_b}{N_o} = \frac{P_r}{2N_r log_2 M} = \frac{bit\ energy}{noise\ density} \tag{4.12}$$

$$C_s = \frac{1}{2} log_2 (1 + SNR) \tag{4.13}$$

$$C = 2BC_s = Blog_2 (1 + SNR) \tag{4.14}$$

Where C is the channel capacity and C_s is the system capacity.

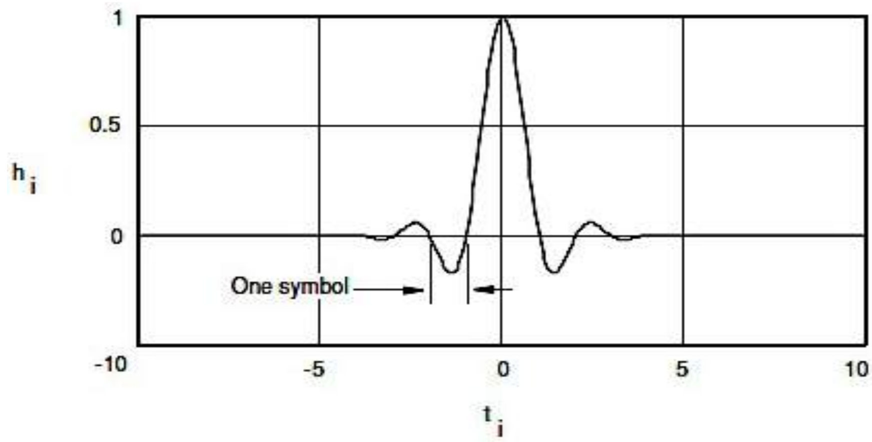


Figure 4.2: One symbol in a Nyquist Filter

4.6 Summary

The discussion done in this chapter is aimed towards the problems related to the UHD-DVB-S2 standard and focuses on the impact of noise on the video signal. A video signal gets heavily distorted when passed through a radio channel of DVB-S2, where it experiences Rician Fading and AWGN. The worst case is when a correlated phase noise is present in the channel, which makes the CIR estimation at the receiver difficult. There are many ways to decrease the spectral noise density. The bandwidth can be reduced, but a minimum bandwidth has to be maintained to transmit the desired data rate (Nyquist Criteria). The energy per bit (E_b) can be increased but interference due to other systems can impose limitation. A lower BER can increase the E_b but capacity has to be compromised for that.

Chapter 5

Proposed Video Performance Evaluation Methodology

5.1 Introduction

In this chapter a number of experiments have been proposed and carried out to test the likelihood of system performance specifications. The standardization of DVB-S2 must take into account the varying parameters that have been used and the range of outcomes under varying scenarios.

5.2 Future Broadcast Scenario: Multiple Video Standards

In the proposed experiments, frames from different videos are used, originally recorded following HD and UHD standard, such as shown in Figure 5.1 and 5.2. Using these original videos, different versions are generated having 1080p and 2160p resolution, 25fps, 30fps and 50fps (where ever possible), and compressed using MPEG-4 and HEVC codec. The following softwares have been used:

- *Frame Rate Converter:* Movavi Video Converter 4 for Mac
- *HEVC Compressor:* DivX Converter 10.2.1 for Mac (Compression only available till 2160p/30fps for HEVC and 2160p/50 for MPEG-4) [78]
- *Operating System*: Mac OS X 10.10.3 – 64 bit and Windows 7
- BER v/s SNR graph simulated using MATLAB R2014a version for mac and windows, limited to 8-bit (experiments done in both OS to confirm results) [79]

The reason to choose two different types of videos (one with native HD and other with the rich colour content of UHD) is that the primary issue being investigated in this thesis is the broadcast of these videos using existing resources and infrastructure, and there are fewer chances for the same video being shot in 1080p and 2160p. It is more likely that the existing HD 1080p content will be upscaled to a higher spatial and temporal resolution and the new UHD 2160p content will be downscaled to a lower resolution [80]. Therefore, the existing HD content will look less dynamic by default, even after upscaling because its pixel density will always be lower than a video shot using an exclusive 4K camera which enhances image sensors and other features. This is because, Rec.2020 (for UHDTV) captures more colours as compared for Rec.709 (for HDTV) [24][37]. Other than the two pictures shown in Figure 5.1 and 5.2, the video also had different scenes, and by using a combination of the available colour information in different pictures, a generalized result has been developed.

Figure 5.1: HD video frames used for experiment

Figure 5.2 UHD video frames used for experiment

Figure 5.3. explains the complete broadcast scenario in the presence of different video standards coming from the source, with different TV receiver sets being used by the consumers, taking into account the challenges faced by the DTH operator. Due to the differences in requirements and availability per video standard, 16 versions of the default HD and UHD video have been used, as explained in Table 5.1. A bit rate decrease between 5% and 13% is observed, per frame (there are 25 - 50 frames per second) when the video is compressed using an HEVC encoder as compared to MPEG-4; while a bit rate increase from 3% to 6% per frame is observed when the frame rate is converted from 25 to 50 fps.

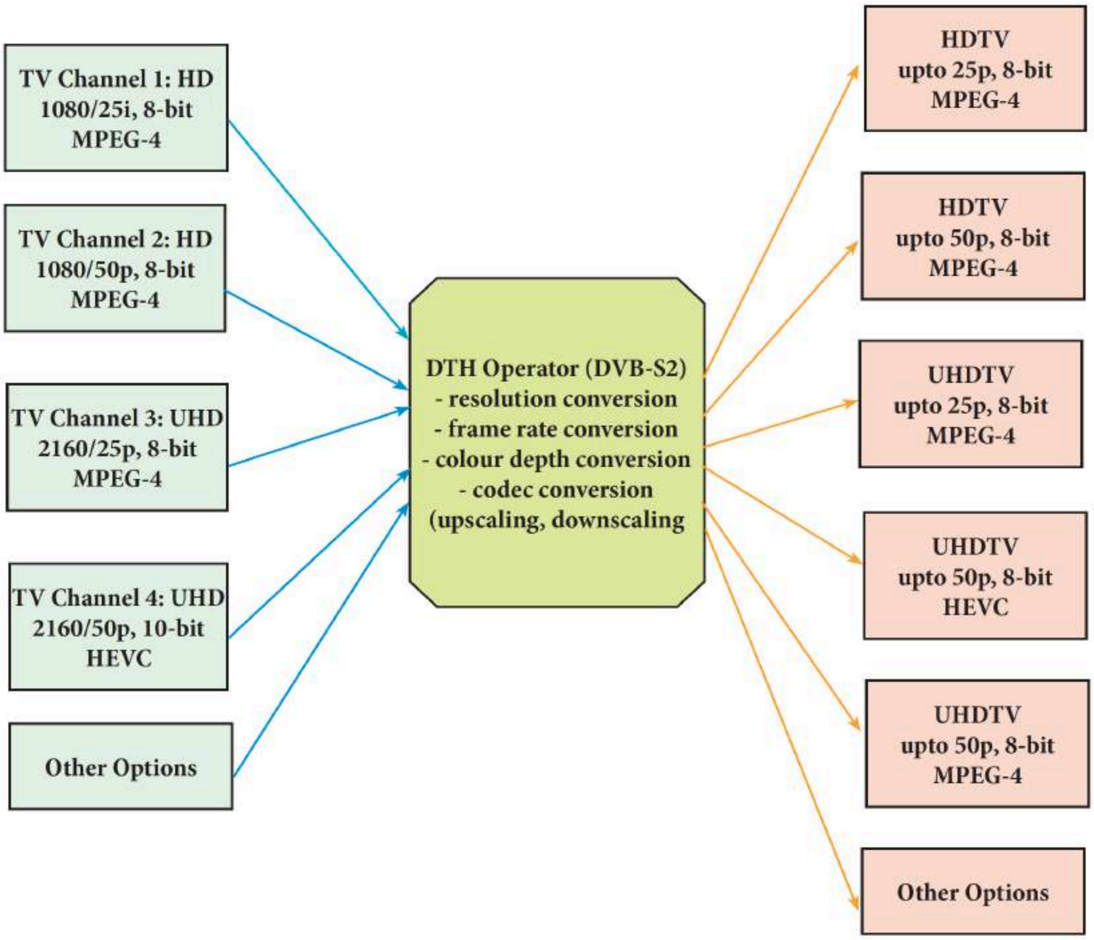


Figure 5.3 Future broadcast scenario [5][81]

Table 5.1: Description of formation of multiple video standards

	Codec	Default Content	Broadcast Resolution	fps	SDI	TV	Channel	HDMI	Size (MB)
1	MPEG-4	HD	1080p	25	HD	HD	HD	1.4a	2.75
		(Default HD: 1080p/25)							
2	MPEG-4	HD	1080p	50	3G	HD	HD+	1.4a	2.90
		(1080p/25 Upscaled to 1080p/50)							
3	MPEG-4	HD	2160p	25	6G	UHD	HD	1.4a	8.55
		(1080p/25 Upscaled to 2160p/25)							
4	MPEG-4	HD	2160p	50	12G	UHD	HD+	2	9.10
		(1080p/25 Upscaled to 2160p/50)							
5	MPEG-4	UHD	1080p	25	HD	HD	HD	1.4a	2.93
		(2160p/25 Downscaled to 1080p/25)							
6	MPEG-4	UHD	1080p	50	3G	HD	HD	1.4a	3.01
		(2160p/25 Downscaled to 1080p/50)							
7	MPEG-4	UHD	2160p	25	6G	UHD	UHD	1.4a	8.70
		(Default UHD: 2160p/25)							
8	MPEG-4	UHD	2160p	50	12G	UHD	UHD	2	9.10
		(2160p/25 Upscaled to 2160p/50)							
9	HEVC	HD	1080p	25	HD	HD	HD	1.4a	2.40
		(Default HD: 1080p/25)							
10	HEVC	HD	1080p	50	3G	HD	HD+	1.4a	2.55
		(1080p/25 Upscaled to 1080p/50)							
11	HEVC	HD	2160p	25	6G	UHD	HD	1.4a	7.55
		(1080p/25 Upscaled to 2160p/25)							
12	**HEVC**	**HD**	**2160p**	**30**	**6G**	**UHD**	**HD+**	**1.4a**	**7.90**
(1080p/25 UP/S 2160p/30. DivX Converter does not support 2160p/50 for HEVC at the moment) [78]									
13	HEVC	UHD	1080p	25	HD	HD	UHD	1.4a	2.73
		(2160p/25 Downscaled to 1080p/25)							
14	HEVC	UHD	1080p	50	3G	HD	UHD	1.4a	2.90
		(2160p/25 Downscaled to 1080p/50)							
15	HEVC	UHD	2160p	25	6G	UHD	UHD	1.4a	8.30
		(Default UHD: 2160p/25)							
16	**HEVC**	**UHD**	**2160p**	**30**	**6G**	**UHD**	**UHD**	**1.4a**	**8.65**
2160p/25 UP/S 2160p/30. DivX Converter does not support 2160p/50 for HEVC at the moment [78]									

5.3 Video Quality Assessment

There are many ways to do a video quality assessment. One of the most common methods is measuring the Peak Signal to Noise Ratio (PSNR) of a video [83]. However, since BER vs. SNR has been computed in this research work, another calculation of PSNR is not required because it comes under the umbrella of SNR. Therefore, first, video assessment has been done in terms of colour range because it consumes video's pixel depth, which contributes towards the size in Megabyte (MB) i.e. bit rate, ultimately leading to bit error rate and wider bandwidth. Figure 5.4 to 5.7 give histograms of video frames shown in Figure 5.1 and 5.2 respectively, varying in parameter, simulated using MATLAB. X-axis has a range of 0 to 255, where each decimal number represents a colour shade included in the Rec.709 standard. Y-axis is a measure of how many times a particular colour is used in the video frame. Since MATLAB is currently limited to reading a video of 8-bit depth, and a broadcaster's infrastructure is also limited to 8-bit depth, only 8-bit depth videos have been included in this experiment.

The results show that the HD video has occupied a lower range of colours and utilized the same colour again and again. In other words, the video frame of 1080p is composed of limited colours, mostly green, blue, orange and its shades. The same is observed for its upscaled version of 2160p. When it comes to UHD, the histogram has fewer peaks across the Y-axis and is more widely spread across the X-axis. This means that one frame of either 1080p or 2160p is composed of a wide range of colours, like, green, purple, red, white, blue, black and more.

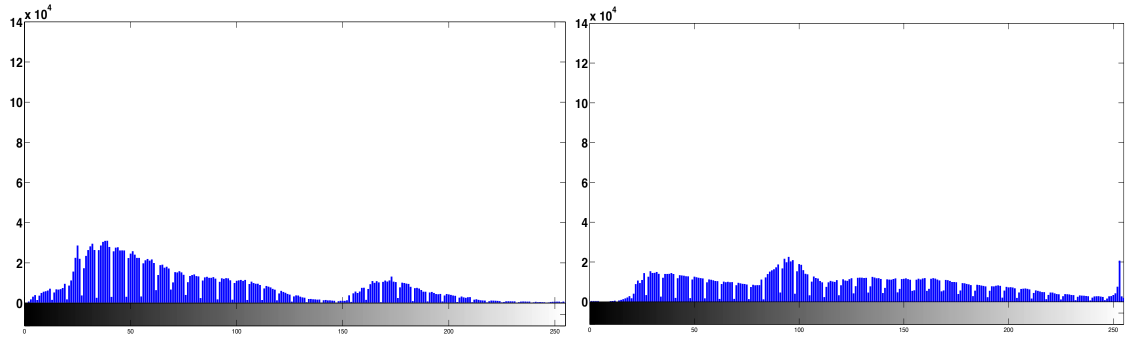


Figure 5.4: Colour range of HEVC HD 1080/25p videos

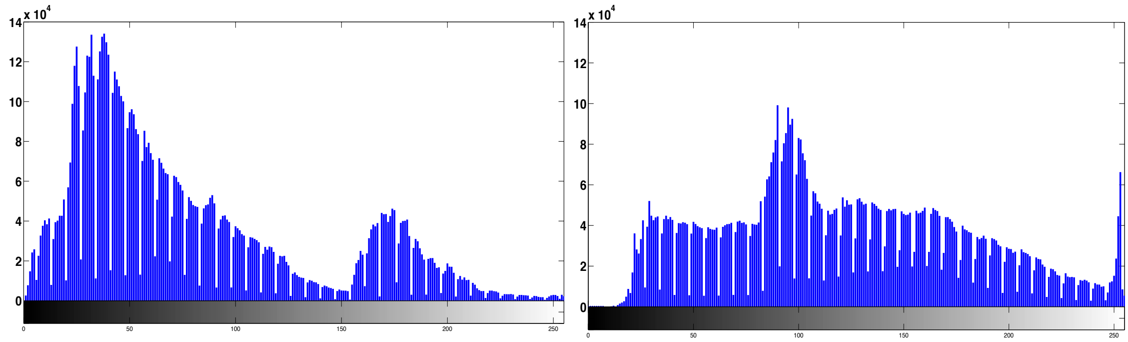


Figure 5.5: Colour range of HEVC HD 2160/25p videos

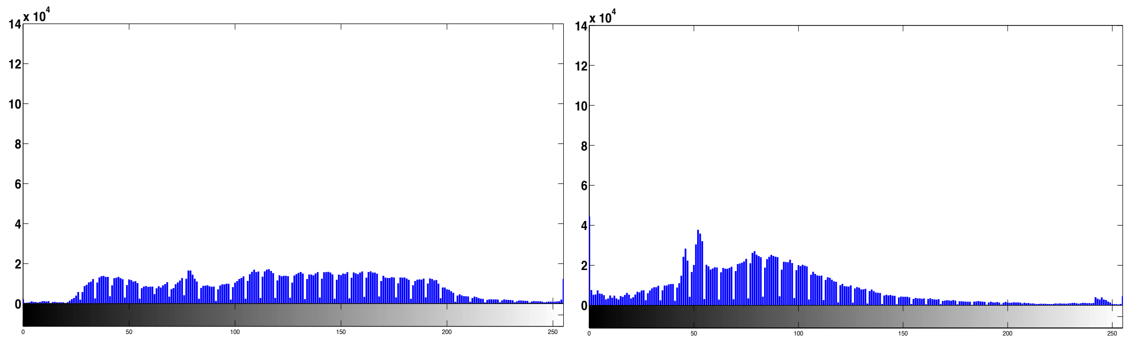


Figure 5.6: Colour range of HEVC UHD 1080/25p videos

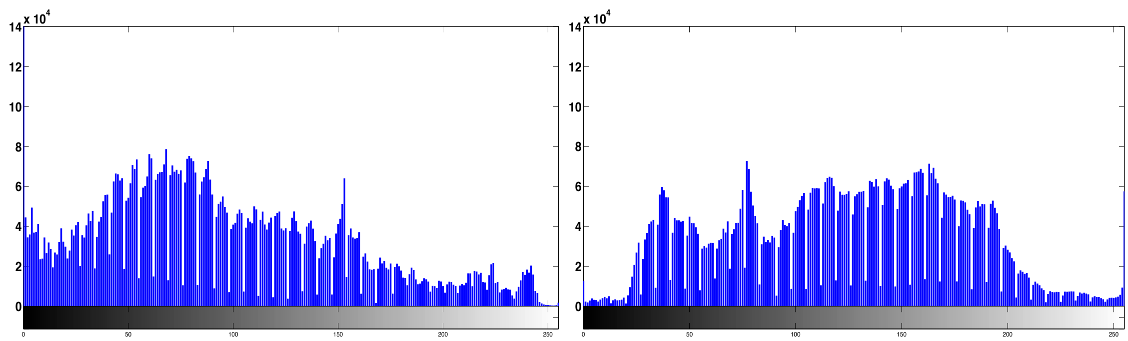


Figure 5.7: Colour range of HEVC UHD 2160/25p videos

5.4 Video Performance Assessment: System Model

Once all the video samples are ready to be experimented, pixel information is extracted from the frames in the range of 0-255. This value is converted to binary bits and reformed into MPEG-Transport Stream (TS) in the form of Base Band Frame or BBFRAME as a part of stream adaptation by DVB-S2 to enter through the BCH Encoder [82], as shown in Figure 5.8.

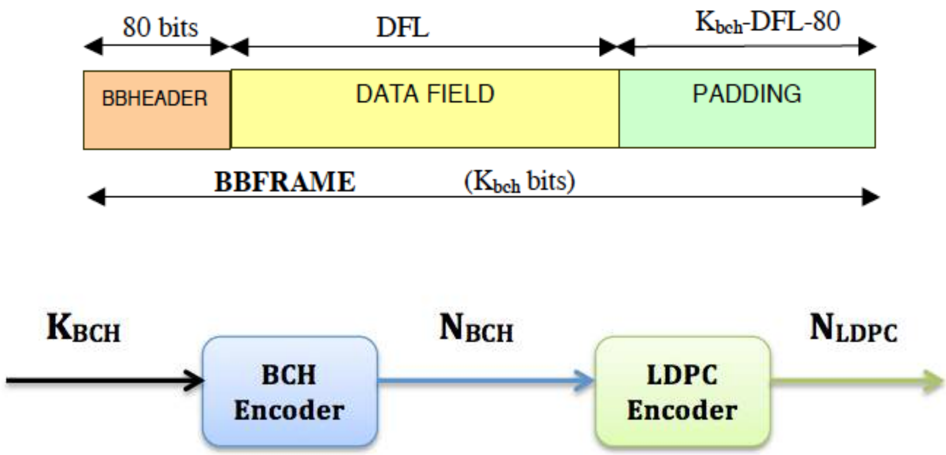


Figure 5.8: MPEG-TS BBFRAME [82]

The length of K_{BCH} or BBFRAME or the input to the BCH encoder varies with the code rate as given in Table 5.2 for 3/4, 5/6 and 9/10 code rates.

Table 5.2: Coding Parameters for FEC Block size = 64,800 [25]

LDPC Code	BHC Uncoded Block (K_{BCH})	BCH Coded block (N_{BCH})	LDPC Coded Block (N_{LDPC})
3/4	48,408	48,600	64,800
5/6	53,840	54,000	64,800
9/10	58,192	58,320	64,800

A BBFRAME or Base Band Frame or K_{BCH} is composed of the following:

- BBHEADER consists of 80 bits
- Data generator = 188 bytes x 8 bits = 1504 bits
- DATA FIELD represents the number of MPEG packets that can be fitted in one BBFRAME and is given by = $\left\lfloor \frac{K_{BCH} - 80}{1504} \right\rfloor$
- ZERO PADDING = K_{BCH} – [(Number of packets * 1504) + 80]

Performance evaluation is done using MATLAB for DVB-S2, using QPSK, 8PSK, 16APSK and 32APSK modulation scheme, with a code rate of 3/4, 5/6 and 9/10. FEC block size = 64800, using BCH + LDPC encoder and a soft-decision decoder, in the presence of AWGN, Rician Fading Channel and a Correlated Phase Noise. For this simulation, the fading factor is generated randomly and multiplied by every incoming frame but is constant over one entire frame. Next, the faded codeword is affected by a time varying and correlated phase noise. This phase noise is deterministic for better channel estimation simulation results. At the receiver, AWGN is added to the message and it affects the signal bit by bit. We generate noise randomly and add it to every bit in the message independently [83]. Channel estimation is performed on the received bits with the help of known pilot bits. Therefore, the estimated Channel Impulse Response (CIR) of the varying signal is computed as the mean of all the pilot bits. After this, pilot bits are removed from the received signal. The computed CIR is fed to the equalizer in which the estimated channel value equalizes (divides) every bit of the received message and compensates for noise. The equalizer output is demodulated which gives the Log Likelihood Ratio (LLR) values. These LLRs are decoded and the message is recovered but there are still errors in it. The number of error bits with increasing signal to noise ratio is plotted. BER varies with SNR; thus, BER v/s SNR graph is plotted in logarithmic scale, as a measure of digital communication performance. The acceptable BER for a video signal is 10^{-6} i.e. 1 bit error in 1,000,000 bits for a video [71]. Therefore, we need to calculate the SNR at which we will achieve this value for different signals. Let us assume transmission of LDPC encoded and complex modulated symbols over a Rician Fading Channel and AWGN channel affected by phase noise:

$$\text{Coded and Modulated message: } C = [\ c_1, c_2, ..., c_k\ ];$$

$$\text{Pilot bits: } P = [\ P_1, P_2, ..., P_k\ ]$$

$$\text{Transmitted message: } M = [P\ C] \tag{5.1}$$

'M' is passed through the Rician channel 'h' where correlated phase noise '$e^{j\Phi k}$' is added to it, and given by

$$= M * e^{j\Phi k} \tag{5.2}$$

$$\text{Channel: } h = [\ h_1, h_2, ..., h_k\ ] = h\ [M * e^{j\Phi k}] \tag{5.3}$$

$$\text{Channel phases: } q = [\ q_0, q_1, ..., q_{k-1}\ ] = h\ [M * e^{j\Phi k}]e^{jq} \tag{5.4}$$

Phase noise according to Wiener random walk model described by:

$$q_K = q_{K-1} + \Lambda_K \tag{5.5}$$

Where: Λ_k: white real Gaussian process: $\Lambda_k \sim N(0, \sigma\Lambda)$

Finally, AWGN 'n' is added at the receiver:

$$\text{Noise: } n = [\ n_1, n_2, ..., n_k\ ]$$

The received message is:

$$Y = R_M(t) = h\,[M * e^{j\Phi k}]\,e^{jq} + \Lambda_K \tag{5.6}$$

Using equation (5.1) in (5.6),

$$Y = R_M(t + 1) = h\,[PC * e^{j\Phi k}]\,e^{jq} + \Lambda_K$$

$$= h\,[PC * e^{j(\Phi k + q)}] + \Lambda_K \tag{5.7}$$

Channel estimation can be done by:

$$CIR = \text{average}\,(Y_{1-P} / P) \tag{5.8}$$

Equalizer:
$$E = Y_{(P-1)-k} / CIR \tag{5.9}$$

Channel estimation and decoding techniques are implemented to compute the CIR of the signal at the receiver. Channel Estimation helps in reducing the BER to 10^{-6}, for Rician factor 'K=5' but not for 'K=0'. This is because as 'K' increases, the ratio of the power received via the LOS path to the power contribution of the non-LOS paths, increases. If 'K' is high, the P_r (Received power) or E_s (Energy per symbol) or E_b (Energy per bit) is high. This gives a higher SNR, which ultimately decreases the BER as per Equation 5.5, where 'B' is the total bandwidth and 'T_s' symbol time and 'T_b' is bit time. BER decreases because as E_s increases, the distance between adjacent symbol increases and correlation decreases. This bootstraps the decoder in signal recovery.

$$SNR = \frac{P_r}{N_o B} = \frac{E_s}{N_o B T_s} = \frac{E_b}{N_o B T_b} \tag{5.10}$$

5.5 Experiment 1: In the presence of AWGN only

In Experiment 1, performances of two videos have been analyzed in the presence of AWGN. Videos used: HEVC HD 1080p/25 and HEVC UHD 2160p/25.

5.5.1 *Result Summary - 1*

As SNR increases, BER decreases because when signal power is more than the noise power, signal detection and decoding is improved, resulting in a lower BER. There is a significant increase in the BER rate of UHD as compared to HD, for QPSK and 8PSK, as compared to 16APSK and 32APSK. UHD video (HEVC UHD 2160/25p) has a higher BER than HD. This can be seen from Figure 5.12 at SNR = 9.36 dB, BER for HD is in the vicinity of 10^{-5}, while BER for UHD is in the vicinity of 10^{-4}, which is a large difference and can result in an increase of the overall cost of transmission power to achieve the desired BER [84]. Complete results of this experiment are given from Figure 5.9 to 5.20.

The maximum increase in BER for UHD, as compared to HD, is seen for code rate = 5/6. Code rate 3/4 also shows an increase in BER, but less than 5/6. While code rate 9/10 rate shows the lowest error rate difference.

- *Result: UHD has a higher BER than HD in QPSK and 8PSK*
- More analysis is done for 8PSK-5/6, with respect to HFR, in Experiment 2
- Cost implications are discussed in Section 6.7

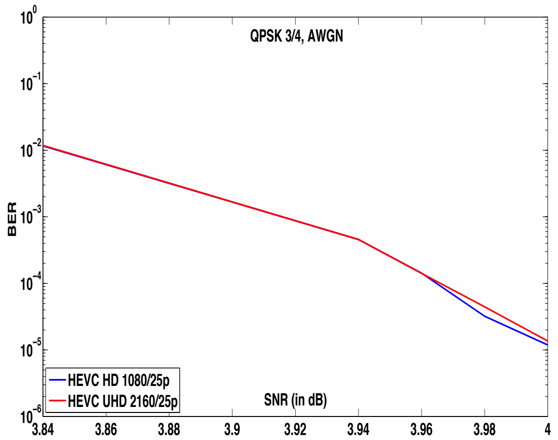


Figure 5.9: BER vs. SNR of UHD and HD for QPSK-3/4, with AWGN

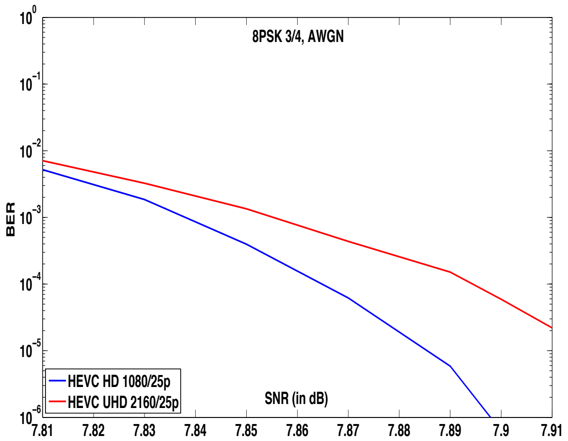


Figure 5.10: BER vs. SNR of UHD and HD for 8PSK-3/4, with AWGN

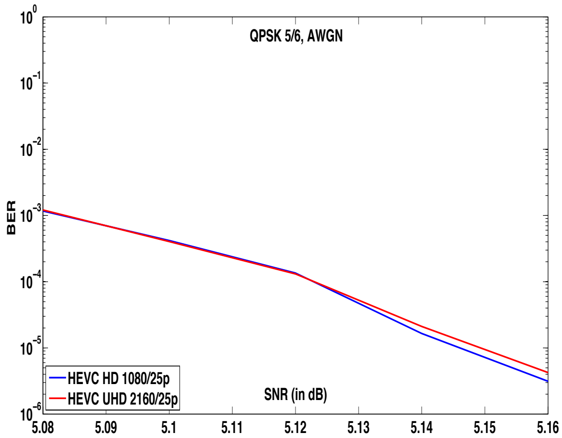


Figure 5.11: BER vs. SNR of UHD and HD for QPSK-5/6, with AWGN

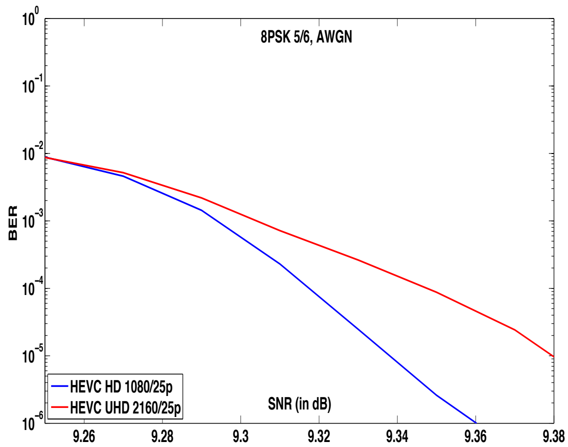


Figure 5.12: BER vs. SNR of UHD and HD for 8PSK-5/6, with AWGN

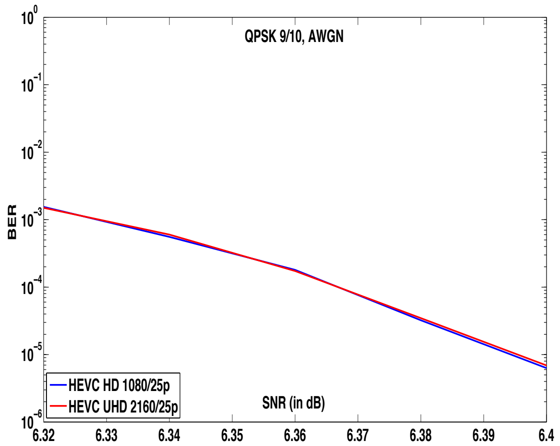


Figure 5.13: BER vs. SNR of UHD and HD for QPSK-9/10, with AWGN

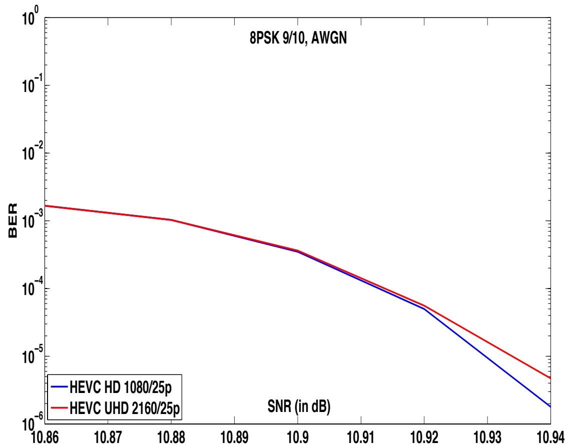


Figure 5.14: BER vs. SNR of UHD and HD for 8PSK-9/10, with AWGN

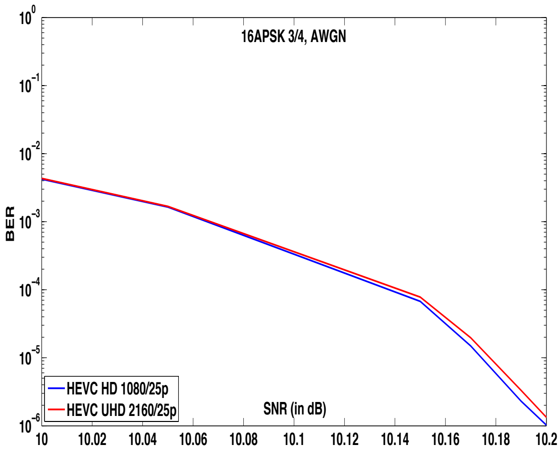


Figure 5.15: BER vs. SNR of UHD and HD for 16APSK-3/4, with AWGN

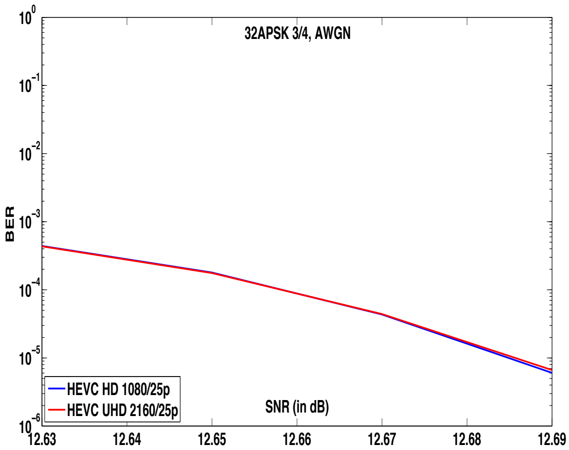


Figure 5.16: BER vs. SNR of UHD and HD for 32APSK-3/4, with AWGN

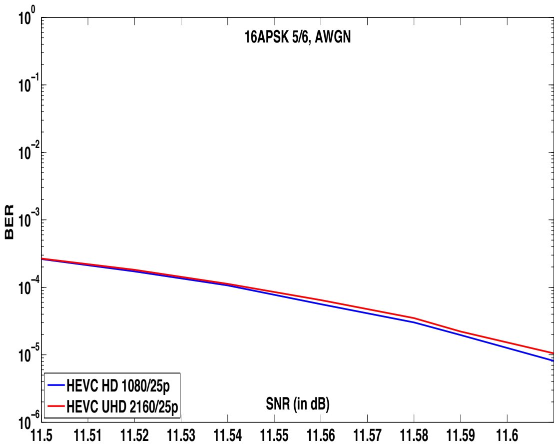


Figure 5.17: BER vs. SNR of UHD and HD for 16APSK-5/6, with AWGN

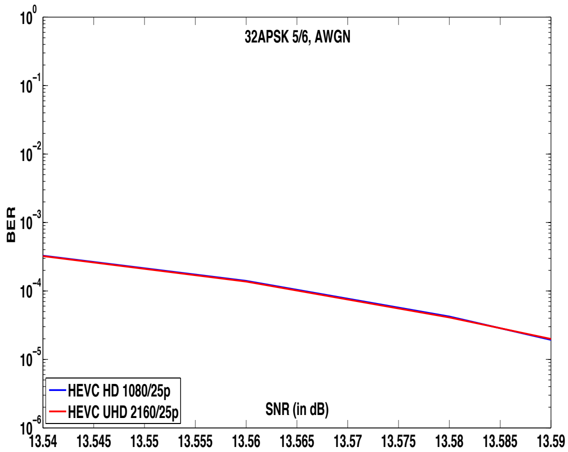


Figure 5.18: BER vs. SNR of UHD and HD for 32APSK-5/6, with AWGN

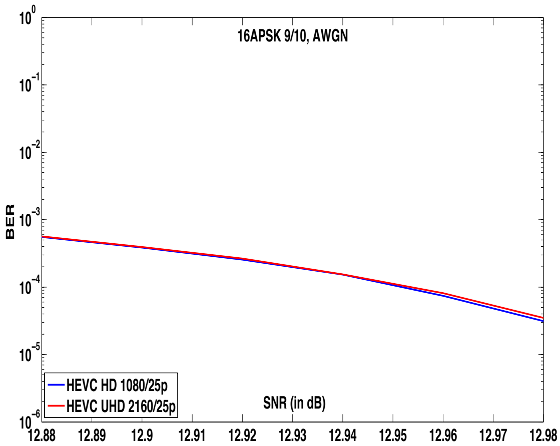


Figure 5.19: BER vs. SNR of UHD and HD for 16APSK-9/10, with of AWGN

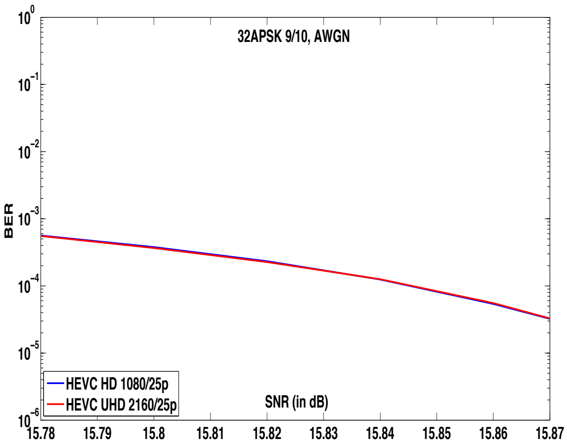


Figure 5.20: BER vs. SNR of UHD and HD for 32APSK-9/10, with of AWGN

5.6 Experiment 2: High Frame Rate Videos

In Experiment 1, QPSK and 8PSK show increased BER when a UHD video is broadcasted, as compared to HD, in the presence of AWGN only. In Experiment 2, 16 different types of videos are transmitted through an 8PSK modulator, using code rate 5/6, in the presence of AWGN. These different videos comprise of HD and UHD video content, both having (1920x1080) and (3840x2160) resolution; 25 and 50 frames per second in progressive mode; using MEPG-4 and HEVC compression method as given in Table 5.1 in section 5.2.

5.6.1 *Result Summary - 1*

The most important finding of this experiment is that the BER of videos having 50fps (or 30fps) is lower than 25fps. This is because as the frame rate increases, even though the number of frames increases, marking an increase in the total video size, but due to compression, the amount of data that every frame carries decreases [85]. In a compressed video, every frame only carries the difference between the current and reference frame. Therefore, as a result of compression, the bits per frame decreases as the number of frames increases. This makes the data less susceptible to noise and bootstraps the signal recovery at the receiver. This can be understood from Figure 5.21. Hence, the signal performance of a video with more frames is better than the same video having fewer frames with a lot of data per frame [86]. The results are the same for HEVC and MPEG-4 video compression as shown in Figure 5.22.

- *Result: BER decreases as frame rate increases*

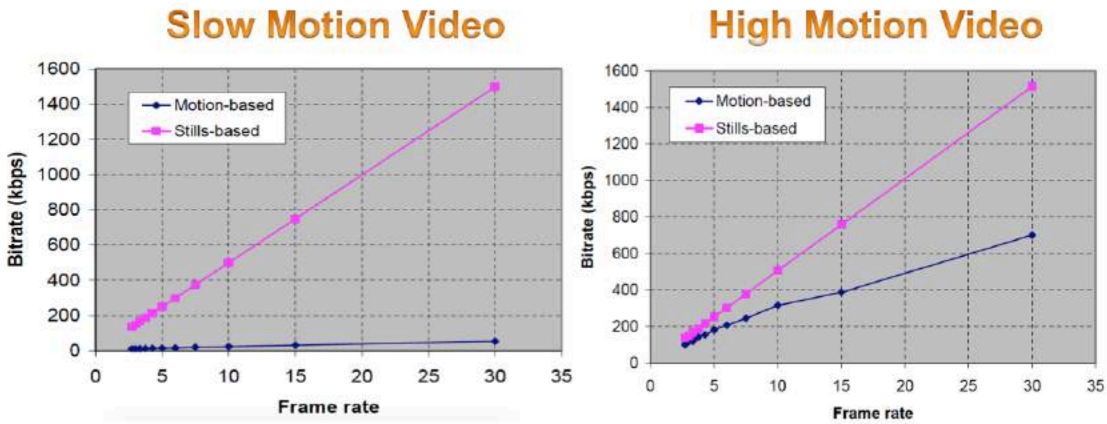


Figure 5.21: Understanding frame rate: For videos (motion based), as frame rate increases, bit rate decreases [85]

5.6.2 Result Summary - 2

UHD 2160p/25 video has the highest BER followed by UHD 2160p/30 (due to the reason stated in the previous section), because it has the highest bit rate of all the videos. The second highest is UHD 1080p/25 (and 1080p/50), which is the downscaled version of 2160p/25. The second lowest is HD 2160p/25 (and HD 2160p/30), which is the upscaled version of HD 1080p/25 and the video with the lowest BER is HD 1080p/25 (and HD 1080p/50).

Interestingly, it is observed that even though UHD/2160p has been converted to UHD/1080p resolution, still its BER is higher than the HD/1080p video and this is due to the difference in the colour pixel density or the amount of information they carry. Therefore, if a broadcaster assumes that the signal performance or BER of a downscaled UHD video will be similar to the HD video, might be wrong.

- *Result: UHD downscaled video BER is higher than HD upscaled video*

5.6.3 Result Summary - 3

HEVC for UHD certainly comes with many advantages for the broadcast media since it not only effectively reduces the size of the video, but also helps in decreasing the BER as compared to MPEG-4. This compression can be used for UHD, but also for HD videos.

These results will help the broadcasters and DVB-S2 hardware manufactures to make an informed decision about their future migration and adoption strategies related to Ultra High Definition Television [85].

- *Result: HEVC video compression results in a lower BER as compared to MPEG-4*

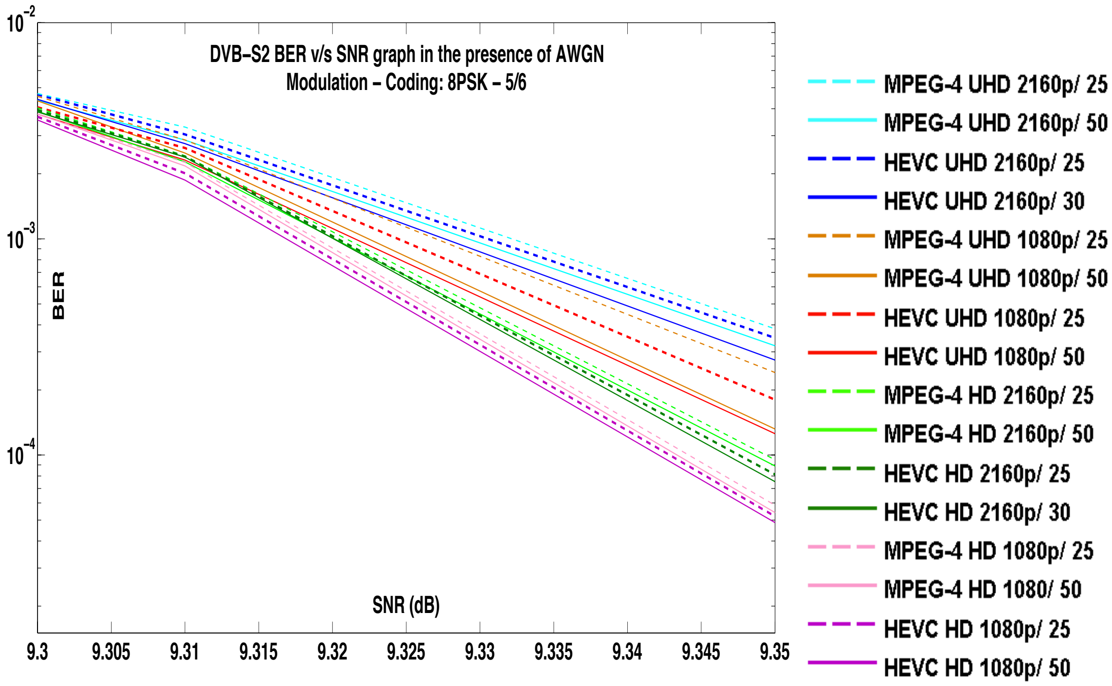


Figure 5.22: Signal performance of different video standards, when transmitted through 8PSK-5/6 in the presence of AWGN

5.7 Experiment 3: Rician Fading & Channel Estimation

In Experiment three, UHD and HD video signals are transmitted through the wireless communication channel in the presence of Rician Fading Channel, Correlated Phase Noise and AWGN. There are two types of Noise Channel: for K = 0 i.e. Rayleigh Fading and for K = 5 i.e. Rician Fading. The results for these two channels are shown separately for each MOD-COD scheme. This experiment is performed with and without using channel estimation.

Results show that the required SNR to achieve the desired BER is higher for a Rician Fading channel, as compared to AWGN. BER of UHD is higher than HD for QPSK and 16APSK only, for 3/4 and 5/6 code rate, instead of QPSK and 8PSK as in the case of AWGN only [87][88].

Figure 5.23 shows the constellation diagrams for Rician Channel, K=5 at SNR=20dB for QPSK, 8PSK, 16APSK and 32APSK. The correlation is lower as compared to what it is for K=0 at SNR=-10dB. When the correlation is high, there is more degradation due to noise and a higher SNR is required to regenerate the signal. The constellations of 8PSK and 32APSK are close to each other and the correlation is high, as compared to QPSK and 16APSK. This is the reason that QPSK and 16APSK are able to detect the difference between UHD and HD video pixel density. Higher correlation results in a higher BER, therefore, the BER vs. SNR graphs (5.24-5.35) depict exactly what a signal goes through under noise.

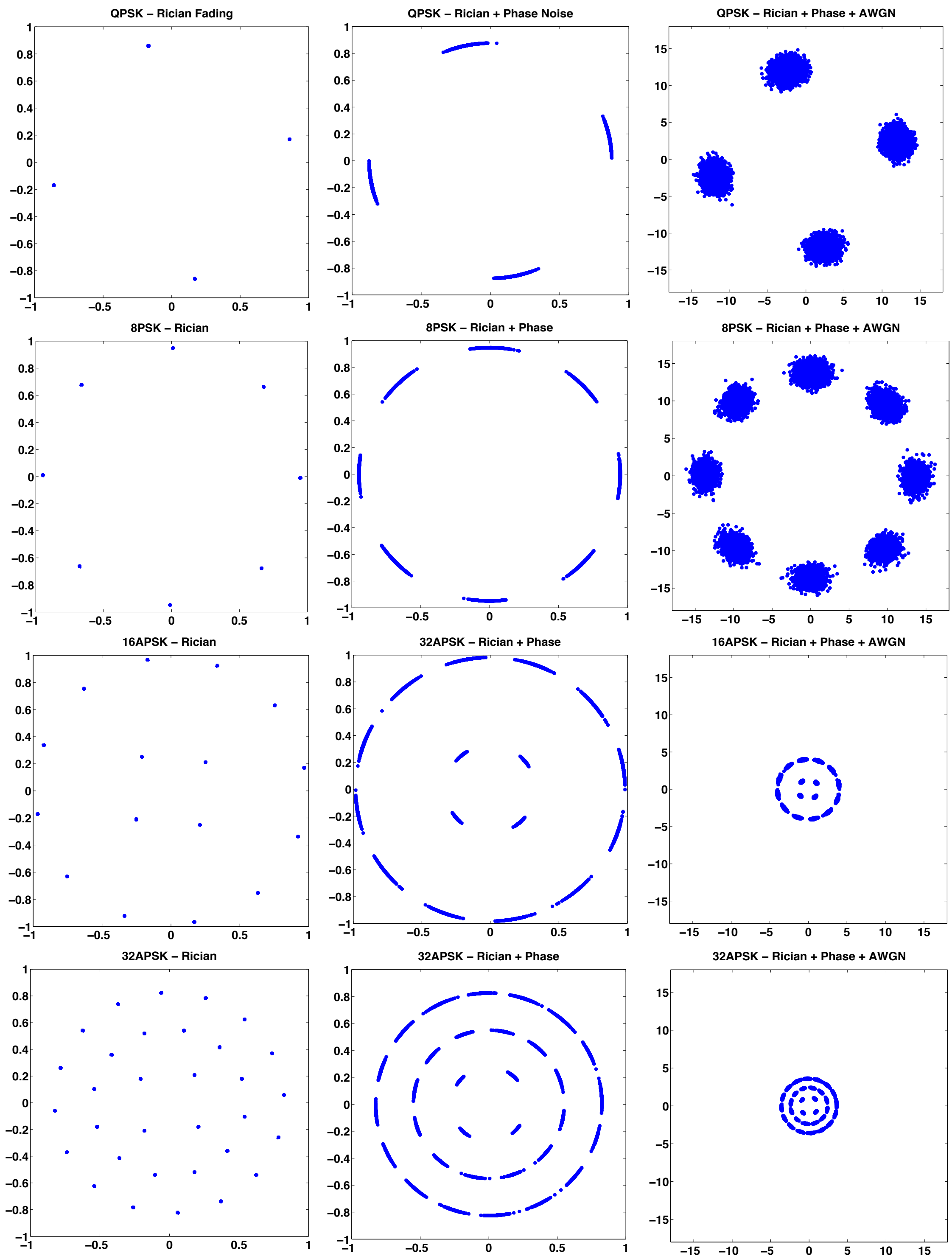
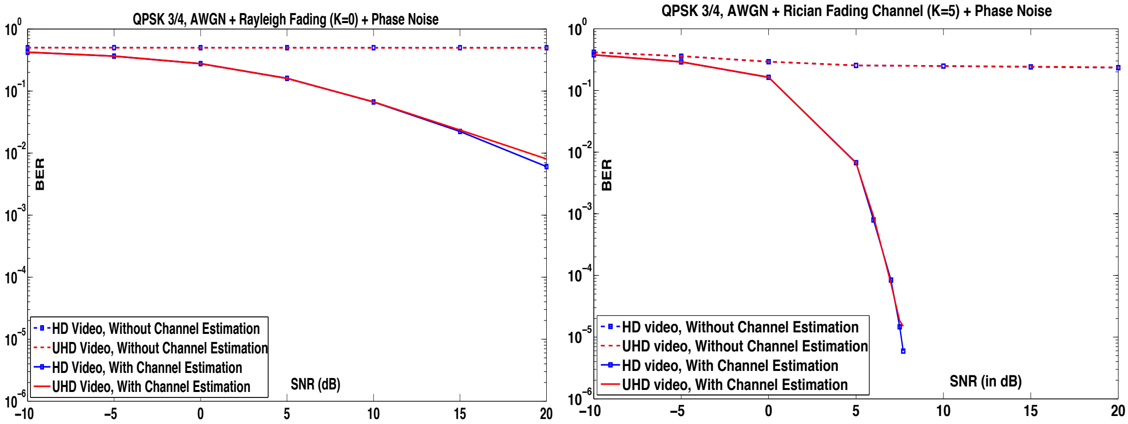
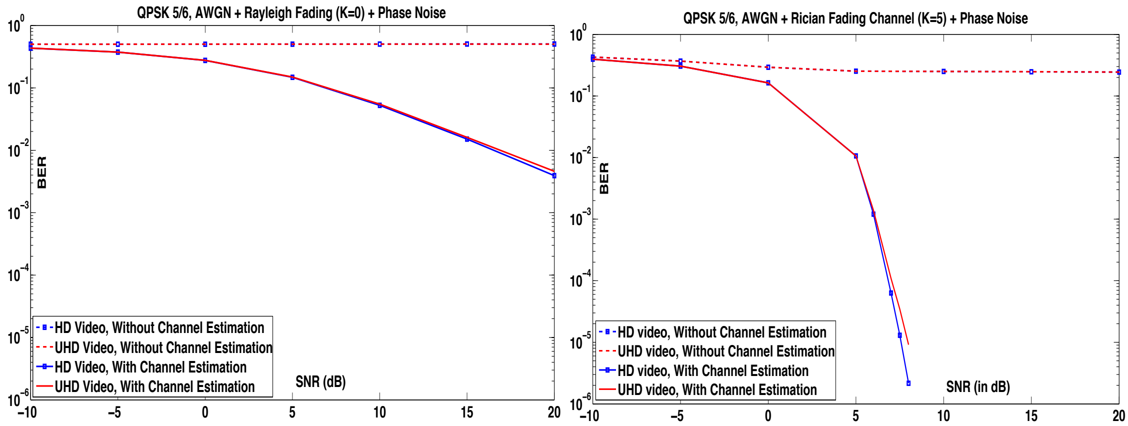


Figure 5.23: Constellation diagrams of different modulation schemes with noise, at SNR=20dB for Rician Fading Channel (K=5)



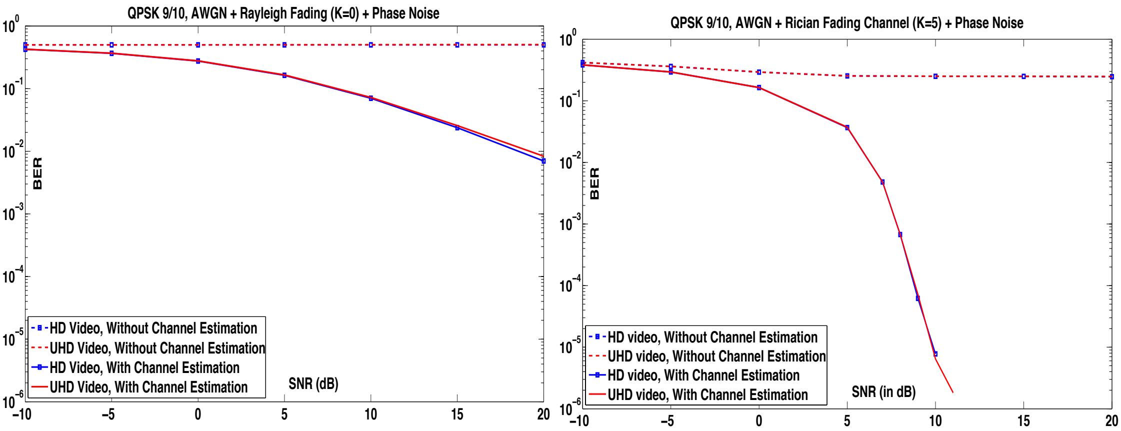
(a) (b)

Figure 5.24: BER vs. SNR for QPSK-3/4 (a) Rayleigh Fading (b) Rician Fading



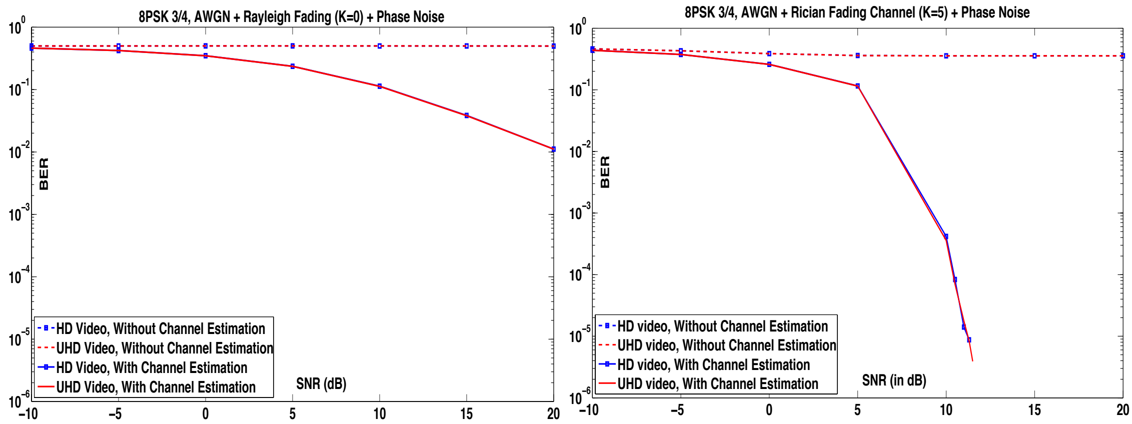
(a) (b)

Figure 5.25: BER vs. SNR for QPSK-5/4 (a) Rayleigh Fading (b) Rician Fading



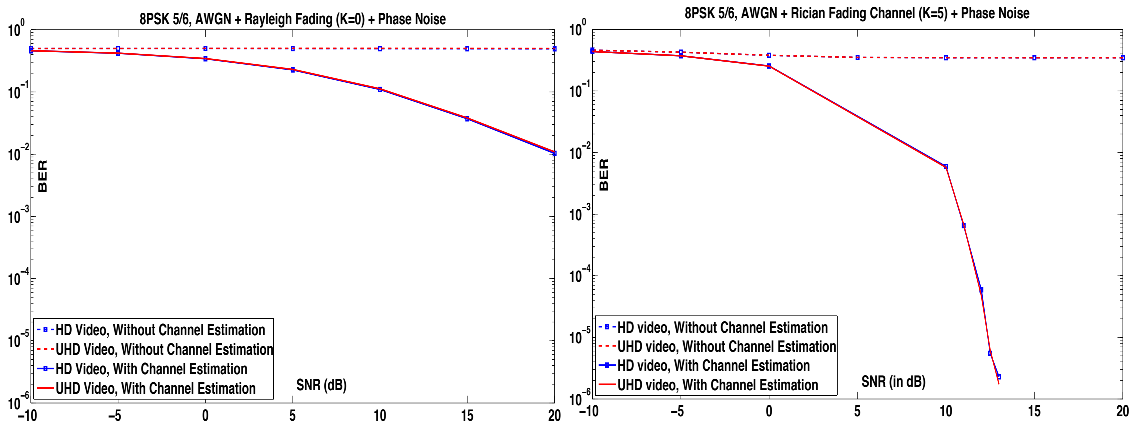
(a) (b)

Figure 5.26: BER vs. SNR for QPSK-9/10 (a) Rayleigh Fading (b) Rician Fading



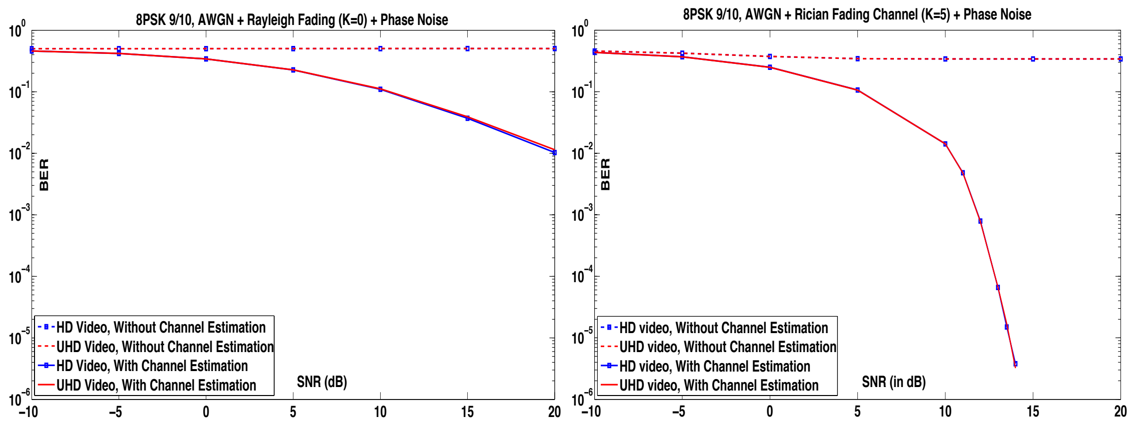
(a) (b)

Figure 5.27: BER vs. SNR for 8PSK-3/4 (a) Rayleigh Fading (b) Rician Fading



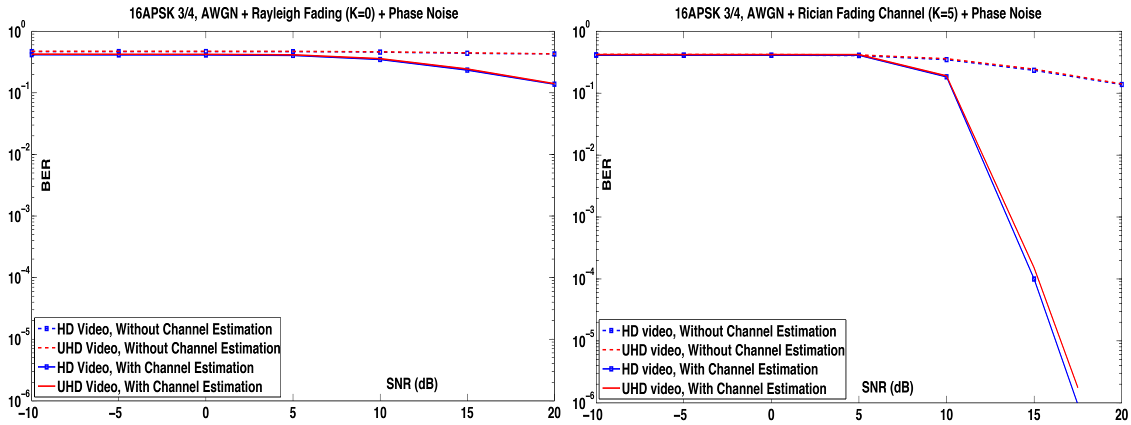
(a) (b)

Figure 5.28: BER vs. SNR for 8PSK-5/6 (a) Rayleigh Fading (b) Rician Fading



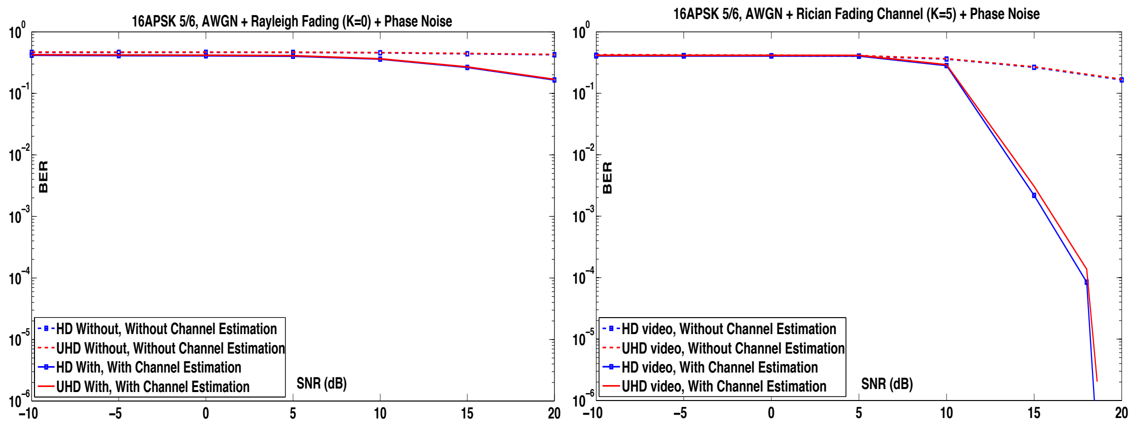
(a) (b)

Figure 5.29: BER vs. SNR for 8PSK-9/10 (a) Rayleigh Fading (b) Rician Fading



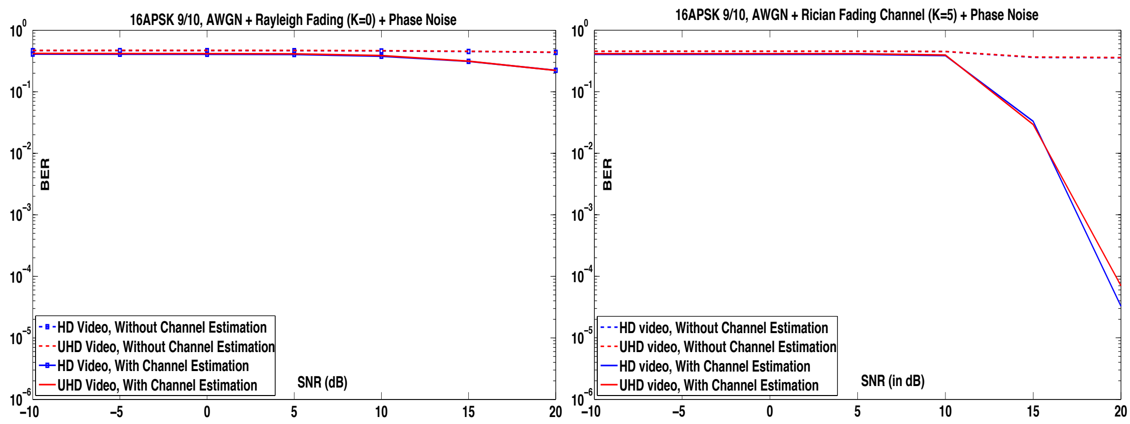
(a) (b)

Figure 5.30: BER vs. SNR for 16APSK-3/4 (a) Rayleigh Fading (b) Rician Fading



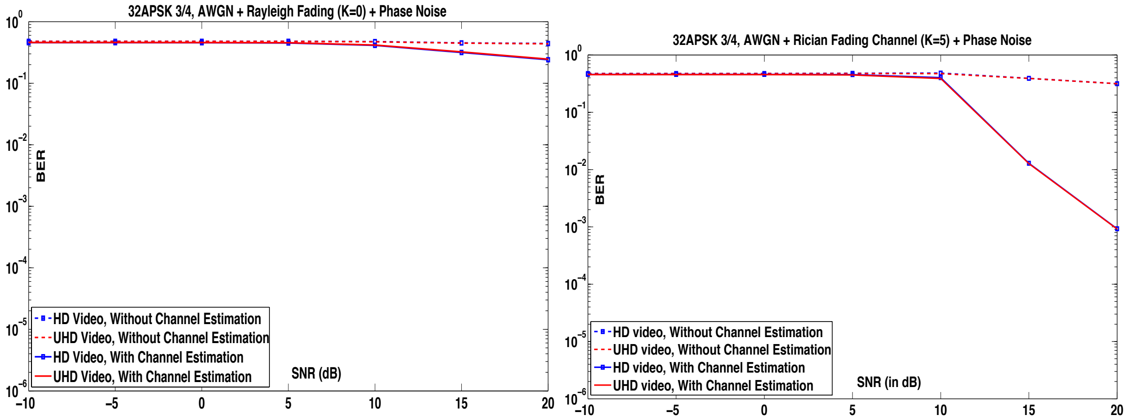
(a) (b)

Figure 5.31: BER vs. SNR for 16APSK-5/6 (a) Rayleigh Fading (b) Rician Fading



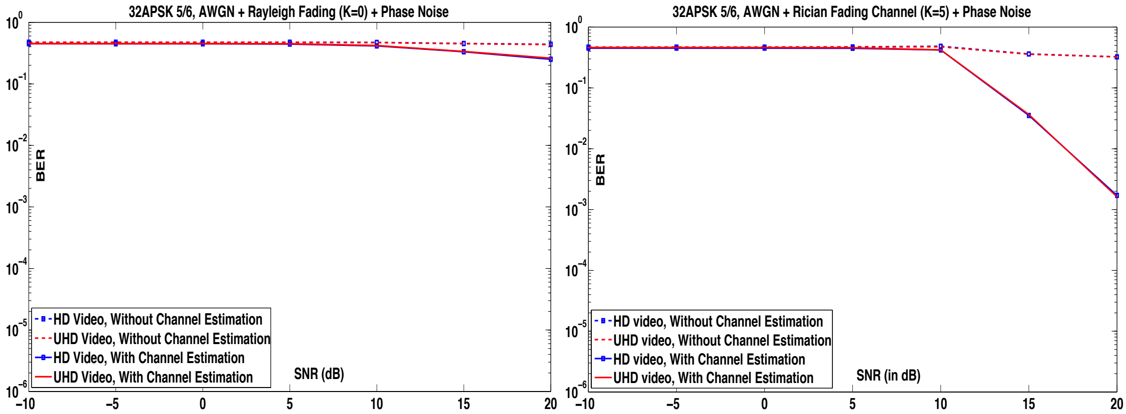
(a) (b)

Figure 5.32: BER vs. SNR for 16APSK-9/10 (a) Rayleigh Fading (b) Rician Fading



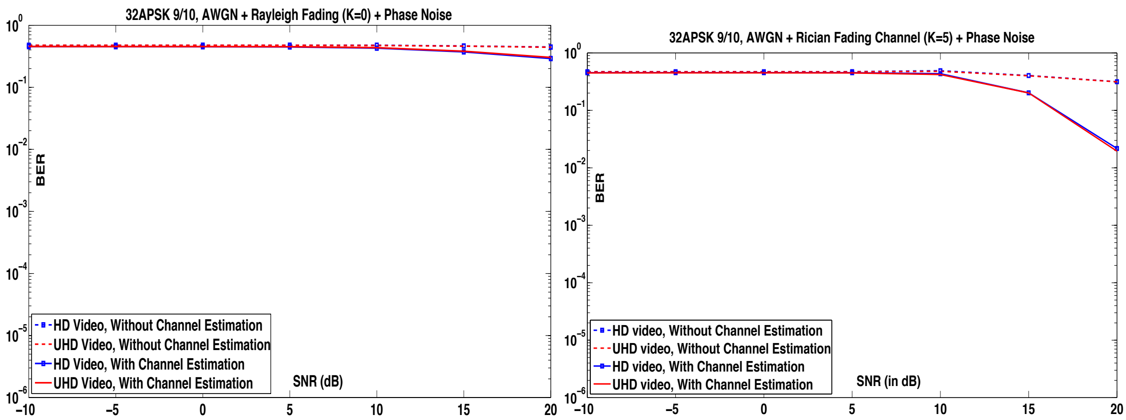
(a) (b)

Figure 5.33: BER vs. SNR for 32APSK-3/4 (a) Rayleigh Fading (b) Rician Fading



(a) (b)

Figure 5.34: BER vs. SNR for 32APSK-5/6 (a) Rayleigh Fading (b) Rician Fading



(a) (b)

Figure 5.35: BER vs. SNR for 32APSK-9/10 (a) Rayleigh Fading (b) Rician Fading

5.7.1 *Channel Estimation Results Comparison*

For a Rayleigh Fading Channel, BER decreases after the implementation of Channel Estimation method, however, the error rate still does not go below 10^{-3}.

For a Rician Fading Channel (K=5), BER decreases to 10^{-6} level for most of the MODCOD schemes, except 32APSK, which is a complex modulation scheme to be decoded successfully in the presence of heavy noise. This can be seen more clearly from Figure 5.36, where the comparison between BER of different modulation and coding schemes is done using signal performance of HD videos only.

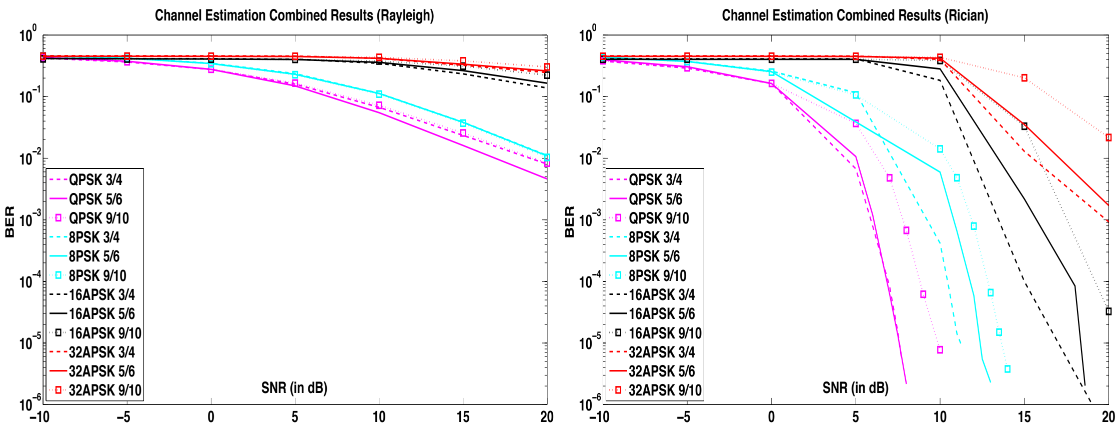


Figure 5.36: Combined results of channel estimation

5.7.2 *HD and UHD Results Comparison*

The difference in BER between HD and UHD is very small and only in QPSK and 16APSK for 3/4 and 5/6-code rate, as seen from the above graphs and Figure 5.24-5.35. 8PSK and 32APSK do not show much difference. A composite graph is also given in Figure 5.37 for a quick comparison between HD and UHD video BERs, in red and black lines respectively.

A small increase in BER for QPSK and 16APSK can change the required SNR or the transmission power to achieve a certain BER, resulting in an overall increase in the transmission cost of a UHD video in the future, as discussed in Section 6.7.

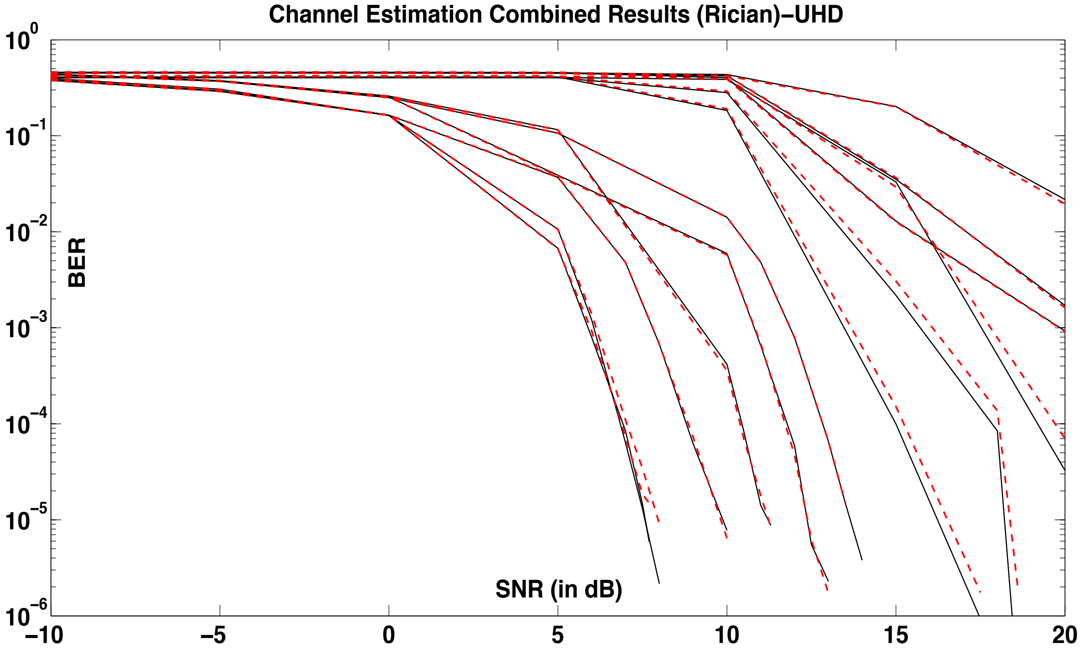


Figure 5.37: Channel Estimation results: UHD (black) vs. HD (red)

5.7.3 *Effect of code rate*

When BER vs. SNR graph for a particular modulation scheme and different code rates is plotted, for HD after using Channel estimation, it is observed that as the code rate increases, the required SNR to achieve a particular BER also increases. This is because, as the code rate increase, system complexity also increases and a higher signal power is required to detect and decode the signal at the receiver, as seen in the plots in Figure 5.38.

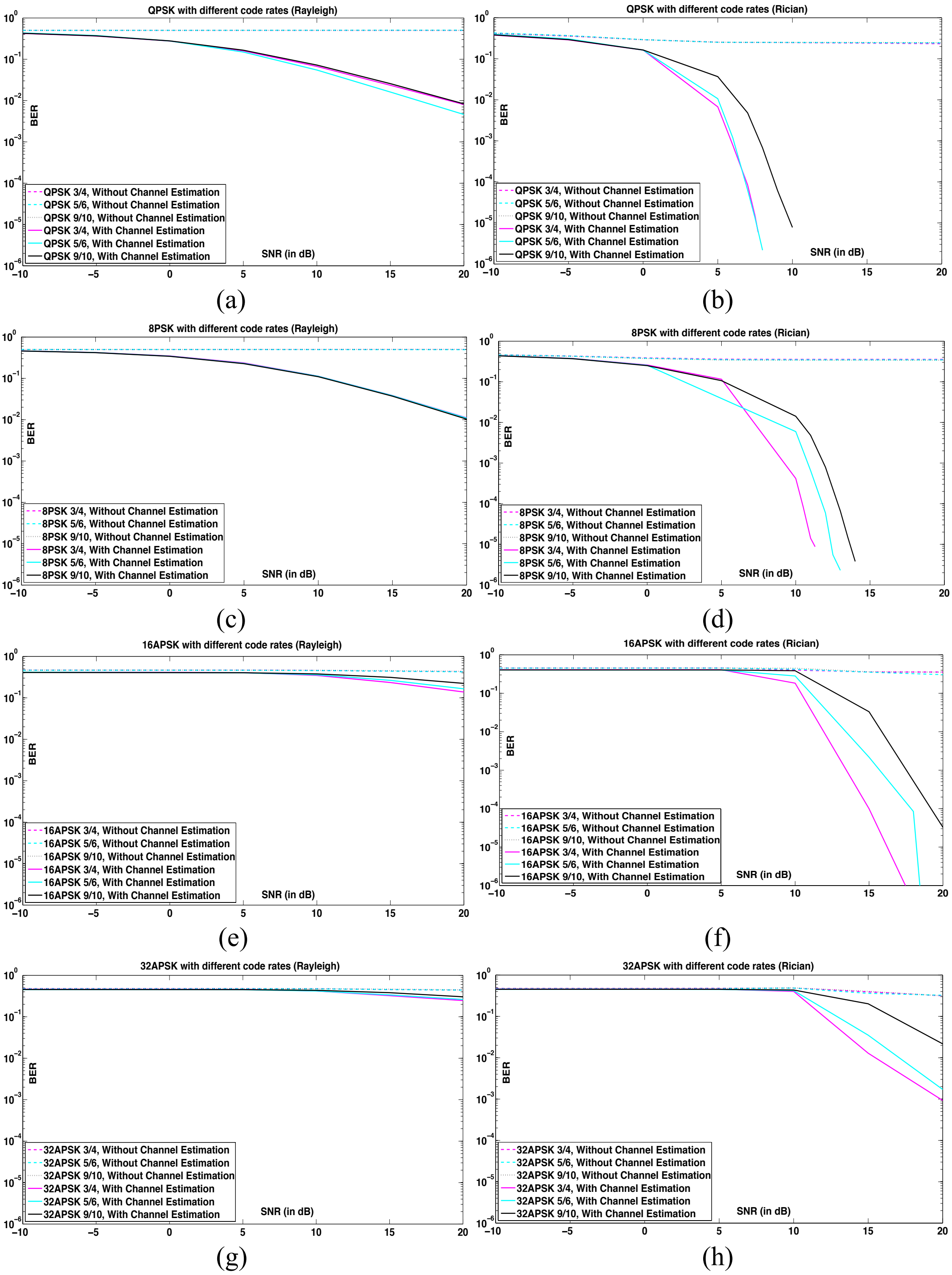


Figure 5.38: Comparison of modulation schemes for different code rates

5.7.4 *Effect of Modulation Scheme*

When BER vs. SNR graph for a particular code rate and different modulation scheme is compared, for HD video after using Channel estimation; it is observed that as the modulation scheme changes, the required SNR to achieve a particular BER also changes, as seen in the plots of Figure 5.39.

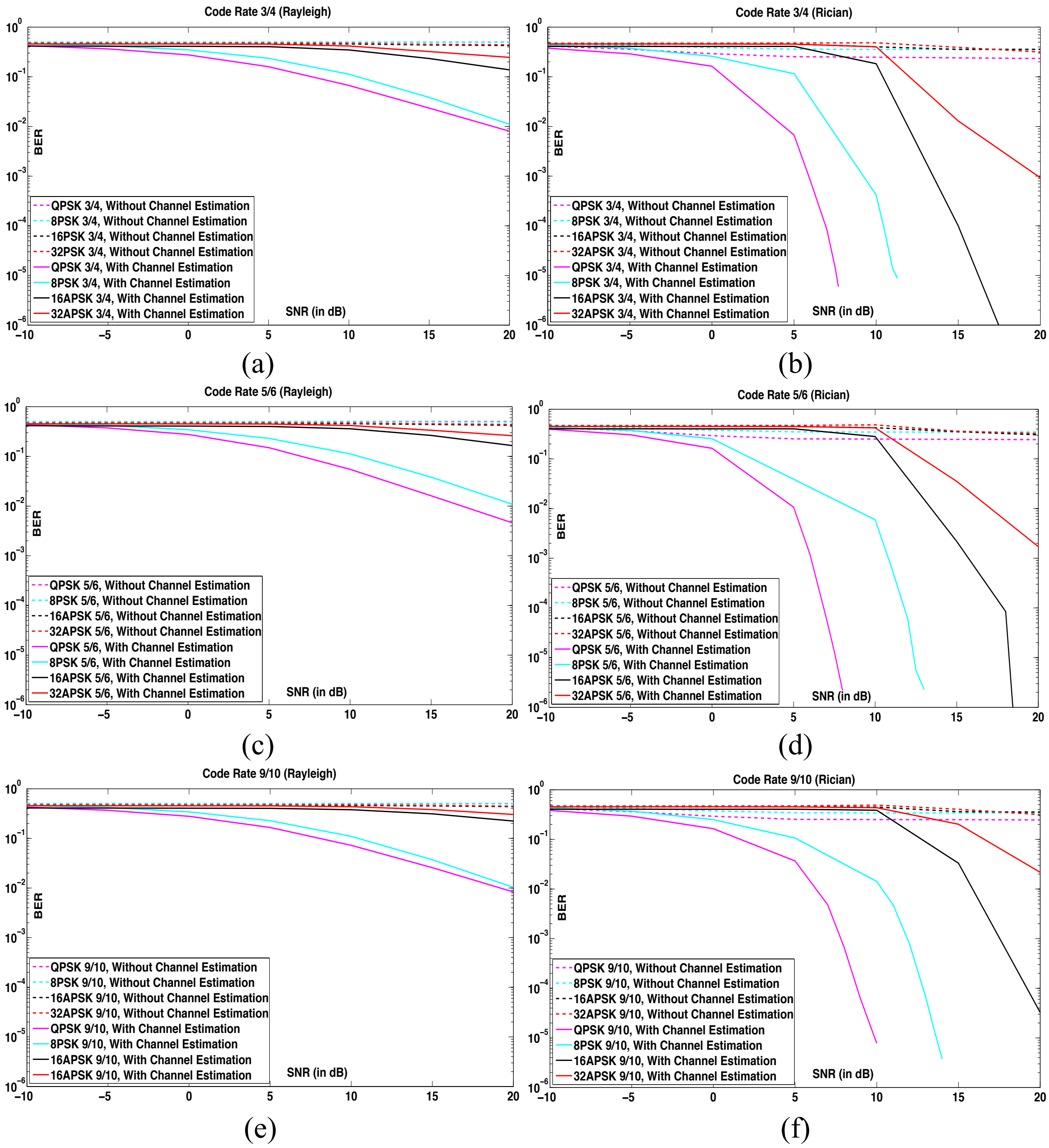


Figure 5.39: Comparison of code rates for different modulation schemes

5.8 Summary

The problems of different video standards for HD and UHD being broadcasted through DVB-S2 have been considered. A MATLAB simulator of wireless system model is built and video samples of HD and UHD, with varying parameters have been analyzed. Results show that UHD videos perform differently compared to HD, under specific conditions. In the presence of AWGN only, QPSK and 8PSK give a higher BER for UHD than HD. This result is significant as the BER for UHD is at a level of 10^{-4}, while HD is at 10^{-5}, at the same SNR. In a Rician fading channel with a correlated phase noise and AWGN, only QPSK and 16APSK at 3/4 and 5/6 code rate give a higher BER for UHD than HD, due to less correlation experienced under noise as compared to 8PSK and 32APSK.

Chapter 6

Proposed Modeling Using Experimental Results

6.1 Introduction

In this chapter, experimental results obtained from Chapter 5 have been used in various scenarios to develop an analysis tool. Using the Principle of Inclusion that takes into account critical parameters that enhance video quality and the methodology applied in the experiments, the overall outcome contributes to DVB-S2 standardization.

6.2 Correlation of Channel Capacity and Results from Experiment 3

Using Shannon Capacity Theorem (equation 6.1) and SNR results from Experiment 3, Shannon Capacity of the channel is calculated and plotted against its BER values. Results are given in Figure 6.1.

$$C = Blog_2\left(1 + \frac{S}{N}\right) \tag{6.1}$$

$$\text{or } \frac{C}{B} = log_2\left(1 + \frac{S}{N}\right) \tag{6.2}$$

Where,

C = Capacity of the channel in bits/second

B = Bandwidth of the channel in Hertz

S = Signal power in Watts

N = Noise power in Watts

C/B = bits/seconds/hertz

Figure 6.1 shows that the maximum capacity of a channel for a Rayleigh Fading Channel is reached at 10^{-3} and at 10^{-6} for a Rician Fading Channel. Also, the maximum capacity is reached earlier by 32APSK and 16APSK, as compared to 8PSK and QPSK. This shows that, even though M-PSK has a lower symbol rate than M-APSK, its probability of error is also low. Therefore, more reliable information can be transmitted though M-PSK than M-APSK. This is the reason that 8-PSK is more commonly used for the DTH system instead of 16APSK and 32APSK. QPSK is not preferred because its symbol rate is very low, even though its error probability is low.

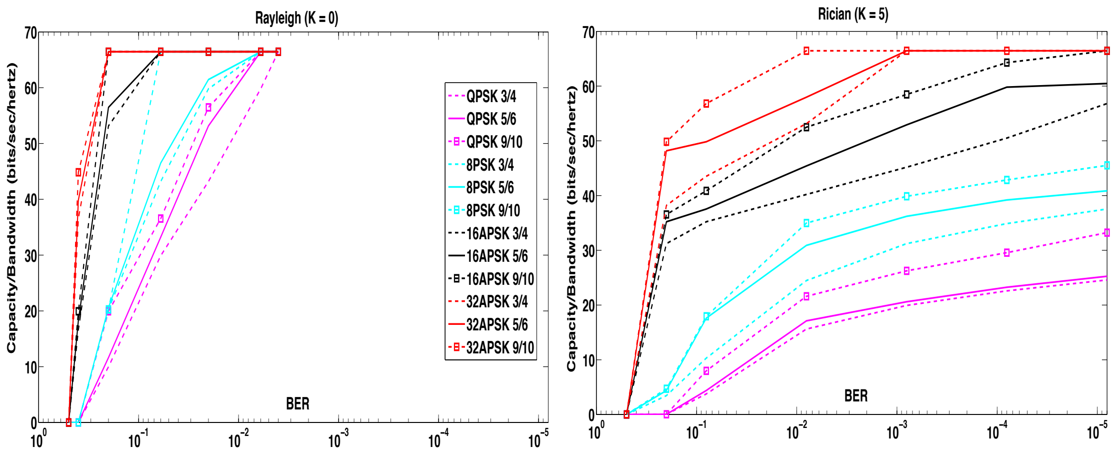


Figure 6.1: Capacity vs. BER graph for Rayleigh and Rician Fading Channel

6.3 Spectral Efficiency

The Spectral efficiency η (bits/symbol/Hz) is the number of bits carried by each symbol, defined by:

$$\eta = \log_2 M \tag{6.3}$$

and

$$E_s = \eta E_b \tag{6.4}$$

where: M = Symbol Rate; E_s = Energy per symbol; E_b = Energy per bit

By plotting Shannon channel capacity results from Figure 6.1 at BER= $3x10^{-5}$ vs. efficiency per MODCOD scheme, we achieve Figure 6.2, which shows that as efficiency increases, the maximum capacity of the channel also increases since spectral efficiency is directly proportional to symbol rate. Therefore, it is lowest for QPSK 3/4 scheme and highest for 32APSK 9/10. Results show that Shannon Capacity limit is reached by 32APSK in the presence of Rician Fading Channel. The capacity is not reached by any of the modulation scheme in the presence of AWGN. Therefore, error probability is more in Rician than AWGN.

Table 6.1: Modulation Efficiency for different MODCOD schemes

Modulation	Code Rate	Modulation Efficiency
QPSK	3/4	1.487
QPSK	5/6	1.654
QPSK	9/10	1.788
8PSK	3/4	2.228
8PSK	5/6	2.478
8PSK	9/10	2.646
16APSK	3/4	2.966
16APSK	5/6	3.3
16APSK	9/10	3.567
32APSK	3/4	3.703
32APSK	5/6	4.119
32APSK	9/10	4.453

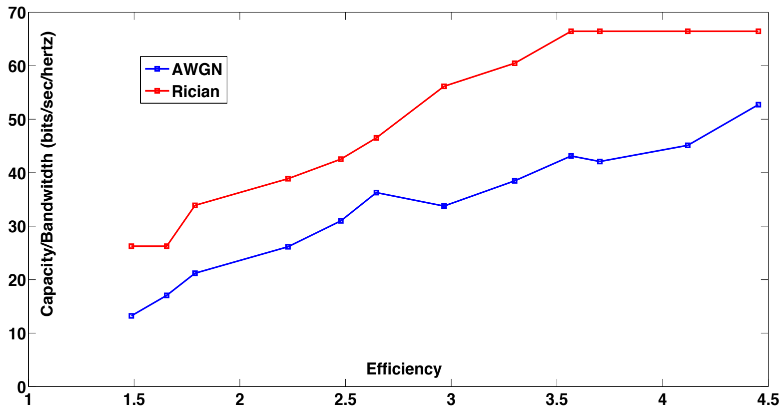


Figure 6.2: Capacity vs. Efficiency graph

6.4 Coverage Area: Distance between Transmitter and Receiver

The link budget model according to Friis free-space path loss formula is

$$P_r = P_t + G_t + G_r - P_L \quad (6.5)$$

$$P_L(dB) = 10log_{10}\left(\frac{4\pi d}{\lambda}\right)^n \quad (6.6)$$

Where P_t is the transmit power, P_r is the received power at distance d, G_t and G_r are antenna gain for transmit and receive antennas respectively, both assumed to be 0 dB for simplicity. The received signal strength is dominated by the distance from the transmitter and the receiver and the general path loss model can be expressed as in equation 6.6 where λ is the wavelength corresponding to the center frequency f_c, 'n' is the path loss exponent which can be approximated as 2 [89]. Suppose, frequency range from 57 to 64 GHz is being used, the constraint on transmit power is $P_t \leq 40$dBm. If thermal noise is the primary source of interference, the required sensitivity (S_r) at the receiver can be calculated as

$$S_r = NF + F + SNR \quad (6.7)$$

Where NF is the noise floor calculated by thermal noise: N = kTWF

F is the noise figure (optimistically) assumed to be 0 dB, SNR is the signal to noise ratio at the receiver, k is Boltzmann's constant, and T is the room temperature (typically 290K). For the 60 GHz systems, the noise floor is calculated as -76 dBm. To ensure adequate performance at the receiver, the minimum received power should be greater than or equal to the required sensitivity as expressed in equation (6.8).

$$SNR \leq 116 - 10\, log_{10} \left(\frac{4\pi d}{\lambda}\right)^2 \quad (6.8)$$

Channel capacity can be calculated according to the Shannon capacity [12] and the relationship between the capacity and communication distance is then given by

$$C \leq Blog_2\left(1 + 10^{116 - 10 log_{10}\left(\frac{4\pi d}{\lambda}\right)^n / 10}\right) \quad (6.9)$$

taking into account the contribution by SNR in equation (6.8).

6.4.1 *Distance between Transmitter and Receiver vs. BER*

Substituting the values of Shannon Capacity 'C' from equation (6.1) into equation (6.9), 'd' is calculated. Using SNR values from experiment 3, we plot Distance 'd' between the Transmitter and Receiver vs. BER graph for Rayleigh and Rician Fading Channel. The results in Figure 6.3 show that as 'd' decreases, Signal strength increases and errors decrease. Inversely, for a low noise signal, the distance between Transmitter and Receiver should be decreased. (Values assumed: n=2, λ= 10, π = 3.14)

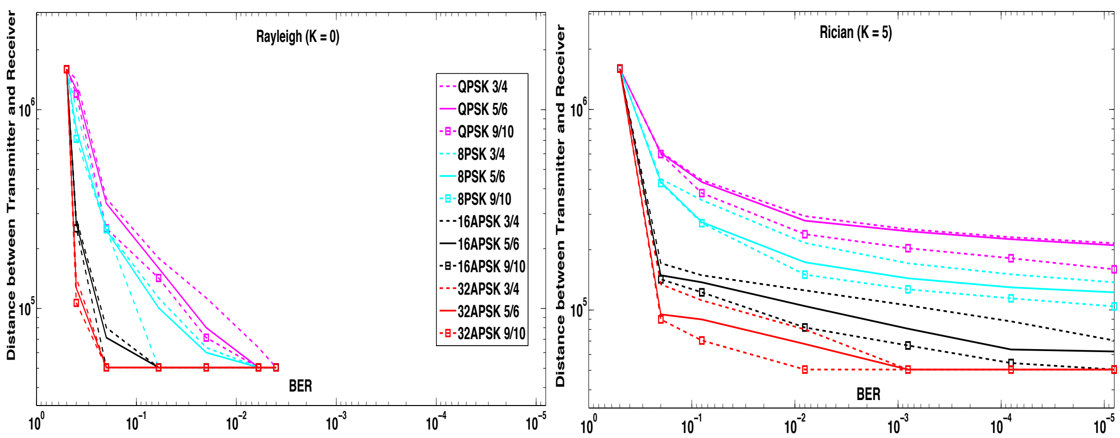


Figure 6.3: Distance between transmitter and receiver vs. BER for Rayleigh and Rician

6.4.2 *Distance between Transmitter and Receiver vs. Efficiency*

Next, a graph is plotted using values of ‘d’ computed using equation (6.9), against its spectral efficiency. To achieve the desired BER (assume = $3x10^{-5}$), the distance between the transmitter and receiver plays a very crucial role. For 16APSK and 32APSK, distance has to be low, otherwise the signal will be highly corrupted with noise and the BER will increase if the receiver is far away from the transmitter. However, this is not the case with 8PSK and QPSK, where QPSK supports the longest distance between the transmitter and receiver while maintaining the desired BER. Figure 6.4 shows the distance vs. Modulation efficiency graph for an AWGN channel, resulting into MODCOD schemes having the highest efficiency, and supporting the shortest distance. Therefore, there is a trade off between modulation efficiency and distance. If a broadcast scheme requires that the receiver remains close to the transmitter, it means that the transmitter’s coverage area is low, which means that more number of transmitters are required to be installed in a particular state to cover N number of users. This will directly increase the cost of broadcasting and hence, is not desirable.

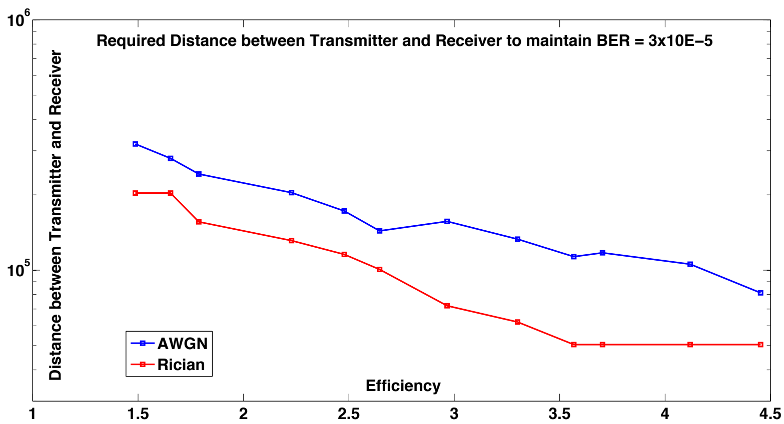


Figure 6.4: Distance between transmitter and receiver vs. Modulation Efficiency graph

6.5 Analysis of Service Area Separation Distance

In general, spectrum efficiency is a function of the size of the broadcasters' coverage area and the separation distance between these coverage areas. We define the required coverage area in terms of coverage probability, which is a function of the SNR for a receiver at a particular location. Hence, the coverage probability is calculated through an approximation of the SNR distribution; in a general setting that considers multiple possibly correlated useful and interfering signals.

For traditional broadcasting like DTH, typically, any point is within the coverage area if coverage probability 'q' for the broadcaster's signal exceeds some fixed threshold q_{thr}. This means that coverage probability will be close to 100% near the transmitter, and will gradually decrease with distance from the transmitter until the threshold is reached at the edge of coverage [90]. If it is assumed two different coverage probability thresholds: a lower threshold q_{thr} near the edge of coverage, and a higher threshold q'_{thr} further inside. Any point with coverage probability greater than the higher threshold q'_{thr} is considered covered.

To obtain the maximum achievable efficiency of spectrum use, which is a function of both the size of the broadcasters' coverage area and the distance separating them, broadcasters are packed in a regular hexagonal constellation, as shown in Figure 6.5, to achieve the highest average density of broadcasters on a per area basis [91]. Consider a statistical path loss model where the median path loss depends only on the distance from each transmitter. For a traditional broadcaster, a circle in the hexagon represents the interference-limited coverage area, centered at the transmitter, with radius R_{trad} equal to the distance between the transmitter and the nearest point on the edge of the coverage area. Where, C_{trad} is the minimum distance between coverage areas of two traditional broadcasters.

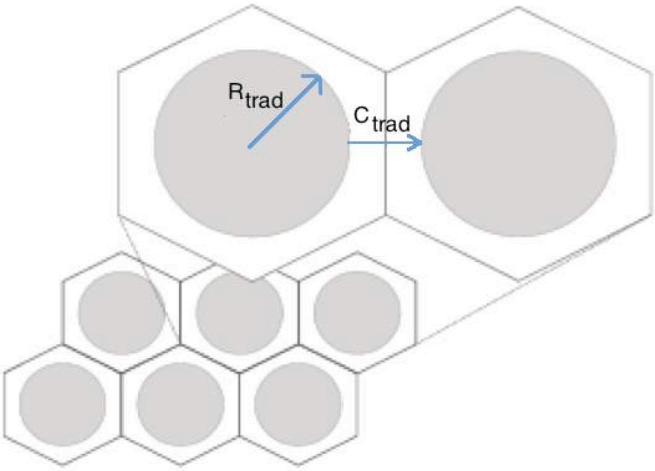


Figure 6.5: Hexagonal packing of co-channel traditional broadcasters [91]

The maximum fraction of area that can be covered by traditional broadcasters divided by the area of their respective hexagonal tile in the lattice [91], is given by:

$$\eta = \frac{{R_{trad}}^2}{(R_{trad}+0.5C_{trad})^2} \cdot \frac{\pi}{2\sqrt{3}} \qquad (6.10)$$

Where,

η = Spectral Efficiency

R_{trad} = Distance between transmitter and receiver

C_{trad} = Separation distance between two coverage areas

Substituting the values of spectral efficiency and distance between transmitter and receiver from section 6.4, in equation (6.10), C_{trad} is calculated.

6.5.1 *Separation Distance vs. BER*

As the distance between the transmitter and receiver increases, required transmit power to maintain a low BER increases. As the transmit power increases, the coverage area increases and the separation distance between two coverage areas decreases. When the separation distance is high, error probability from the adjacent coverage area is low. But when the separation distance is small, noise is high and coverage area is small.

Large coverage areas require larger separation distance to maintain low interference from adjacent cells. Therefore, there is a trade-off between transmit power and noise as spectrum efficiency increases with coverage area and decreases with separation distance.

Hence, the larger the coverage area, the lower the spectrum efficiency. As a result, it is efficient in terms of spectrum efficiency to provide TV service to a given area by using many small individual coverage areas rather than few large coverage areas. The graph for separation distance vs. BER is plotted in Figure 6.6, which shows that as the separation area decreases, BER or noise increases.

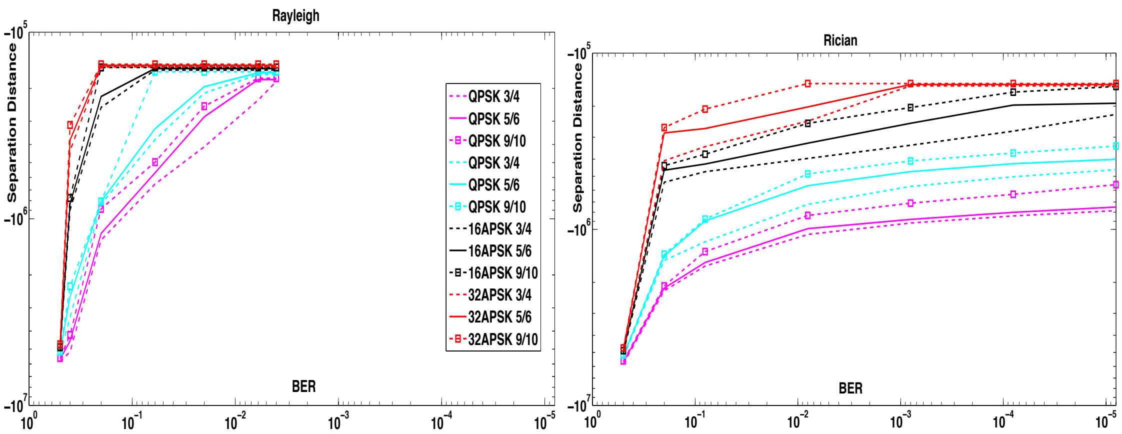


Figure 6.6: Separation distance vs. BER graph for Rayleigh and Rician

6.5.2 *Separation Distance vs. Efficiency*

Another method to understand the trend of separation distance is by plotting a graph of Separation distance vs. Efficiency, as shown in Figure 6.7. The results show that as the spectral efficiency increases, the required separation distance to maintain the desired BER also increases, and the coverage area (distance between transmitter and receiver) decreases. This means that QPSK has a higher coverage area than 32APSK, for the same transmitted power and other parameters, which can be understood using Figure 6.8, which is an approximate depiction of this scenario.

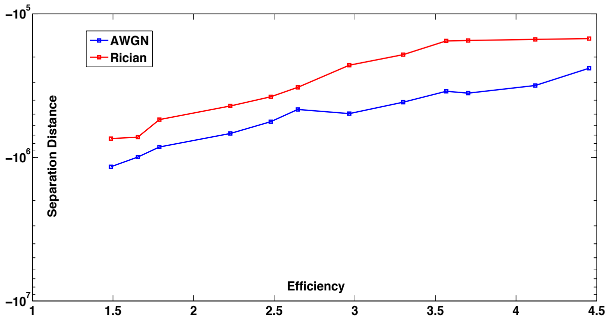


Figure 6.7 Separation distance vs. Efficiency graph

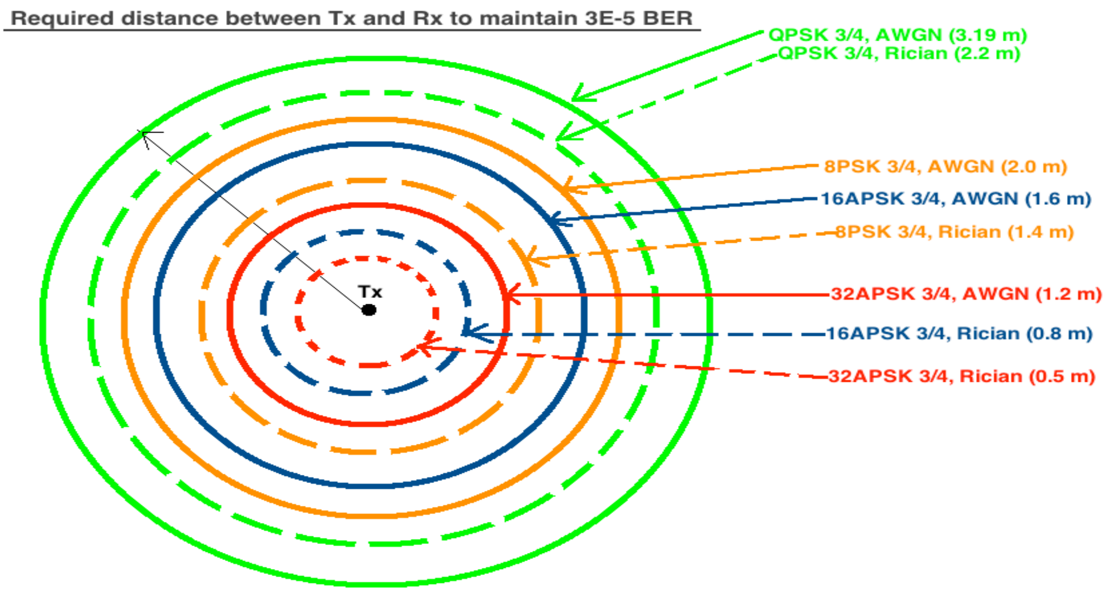


Figure 6.8: MODCOD scheme affecting the transmitter coverage area (apprx depiction)

6.6 Applying the Principle of Inclusion

In this section, an adaptive video quality algorithm is developed for DVB-S2, where three conditions are responsible for enhancing or reducing the quality of a video signal received by the DVB-S2 STB. The conditions are: Coverage area, Distance between transmitter and receiver and Separation distance. These conditions are responsible for the required SNR, resultant BER and the overall capacity of the system. Based on these conditions, received parameters of an HD or UHD video vary; and the quality viewed by the user changes. This algorithm can be adopted in the future broadcast scenario where the broadcasters will be dealing with simulcasting of multiple video standards of HD and UHD, varying in resolution, frame rate and codec [92]. This algorithm is developed using the Principle of Inclusion [93].

Suppose, number of cells in active set ≤ 4; respectively represented by b_1, b_2 and b_3. Let K be a set with |K| = Z in service area J, and let b_1, $b_2 \ldots b_t$ be a collection of conditions, such as Coverage area, Distance between transmitter and receiver, and Separation distance, satisfied by some or all of the elements of K. Some elements of K, such as SNR, BER and Capacity, may satisfy more than one of the conditions, whereas others may not satisfy any of them. Denote the number of elements in K that satisfy condition b_i for $1 \leq i \leq t$ by Z (b_i). Elements of K are only valid when they satisfy only condition b_i as well as when they satisfy other conditions b_j for $j \neq i$. Therefore for any $i, j \in 1,2,3,\cdots,t$ where $j \neq i$ Z (b_i b_j) denotes the number of elements in K that satisfy both of the conditions b_i and b_j. If $1 \leq i, j, k \leq t$ are three distinct values, then $Z(b_i\ b_j\ b_k)$ denotes the number of elements in K satisfying each of the conditions b_i, b_j and b_k.

Therefore for each $1 \leq i \leq t$, $Z(b_1') = Z - Z(b_i)$ will denote the number of elements in K that do not satisfy condition b_i. However if $1 \leq i, j \leq t$ with $i \neq j$, $Z(b_i'\ b_j')$ equates to the number of elements in K that do not satisfy either of the conditions b_i or b_j. Hence,

$$Z\ (b_i'\ b_j') = Z - [Z\ (b_i) + Z\ (b_j) + Z\ (b_i b_j) \qquad (6.11)$$

The 3rd term in equation (6.11) is added because it is eliminated twice in the second term [Z (b_i) + Z (b_j)]. From equation 6.11, it is possible to determine the number of elements of K that satisfy none of the conditions b_i, for $1 \leq i \leq t$. This is denoted by $Z' = Z\ (b_1'\ b_2'\ b_3'\ \ldots b_t')$ and by expansion,

$$Z' = Z - \sum_{1 \leq i \leq t} Z(b_i) + \sum_{1 \leq j \leq t} Z(b_i b_j) - \sum_{1 \leq i<j<k \leq t} Z\ (b_i\ b_j\ b_k) + \ldots + (-1)^t Z\ (b_1\ b_2\ b_3 \ldots b_t) \quad (6.12)$$

Using equation (6.12) for 's' $\in K$ and that 's' satisfies none of the conditions in (6.12); it is clear that 's' is counted once in Z' and once in Z but will not be counted in any of the other three terms in equation (6.12). It is evident that the number of elements in K that satisfy at least one of the conditions b_i where $1 \leq i \leq t$ is given by Z (b_1 or b_2 or … or b_t) = $Z - Z'$. The following notation further simplifies equation (6.12) such that

$$K_1 = Z\ (b_1) + Z\ (b_2) + \cdots + Z\ (b_t)]$$

$$K_k = [\sum Z\ (b_{i1}\ b_{i2} \ldots b_{ik})],\ 1 \leq k \leq t\ (5) \qquad (6.13)$$

The summation in equation (6.13) is taken overall selections of size k from the collection of t conditions and K_k has $\binom{t_J}{k_J}$ summands in it. Equation (6.12) and (6.13) can be used to establish whether all the conditions that enhance the video quality are met. If one of the conditions is not met then the user/client cannot view a video having the best quality parameters. This may mean a change in video parameters to the active set or may necessitate requiring more resources to be allocated.

In Table 6.2, the best-case scenario is represented by $R_1S_1D_1$ case where the coverage area is small, separation distance is big and the distance between transmitter and receiver is also small. Due to these factors, it is possible to achieve the BER of 10^{-6} at a SNR ≥ 6dB. Therefore, the capacity consumed is ≤ 75%. As a result of these conditions, the video quality viewed on TV has a resolution and frame rate of 2160p/50, colour profile of Rec.2020, with HEVC codec. Such a video must be viewed on TV screen of size ≥ 55″. However, as the conditions vary, the resultant video quality also varies. Different conditions have been denoted using the following symbols and assumptions.

R1 = small coverage area, denoted by ↓

R2 = large coverage area, denoted by ↑↑

R3 = very large coverage area, denoted by ↑↑↑

S1 = large separation distance, denoted by ↑

S2 = small separation distance, denoted by ↓↓

S3 = very small separation distance, denoted by ↓↓↓

D1 = small distance between transmitter and receiver, denoted by ↓

D2 = large distance between transmitter and receiver, denoted by ↑↑

D3 = very large distance between transmitter and receiver, denoted by ↑↑↑

Table 6.2: Video quality result in different scenarios applying the principle of inclusion

	Scenario		Video Result
1	Coverage Area = ↓ Separation Distance = ↑ Distance between Tx and Rx = ↓ BER = 10^{-6} SNR ≥ 6dB Capacity ≤ 75%	$R_1S_1D_1$	Resolution/Frame Rate = 2160p/50 Colour = Rec2020 Codec = HEVC Ideal TV Size ≥ 55″ Best video quality using future resources
2	Coverage Area = ↓ Separation Distance = ↓↓ Distance between Tx and Rx = ↓ BER = 10^{-6} SNR ≥ 6dB Capacity ≤ 75%	R_1**S_2**D_1	Resolution/Frame Rate = 1080/50p Colour = Rec2020 Codec = HEVC Ideal TV Size = 45-55″ Using many resources
3	Coverage Area = ↓ Separation Distance = ↓↓ Distance between Tx and Rx = ↑↑ BER = **10^{-5}** SNR ≥ 6dB Capacity ≤ 75%	R_1**S_2D_2**	Resolution/Frame Rate = 1080/25p Colour = Rec709 Codec = MPEG-4 Ideal TV Size = 40-50″ Using available resources
4	Coverage Area = ↑↑ Separation Distance = ↓↓ Distance between Tx and Rx = ↑↑ BER = **10^{-4}** SNR ≥ **5**dB Capacity ≤ 75%	**$R_2S_2D_2$**	Resolution/Frame Rate = 1080/25i Colour = Rec709 Codec = MPEG-4 Ideal TV Size = 30-40″ Resources used more than necessary
5	Coverage Area = ↑↑↑ Separation Distance = ↓↓↓ Distance between Tx and Rx = ↓ BER = 10^{-4} SNR ≥ **4dB** Capacity > 75%	**R_3S_3**D_1	Resolution/Frame Rate = 720/25i Frame Rate = 25i Colour = Rec709 Codec = MPEG-4 Ideal TV Size = 20-30″ Unacceptable resource usage
6	Coverage Area = ↑↑↑ Separation Distance = ↓↓↓ Distance between Tx and Rx = ↑↑↑ BER = 10^{-2} SNR ≥ **20dB** Capacity > 75%	**$R_3S_3D_3$**	No Video Received Video Outage Should not be allowed to happen

6.7 Cost increase due to UHD video broadcasting

In this section, increase in cost due to UHD video transmission as compared to HD is calculated, using SNR results to achieve a BER of $3x10^{-5}$. In terms of cost per traditional broadcaster, consider a transmitter operating 24 hours, 365 days per year. An estimate of the Net Present Value (NPV) of the cost of building is considered. In this estimate, only the costs associated with equipment and its installation, and operation and maintenance of each site (energy included) is considered, but not other costs in the programming distribution chain. The NPV [91] of the cost per broadcaster is given by:

$$NPV = \sum_{t=1}^{N_{per}} \frac{P_{[KW]}.365.24.C_{k-W-h}}{(1+i)^t} . \frac{1}{\eta} \quad (6.14)$$

Where,

η = Spectral Efficiency

$P_{[KW]}$ = Transmission Power (in KWatts)

$C_{K\text{-}W\text{-}h}$ = Cost per KW per hour (assume \$0.12)

N_{per} = Evaluation period in years (assume 20 years)

i = Annual discount rate (assume 7%)

To calculate Transmit Power:

ERP (dBm) = Transmit Power (dBm) – Cable loss (dB) + Antenna Gain (dBi) (6.15)

Where,

ERP = Effective Radiated Power

Transmit Power (dBm) = ERP (dBm) + Relative Noise Power (dB) (6.16)

or Transmit Power (dBm) = SNR (dB) + Relative Noise Power (dB) (6.17)

$$\text{Transmit Power (W)} = [10^{(\text{Transmit Power in dBm})/10}] \qquad (6.18)$$

Transmission Power is calculated using the SNR results from Experiment 3 and assuming Relative Noise Power = 10 dB. Figure 6.9 depicts the transmission power of a UHD video, for different modulation and coding schemes using equation (6.17).

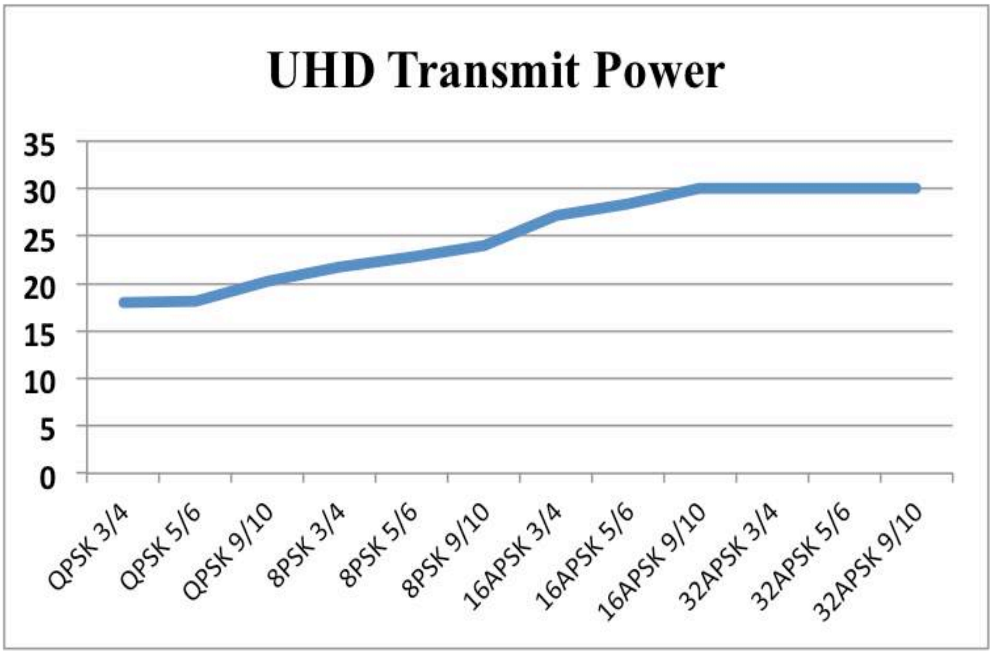


Figure 6.9: UHD Transmit Power in dBm

To calculate Received Power:

$$P_r = P_t \, G_t G_r \left(\frac{\lambda}{4\pi R}\right)^2 \qquad (6.19)$$

Where,

P_r = Received Power

P_t = Transmitted Power

G_r = Receiver Gain (assume 54 dB)

G_t = Transmitter Gain (assume 26 dB)

R = Distance between transmitter and receiver (assume 37,500 x 10^3 m)

λ = Wavelength (assume 0.05 m)

$$ERP = P_t G_t \quad (6.20)$$

$$P_r = (ERP) * G_r \left(\frac{\lambda}{4\pi R}\right)^2 \quad (6.21)$$

or,

$$P_r = P_t + G_t + G_r - L_p \quad \text{(dBW)} \quad (6.22)$$

where,

$$L_p = \text{Path loss} = 20 \log [(4 \pi R)/ \lambda] \quad \text{dB} \quad (6.23)$$

Figure 6.10 depicts the received power of a UHD video, for different modulation and coding schemes using equation (6.22).

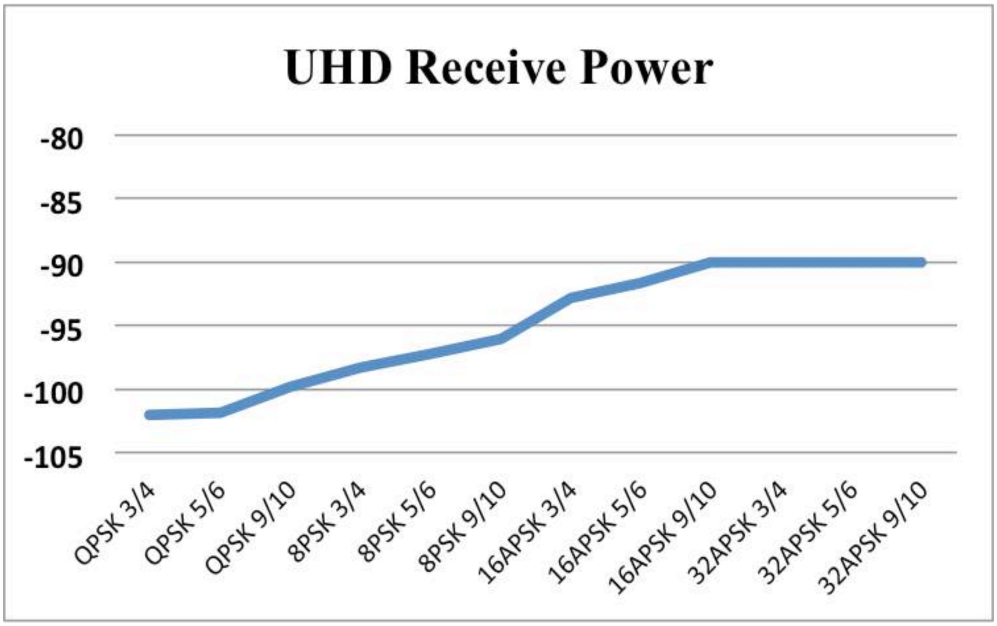


Figure 6.10: UHD Transmit Power in dBW

Hence, NPV of broadcasting HD and UHD video is calculated; there is an increase in the cost due to UHD video broadcasting as compared to HD.

The results are given in Figure 6.11, which clearly shows that a small increase in the SNR due to UHD video broadcasting can result in a significant increase of transmission cost.

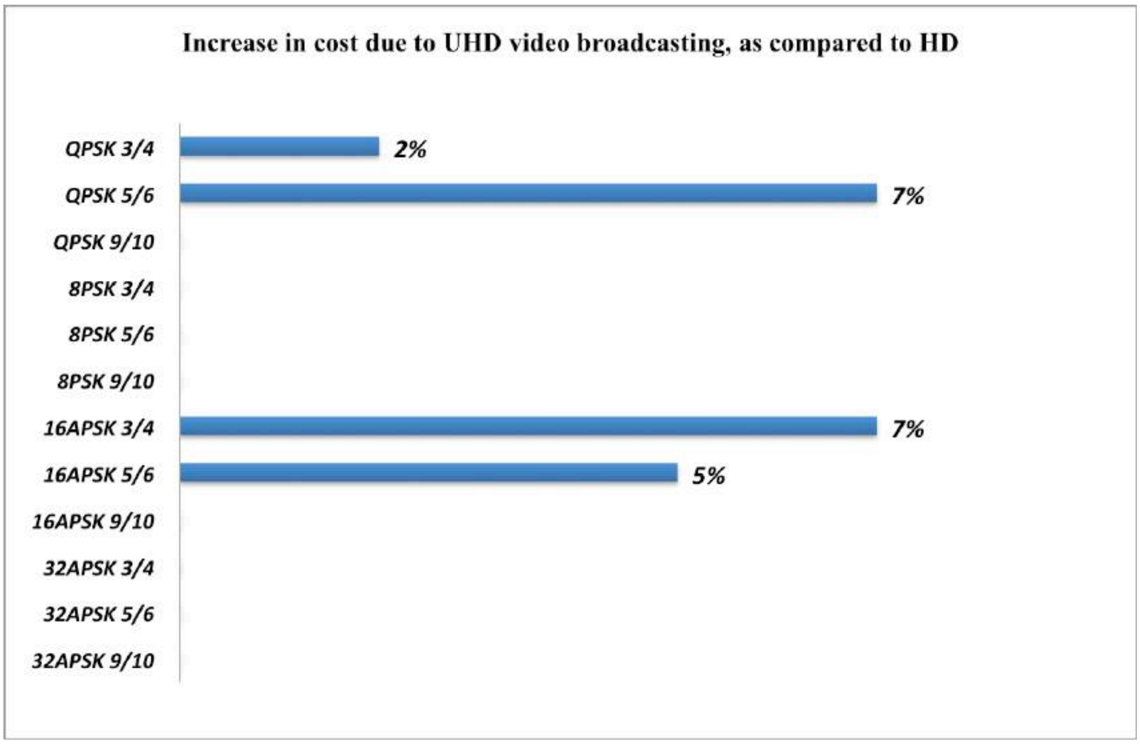


Figure 6.11: Increase in cost due to UHD video broadcasting as compared to HD

6.8 Summary

In this chapter, experimental results obtained from Chapter 5 have been used to calculate system capacity, spectral efficiency and the distance between transmitter and receiver. Using these results, an adaptive video quality scenario is assumed and the impact on UHD video parameter is explained, using the principle of inclusion. The cost of UHD video broadcasting is also computed and compared with HD.

Chapter 7

Conclusion and Future Work

7.1 Summary

This thesis is aimed towards the investigation of UHD video signal performance through the DVB-S2 broadcast system. This detailed research work is focused towards the standardization of UHD Video broadcasting as compared to the current HD standards. Parameters of a video are varied and signal performance is measured in terms of BER vs. SNR graph, computed using MATLAB simulations.

Chapter 2 describes the UHD ecosystem, which involves video production and broadcasting. Video parameters such as resolution, frame rate, colour depth and compression vary the signal behavior when transmitted wirelessly in the presence of noise. Therefore, all the parameters have been briefly described and various methods of video broadcasting are discussed.

Chapter 3 discusses what a video signal goes through over the air. Noise channel responsible for signal degradation is explained and a method of signal recovery at the receiver is proposed i.e. channel estimation using pilot bits.

Chapter 4 highlights the importance of BER calculation for UHD-DVB standardization and in Chapter 5 numerous experiments have been performed. The experiments involve video quality evaluation in terms of colour range and signal quality evaluation in the presence of a Rayleigh Fading Channel (K=0), Rician Fading Channel (K=5), Correlated Phase Noise and AWGN.

Resultant graphs are plotted for all scenarios, for different video parameters, modulation scheme and code rates. The results are compared without and with channel estimation method.

This thesis can be concluded with the most significant results being:

- QPSK and 8PSK in 3/4 and 5/6 code rate, gives a higher BER for UHD than HD, in the presence of AWGN.
- QPSK and 16APSK for 3/4 and 5/6 code rate, gives a higher BER for UHD than HD, in the presence of a Rician Fading Channel (K=5).

When 8PSK 5/6 scheme is further analyzed by transmitting a 25fps and 50fps videos of HD and UHD, encoded by MPEG-4 and HEVC, it is observed that:

- 50fps videos have a lower BER than 25fps
- UHD downscaled videos have a higher BER than HD upscaled videos
- HEVC compressed videos have a lower BER than MPEG-4

In chapter 6, using the BER results, capacity of the system is calculated. BER is also responsible for the coverage area network planning; therefore, the distance between transmitter and receiver is calculated and service area separation distance is also calculated. Using these results, an adaptive video quality scenario is assumed and the impact on UHD video parameter is explained, using the principle of inclusion. Finally, the difference in the cost of transmission power between broadcasting HD and UHD is calculated. These results will contribute towards the UHD-DVB standardization, and will help the broadcasters take an optimum decision in the future broadcast scenario.

7.2 Conclusion

Almost ten years ago, the television industry was in the same situation as it is now, when HD was the new technology and high compression capability of MPEG-4 made its broadcasting feasible. History is repeating again and the television industry is all geared up for UHD broadcasting with the help of HEVC this time [94].

Rec.2020 for UHD specifications was released in 2012 and HEVC's specifications were finalized in 2013. HDMI 2.0 was also released in 2013. 6G-SDI cable is still being developed and new features are still being added in Rec.2020, HEVC and HDMI 2.0. DVB-UHD-1 initial specification was also recently finalized in 2014. Cinema producers, editors, manufacturer and distributers, with the help of these standards are working towards making the UHDTV broadcasting practically possible by 2017 to 2020.

Everything is in its initial stage and any kind of information could be helpful in anticipating the areas to be focused in the future [95]. Hence, this thesis works towards analyzing the behavior of multiple video standards that the UHD broadcast profile will be dealing with.

The effect of video parameters on the bit error rate has been simulated which shows that the some video signals undergo higher noise due to certain parameters as compared to other. These results will encourage the television and media industry to adopt HFR and HEVC for UHD and HD, in the future due to their significant advantages, as discussed in this thesis.

7.3 Future Work

There are many experiments that can be done in the future, in continuation to this thesis. These future experiments could not be implemented in this thesis due to the lack of resources and technology at the moment.

Resolution: The video performance analysis can be done for UHD-8K, which will be possible once genuine 8K content is easily available, along with supporting software for simulation, for example: MATLAB, DivX, etc [96][97].

HFR: An extensive study on frame rates: In this thesis, a brief study has been done on High Frame Rates, taking the frames from a 25 and 50 fps video. This 50fps video is converted from a 25fps video using frame converter software. However, the real study has to be done using a native content i.e. originally shot with HFRs [98][99]. This content will have better pixel information and its simulation results will be more helpful in predicting its signal behavior.

HEVC: When this thesis simulation was performed, there was no software that could convert an MPEG-4 4K 50fps video into HEVC 4K 50fps. However, in the future there will definitely be many softwares to do so [100][101]. Hence, further work must be done in this area.

Colour Depth: At present, there is hardly any software available that can process, convert or simulate a video higher that 8-bit depth. 10 and 12 bit depth videos are also not easily available at the moment. Wider Gamut Videos are still being circulated through the Internet sources; however, everything mostly is a result of software simulation. Hence, genuine content and advances softwares are required to do that [36].

DVB-S2X: DVB-S2X standard has been recently introduced with added modulation schemes and code rates. These schemes and code rate are not yet adopted by MATLAB in their modulator-demodulator and encoder-decoded functions. Once this is done, a new range of simulations can be performed.

DVB-T2 Lite: A detailed signal behavior analysis for UHD video broadcasting to mobile through terrestrial technology is also important and since DVB-T2 Lite is a new standard, and a lot of research work can be done in this area.

Overall, the entire broadcast architecture is being modified for UHD video broadcasting. Some standards have been finalized, but its improvements and modifications is still going on. Along with the hardware, compatible softwares are also required for an extensive research work in this field. Therefore, the future of research in the area of video broadcasting is vast, especially in the coming years.

While, BER and PSNR values are quantitative measures of video quality, perception based measures can also be performed in the future as an extension of this thesis. In this way, both the qualitative and quantitative results can be analyzed for UHD broadcasting by varying the parameters of a video.

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