Performance Analysis of H.264 Encoder for High-definition Video Transmission over Ultra-wideband Communication Link

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Abstract

With the technological advancement, entertainment has become revolutionized and the High-definition (HD) video has become a common feature of our modern amusement devices. Moreover, the demand for wireless transmission of HD video is rising increasingly for its ubiquitous nature, easy installation and relocation. The high bandwidth requirement is the main concern for wireless transmission of high quality video streams. Research has been going on by the consumer electronics industry to provide different solutions of this issue, for the last few years.

In this research work, HD video transmission feasibility using the Ultra-wideband (UWB) communication channel is analyzed. The UWB channel is selected for its short-range, high-speed data transmission capability at low-cost, and low-power consumption. The maximum transmitting range of this technology is about 10 m at 100 Mbps data rate. Simulation is conducted by controlling key parameters, such as, in-loop deblocking filter, group of pictures, and quantization parameter of an H.264/AVC encoder. Here, standard HD video streams with different motion characteristics are used, and the impact of these parameters change on the reconstructed video quality and the broadcasting data rate are analyzed. Finally, a generalized parameters settings, and a video content dependent settings for an H.264/AVC encoder are proposed for different bandwidth requirements, as well as acceptable video quality. Performance evaluation of these parameters settings is performed, and the results are quite satisfactory as long as the symbol energy to noise power density ratio, E_s/N_o, is above 15. With the proposed parameters settings, maximum 20 Mbps data rate is achieved with 33.5 dB Y-PSNR.

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This thesis is dedicated to my loving parents.

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List of Abbreviations

AVC	Advanced Video Coding
ATSC	Advanced Television Systems Committee
AWGN	Additive White Gaussian Noise
BER	Bit Error Rate
CABAC	Context Adaptive Binary Arithmetic Coding
CAVLC	Context Adaptive Variable Length Coding
CPU	Central Processing Unit
CR	Compression Ratio
DCT	Discrete Cosine Transform
FCC	Federal Communications Commission
FPGA	Field Programmable Gate Array
GOP	Group of Pictures
HD	High-definition
HDL	Hardware Description Language
HDTV	High-definition Television
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
ISO	International Organization for Standardization
ITU	International Telecommunication Union
JPEG	Joint Photographic Experts Group
JVT	Joint Video Team
LOS	Line-of-Sight
MAC	Media Access Control
MB	Macroblock
ME	Motion Estimation

MPEG	Moving Pictures Expert Group
MV	Motion Vector
NAL	Network Adaptation Layer
NLOS	Non-Line-of-Sight
OFDM	Orthogonal Frequency Division Multiplexing
PSD	Power Spectral Density
PSNR	Peak Signal to Noise Ratio
QP	Quantization Parameter
QPSK	Quadrature Phase Shift Keying
RAM	Random Access Memory
RMS	Root Mean Square
SD	Standard-definition
SV	Saleh-Valenzuela
UWB	Ultra-wideband
VCEG	Video Coding Experts Group
VCL	Video Coding Layer
WHDI	Wireless Home Digital Interface

Chapter 1

Introduction

1.1 Introduction

In recent times, the High-definition (HD) video is taking over the Standard-definition (SD) video and has become an increasingly common feature of our TVs, video cameras, home theater system, and gaming consoles. Moreover, getting the pleasure of the high quality, high resolution video without cumbersome wire is one of the rising consumer's demands of the present entertainment world. The user wishes their home to become free from wires, and desires the flexibility to setting up their HD display wherever (wall or ceiling mounted) they want without trouble and complexity. The consumer electronics industry has been working on different solutions to facilitate consumer with high quality video over wireless channels.

The Ultra-wideband (UWB) technology is one of the promising and potential high speed wireless link for indoor applications. Furthermore, the advantages of the UWB technology include low-power transmission, robustness to multipath fading and low

power dissipation. The maximum theoretical data rate for the UWB technology is 480 Mbps [1]. Uncompressed HD multimedia data require considerable storage capacity and transmission bandwidth. A 1080p (1920×1080, progressive scan) resolution HD video requires at least 3.2 Gbps transmission speed [1]. Therefore, it is prerequisite to compress the video prior to wireless transmission over the UWB channel. Video compression is a process, in which redundant data from the sequence is removed to meet a bit rate requirement, while the quality of the reconstructed video satisfies the requirement of the application. Removing redundant data from the video sequence reduces the reconstructed video quality. Compression schemes therefore involves trade-offs between the compression capability and the amount of introduced distortion. Hence, optimum compression of the video prior to transmission is very important in wireless video communication.

Considering the current demand, in this work, HD video transmission feasibility over the UWB communication link for indoor applications is analyzed by applying apposite video compression technique. When compressed high-definition movie or other video clips are broadcasted, it includes compressed HD video data, compressed audio data, controlling signals, synchronization data, error checking signals etc. If the UWB channel is used as wireless link for home entertainment network, the throughput of the compressed data should be limited to 100 Mbps; as the maximum realistic transmitting range for the UWB communication link is about 10 m at 100 Mbps data rate [2]. Since effective transmission of the compressed HD video is the main objective of this research work, the maximum throughput of the compressed HD

video has been targeted to 40 Mbps to provide room for other data types. Block diagram of the wireless network is presented in Figure 1.1.
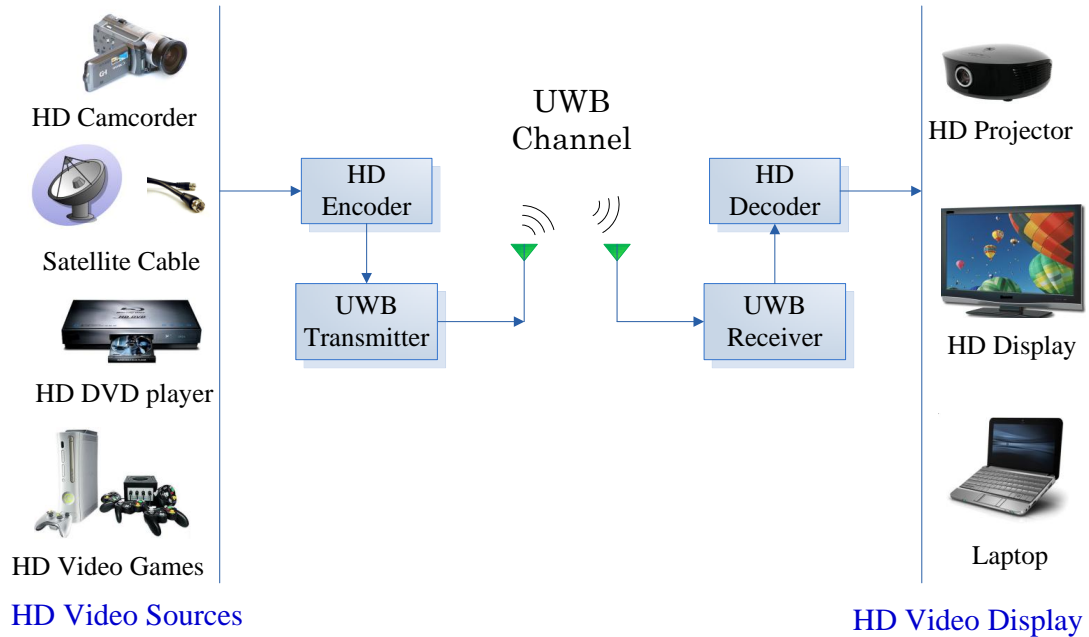
Figure 1.1: Block diagram of the wireless network

1.2 Motivation

There has been a few efforts reported in the past, where feasibility of the HD video transmission through the UWB communication channel is analyzed. In [3], performance of high-quality video streaming over the UWB channel is evaluated by analyzing the features like physical and Media Access Control (MAC) layers. In [4], physical testing of HD video streaming over the UWB channel for three compression standards (Motion-JPEG2000, MPEG-2, H.264/AVC) is performed, and the successful transmission of data is achieved up to 1.5 m. The assessment of the throughput

verses HD video quality using two commercial UWB products, ZeroWire Mini-PCI and ZeroWire HDMI from TZero Technologies Inc., is reported in [5]. In most of the previous work more emphasis is given on exploring the physical layers for successful transmission of HD video over the UWB communication channel. High video quality at the receiving end can also be achieved by reducing the Bit Error Rate (BER) of the transmission channel, which is proportionally related to the throughput. Therefore, there is scope to explore new approaches to reduce the throughput, and thereby achieve a successful HD video transmission over the UWB communication channel. The transmitted data rate can be reduced at high perceived quality by selecting appropriate video compression standard, and performing strong data compression by applying optimum coding parameters settings. Being motivated from the earlier research work, in this work, the latest, feature-rich, and advanced coding standard of the MPEG family, H.264/AVC coding standard, is chosen. The compression ratio (CR) of this coding standard at 40 dB PSNR (visually lossless) is 7:1 [4]. Some advanced features of the H.264/AVC encoder are also explored to achieve optimum encoder settings to get high data compression at the acceptable video quality.

1.3   Objective

The foremost concern of this work is to provide the consumer a wireless entertainment indoor network with high quality HD video and thereby make their leisure time more pleasant and satisfying. To accomplish the task, the thesis work is focused on the following subjects:

- To investigate coding standards for HD video compression, depending on their compression efficiency.

- Once the best coding standard is found, a detail exploration of its features will be carried out to find the key features which have greater impact on the data compression, and can deal with both subjective and objective video quality.

- The selected key features will be further investigated to find out their appropriate settings, targeting wireless high quality HD video applications.

- Finally, to evaluate the performance of the HD video transmission over the UWB communication channel, a software based end to end simulation will be performed.

The simulations and the performance assessment of the final results will be conducted by using a set of standard HD video sequences, and the transmission performance will be assessed in terms of the reconstructed video quality. The diagram of the entire process is presented in Figure 1.2.
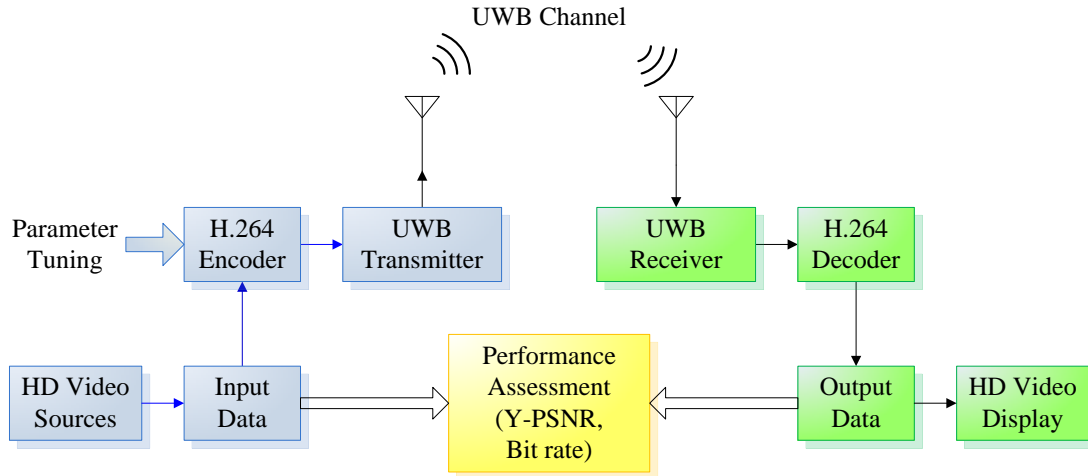
Figure 1.2: Overall working process

1.4 Thesis Organization

The thesis is organized into six chapters. Chapter 2 presents a brief overview of the popular high-definition video formats, a concise description of the advanced features of the H.264/AVC codec along with a short introduction to the UWB indoor communication channels. In Chapter 3, an overview of the working procedure to determine optimum parameters settings for the H.264/AVC encoder and their performance assessment process are explained. The required experimental software and their settings are also presented in this chapter. The simulation results and their explanation are presented in Chapter 4. A set of optimum H.264/AVC encoder parameters settings for the high-definition video transmission through the UWB communication link is proposed in this chapter. In Chapter 5, performances assessment of the proposed encoder parameters settings is presented. Finally, Chapter 6 concludes the thesis by summarizing the achievements and providing recommendations for future research.

Chapter 2

Literature Review

2.1   Introduction

This chapter presents a brief overview of the subject matters that are related to this research work. Here, at first, brief outline of the commonly used high-definition video formats are presented. After that, short discussions of the HD video coding standards along with a description of the advanced features of the H.264/AVC codec are illustrated. Finally, the chapter is concluded with a short introduction to the UWB technology and its indoor communication channel models.

2.2   High-definition (HD) Video

The high-definition standard has been developed by the Advanced Television Systems Committee (ATSC) and was adopted by the Federal Communications Commission (FCC) in 1996 [6]. HD video is getting popular to the consumer than standard-definition video day by day for its higher resolution and richer colour. Two commonly used display resolutions of the HD video are 1280×720 pixels (720p) and

1920×1080 pixels (1080i/1080p) [7]. In 720p resolution, the number '720' stands for the number of horizontal scan lines of display and the letter 'p' stands for progressive scan. The widescreen aspect ratio of this resolution is 16:9. It contains a vertical resolution of 720 pixels and a horizontal resolution of 1280 pixels, for a total of 921,600 square format pixels. The 1280×720 format is always progressive scan, where the entire frame is scanned sequentially from top to bottom in horizontal direction [8]. The commonly used frame rates for this resolution are 23.976, 24, 25, 29.97, 30, 50, 59.94, and 60 frames/sec. 1080i and 1080p HD resolution have 1080 horizontal scan lines of display with interlace scan and progressive scan respectively. In interlace scan, the display is divided into two fields - odd horizontal lines and even horizontal lines - and processed one after another [8]. The bandwidth requirement to transmit the raw HD video without any compression algorithms is around 4 Gbps. Therefore, for wireless data transmission, video compression is essential to reduce the data rate.

2.3   Video Coding Standards

Video compression is nothing but reducing the quantity of data and is a combination of spatial image compression and temporal motion compensation [9]. High degree of video compression became essential, due to the limitation of the transmission bandwidth. Most of the video compression techniques are lossy and degraded the reconstructed video quality compared to the original one after compression. Often this is because the compression scheme completely discards redundant information to achieve high compression efficacy. The available coding standards that are capable

of compressing HD video are:

- H.264/ MPEG-4 Part 10 AVC [10, 11]

- MPEG-4 Part 2 [12]

- MPEG-2 [13, 14]

- Motion-JPEG2000 [15]

2.3.1   Coding Standard Comparison

MPEG-2 [13, 14] is a very popular and widely used video coding standard developed by Moving Pictures Expert Group (MPEG) and ITU-T, telecommunication standardization sector of International Telecommunication Union (ITU). MPEG-4 Part 2 [12] is an advanced video coding standard developed by MPEG and its documentation is first released in 1999. It includes many features of the MPEG-2 in addition to its advanced features. H.264/AVC is the newest video coding standard developed by a Joint Video Team (JVT) consisting of experts from the ITU-T Video Coding Experts Group (VCEG) and the ISO/IEC Moving Picture Experts Group [10]. Motion-JPEG2000 [15] is a wavelet-based coding scheme developed by Joint Photographic Experts Group (JPEG) as an extension of the JPEG2000 [16] still image coding standard, and is an intra-frame only compression scheme, where each frame is compressed individually. Therefore, its compression efficiency is much less than inter-frame based coding standards, MPEG-2, MPEG-4 and H.264/AVC, where the redundancy between successive frames are considered to enhance compression effi-

ciency. All these coding standards have the feature to support HD video resolution. However, the H.264/AVC standard has a number of advantages over the MPEG-4 Part 2 and MPEG-2, which are summarized below:

- **Bit rate saving:** Compared to the MPEG-2 and MPEG-4 Part-2 codec, the H.264/AVC codec allows a higher compression ratio. For a given video quality, the H.264/AVC codec can achieve 39% and 64% of bit rate reduction compared to the MPEG-4 Part-2 and MPEG-2 codec respectively [17]. Compression efficiency of different coding standards are presented in Figure 2.1. According to [17], for the same video quality, if the MPEG-2 encoder requires 100 bits to encode a video, on average, the MPEG-4 Part 2 encoder will need 50.04 bits and the H.264/AVC encoder will need 36 bits to encode the same video.
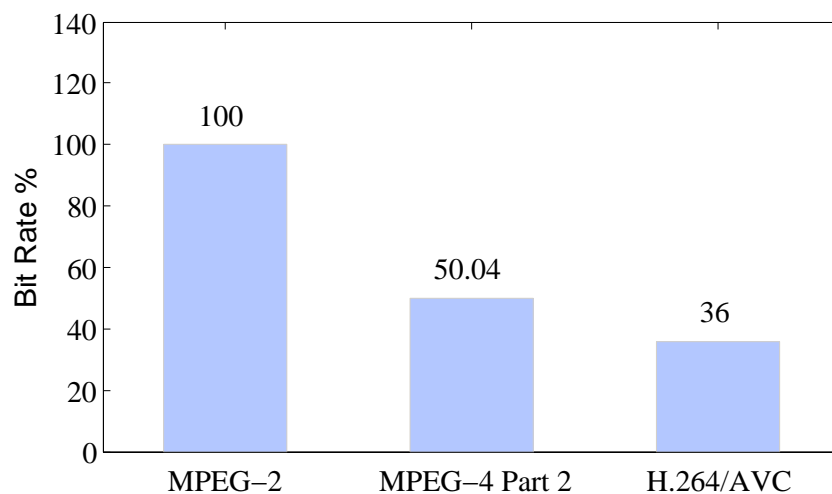
Figure 2.1: Compression efficiency

- **High quality video:** The H.264/AVC standard offers consistently high qual-

ity video at low and high bit rate.

- **Error resilience:** Compressed video streams are vulnerable to transmission errors, and that are almost inevitable in video transmission over wireless channels. The H.264/AVC standard provides advanced features to deal with the packet loss in packet networks and bit errors in error prone wireless networks [18, 19].

Considering the above advantages, especially the high compression efficiency, in this research work, the H.264/AVC standard is chosen as video compression tool.

2.3.2   H.264/MPEG-4 Part 10 AVC

The official name of the H.264/AVC is Advanced Video Coding (AVC) of MPEG-4 part 10 in ISO/IEC and H.264 in ITU-T, respectively [11]. The H.264/AVC encoder consists of two conceptual layers, the video coding layer (VCL)- defines the efficient representation of the video, and the network adaptation layer (NAL)- converts the VCL representation into a format suitable for specific transport layers or storage media [20]. Simplified block diagrams of the H.264/AVC encoder and decoder are presented in Figure 2.2 and Figure 2.3 respectively. Video coding layer of the encoder consists of three main functional units: prediction, core coding and entropy coding unit. The prediction unit includes a decoded video path to generate reference frames to enhance prediction efficiency. An H.264/AVC video decoder carries out

the complementary processes of encoder to reconstruct the decoded video sequence.
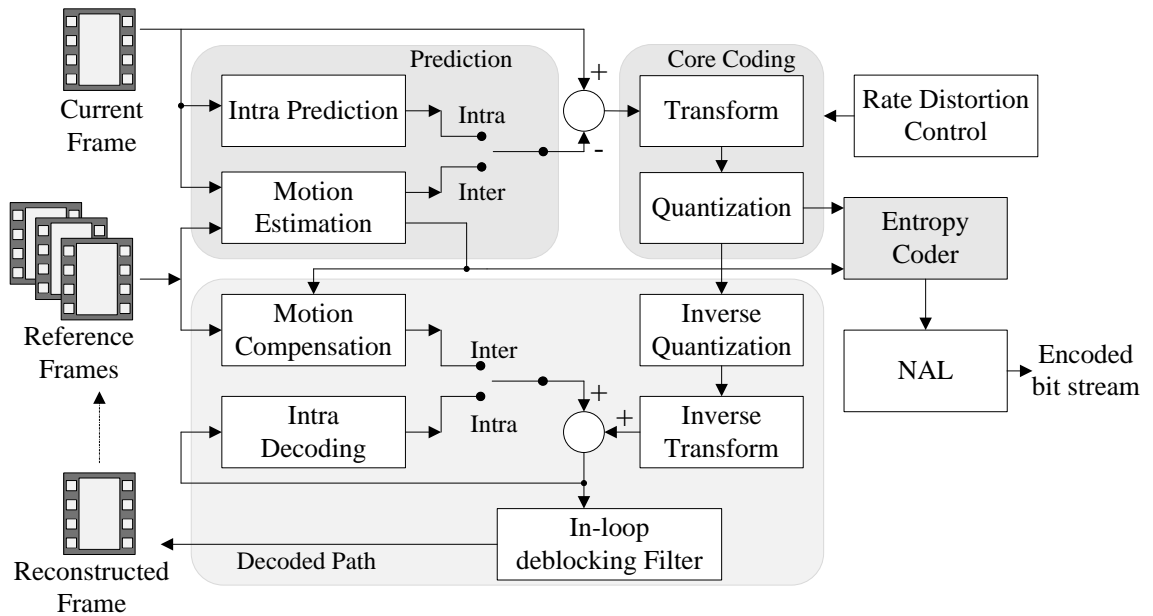
Figure 2.2: H.264/AVC encoder
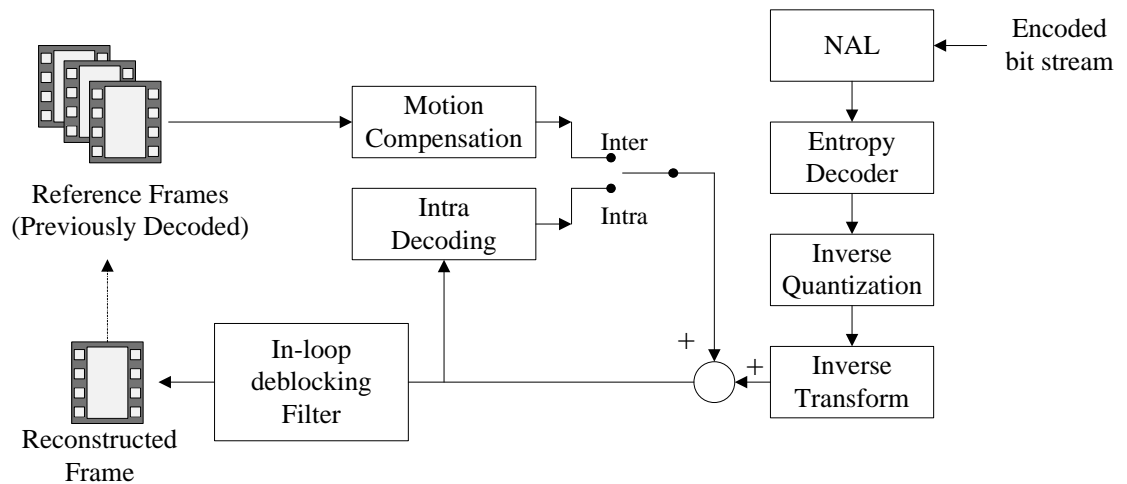
Figure 2.3: H.264/AVC decoder

2.3.2.1   Prediction

In video sequence, the data in pictures are often redundant in space and time. Therefore, prediction process is categorized in two sections: Intra prediction - considers the spatial redundancy in a video frame, and Inter prediction - take care of the temporal redundancy of the sequence. In H.264/AVC standard, each video frame is segmented into small blocks of pixel, called macroblocks (MB), and all the processing are performed on these macroblocks. Each macroblock consists of three components, Y, Cr, and Cb. Y is the luminance component, which represents the brightness information of the image. Cr and Cb are the chrominance components, and represent the colour information of the image. Figure 2.4 shows three components of an image with 4:2:0 subsampling. The image is in YUV format, where Y represents the luminance component, and U, V represent the chrominance components.

(a) Original video frame

(b) Y component

(c) U component

(d) V component

Figure 2.4: Luminance and chrominance components of an image

2.3.2.1.1   Intra Prediction

Intra prediction achieves moderate coding efficiency by exploiting correlation between adjacent macroblocks and eliminating spatial redundancy. In intra mode, an MB is predicted from neighbouring previously decoded and reconstructed macroblocks within the same frame (Figure 2.5). For the luminance (luma) component, intra prediction uses 16×16 and 4×4 macroblock sizes. There are a total of 9 optional prediction modes for each 4×4 luma block and 4 optional modes for a 16×16 luma block [21, 22]. Due to the less sensitiveness and importance of chrominance components in an image, each chroma block is down sampled by a factor of two in both vertical and horizontal directions. Therefore, if the luma prediction uses 16×16 MB, corresponding chroma block size will be 8×8 and will use a similar prediction technique. The frame, which contains only intra predicted macroblocks is called I-picture. It is an independent frame and used for predicting other frames.
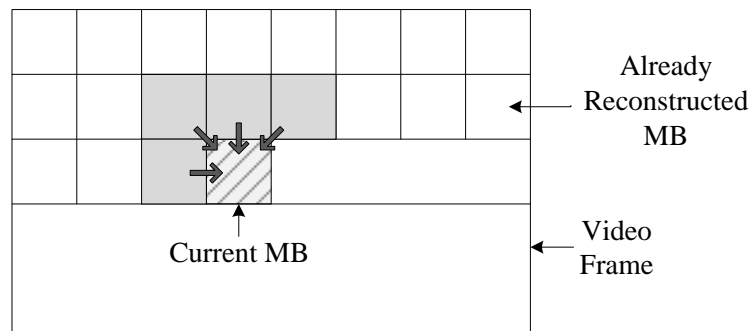
Figure 2.5: Intra prediction

2.3.2.1.2   Inter Prediction

Inter prediction takes the advantage of temporal correlation between successive frames of a video sequence to reduce the temporal redundancy. In inter prediction, the current frame is predicted from one or more previously encoded frames (Figure 2.6). The H.264/AVC encoder uses block-based motion compensation and supports variable block-size motion compensation, ranges from 16×16 to 4×4 pixels [23]. In inter prediction method, to predict a macroblock in the current frame, at first, a search for closely matched MB in the previously decoded reference frames is conducted and the best matched MB is chosen. This process of finding the best matched MB is known as motion estimation (ME) [9]. The number of reference frame to be searched is defined by the parameter. The best matched MB is then subtracted from the MB of the current frame and the residue is known as motion compensation. The offset between the current block and the position of the candidate region is known as motion vector (MV) [9]. This motion compensation block, together with the motion vector are encoded and transmitted.
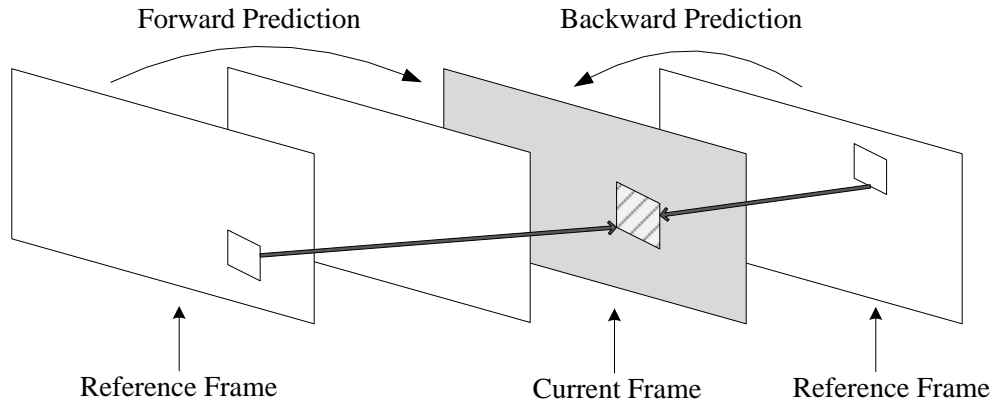
Figure 2.6: Inter prediction

Different frames during inter prediction is presented in Figure 2.7. The interactive image and video compression learning tool, VCDemo software [24], is used to produce these frames. In Figure 2.7, (a) and (b) are two successive frames of a video clip, (c) is the difference between these two frames. In (d) the white arrows represent the motion vectors and (e) is the motion compensated frame of frame 1 and frame 2. The H.264/AVC encoder supports sub-pixel and quarter-pixel precision motion compensation [25]. There are generally two types of inter frames: P-picture and B-picture. P-picture is called forward predicted picture and is generated from previously encoded I or P pictures. It requires less number of coding data compared to I-pictures. B-picture is known as bi-directionally predicted picture and is reconstructed from earlier or later I or P pictures. Hence, it provides highest degree of data compression in comparison to I and P pictures.

(a) Frame 1

(b) Frame 2

(c) Residual (difference) frame
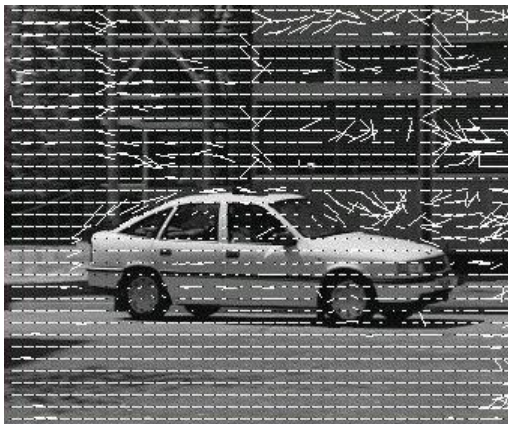
(d) Motion Vector
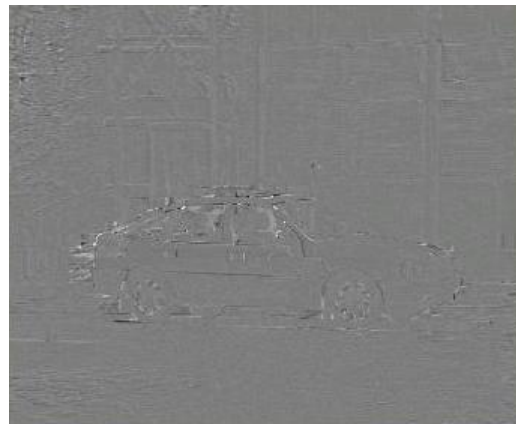
(e) Motion compensated residual frame

Figure 2.7: Frames during Inter prediction

2.3.2.1.3 Group of Pictures (GOP)

In video coding, group of pictures represents the organization of intra and inter predicted frames within a coded video stream. Each coded video stream consists of successive GOPs. A GOP normally begins with an I-picture followed by several P and B pictures. A widely used GOP structure "IBBPBBP..." is shown in Figure 2.8. In this structure, the fourth frame (P-picture) is needed in order to predict the second and the third frames (B-pictures). Therefore, the P-picture is required to transmit before the B-pictures, which introduce delay in the transmission. However, this structure minimizes the problem of possible uncovered areas in a video frame and reduces the transmitted data rate significantly. In error-prone network, error happing in previous frame may continue to propagate in successive frames, until the starting of next GOP [26], which is an I-picture, independent frame; do not require any additional reference frame to reconstruct.
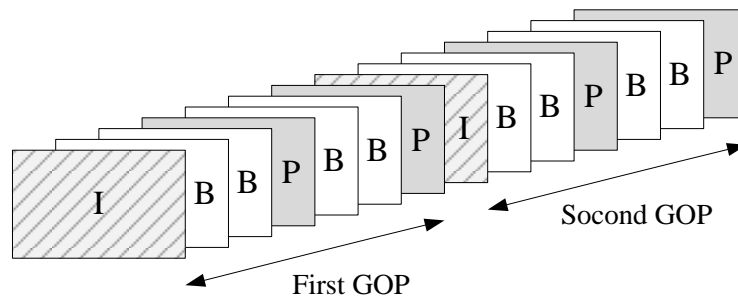
Figure 2.8: GOP structure in a coded video stream

2.3.2.2   Core Coding

After the intra or inter prediction, the predicted MBs are transformed and quantized. In H.264/AVC encoder, an approximated 4×4 Discrete Cosine Transform (DCT), known as integer spatial transform is used. Here, the 4×4 approximated DCT is divided into two parts, 4×4 integer transform and fractional scalar multiplication factors that is further merged in quantization stage [27]. This small block base transform helps to reduce the blocking and ringing artifacts, and the integer transform eliminates the mismatch issues between the transform and inverse transform both in the encoder and decoder.

Significant portion of data compression is taken place in the quantization stage. However, quantization is a lossy process and introduces unavoidable and irretrievable quantization error which leads to degradation of decoded video quality. In H.264/AVC encoder, the quantization stage has 52 values of quantization parameters and corresponding quantization steps. The quantization step size increases by approximately 12% for increase in each quantization parameter [28]. This allows addressing a wide range of quality level in the decoded video in compensation to data compression. The fractional scaling factors mentioned above are incorporated into the quantization coefficients. After this stage, the quantized data are sent to entropy coding unit, as well as, to the feedback loop, to reconstruct the reference frames for inter prediction.

2.3.2.3 Entropy Coding

Entropy coding is the last stage of video coding. It is a lossless coding technique that replaces the data element with coded representation, which reduces the data size significantly. In H.264/AVC, two modes of entropy coding - context adaptive variable length coding (CAVLC) [29] and context adaptive binary arithmetic coding (CABAC) [30] - are used. The CABAC mode offers approximately 10%-15% enhanced compression efficiency compared to the CAVLC mode [30]. The CABAC consists of two stages. First, the blocks produced during the core coding process, transformed and quantized motion compensated macroblocks, motion vectors, different flags, and parameters, are converted into a sequence of binary symbols, known as binarization. Second, a binary arithmetic encoder is used to perform the compression.

2.3.2.4 In-loop deblocking Filter

The H.264/AVC standard offers adaptive in-loop deblocking filter, which operates on the horizontal and vertical block edges within the motion-compensated prediction loop in order to remove the blocking artifacts and improve the quality of inter-picture prediction [31]. In block oriented coding scheme, visually annoying blocking artifacts are introduced in various steps of encoding process, such as, during motion compensated prediction, in integer discrete cosine transformation of intra and inter predicted frames, due to coarse quantization of the transformed coefficients [32]. The

aim of in-loop deblocking filter is to smooth the edges of each macroblock without affecting the sharpness of the picture, thus improving both objective and subjective quality of the decoded video. The filter is applied to the reconstructed frame both in encoder and decoder.

After encoding HD video, the encoded bit stream is transmitted using the UWB communication link.

2.4 Ultra-wideband Technology

Ultra-wideband is one of the most promising wireless technology for high speed indoor data transmission. This technology has become popular for its high data rate, and short-range wireless link at low energy level. In February of 2002, the Federal Communications Commission approved the unlicensed use of 3.1 to 10.6 GHz spectrum for the UWB technology for commercial applications [33]. The power spectral density (PSD) level of the UWB channel is limited to -41.3 dBm/MHz. Figure 2.9 presents the spectrum allocation and low power spectral density for the UWB communication devices. This low power spectral density ensures that the UWB devices do not cause harmful interference to other existing licensed services and important radio systems.
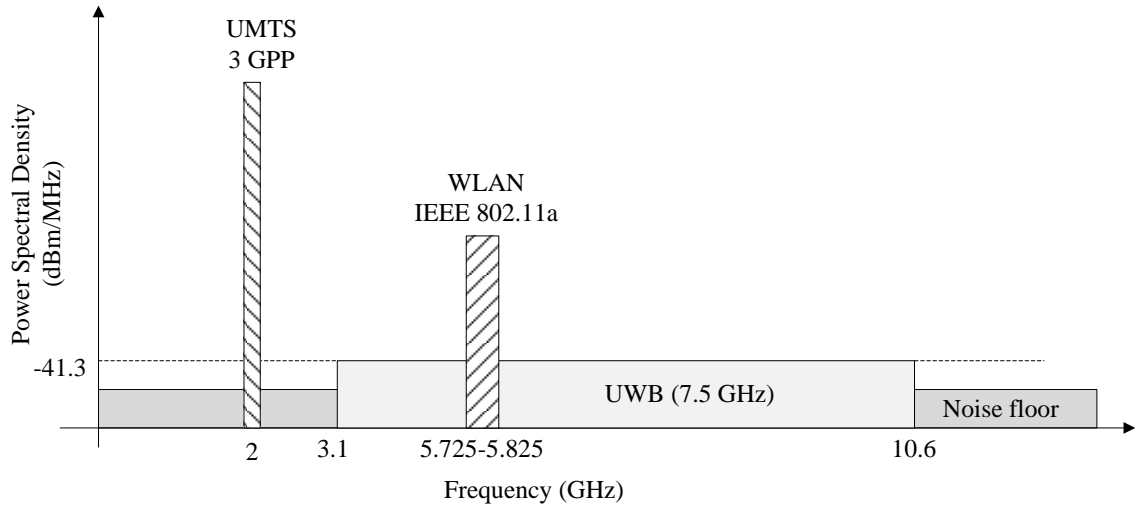
Figure 2.9: Spectrum allocation

The UWB technology has several advantages over other wireless technologies, which are summarized below:

- **High data rate:** The maximum theoretical data rate of the UWB technology is 480 Mbps and the maximum transmitting range is 20 m [1], which makes this technology very suitable for high speed indoor multimedia applications, such as, video distribution, video teleconferencing and high-definition television (HDTV).

- **Lower energy consumption:** As the power spectral density of the UWB technology is limited to -41.3 dBm/MHz, the total emitted power over several GHz of bandwidth is a fraction of milliwatt [34]. This low energy consumption feature is very attractive for developing economic transmitting devices.

- **Widespread and low interference:** The UWB technology is less susceptible

to interference and is robust to multipath fading due to its widespread nature

[34].

2.4.1   UWB Channel Model

An UWB channel model is derived from the modified Saleh-Valenzuela (SV) [35] model suitable for home environment with both line-of-sight (LOS) and non-line-of-sight (NLOS) conditions [36]. In the SV models, both the cluster and the ray arrival times are modeled independently by Poisson processes [37]. The mathematical representation of the multipath channel impulse response can be presented as

$$h_i(t) = X_i \sum_{l=0}^{L_C^{-1}} \sum_{k=0}^{K_{LC}^{-1}} \alpha_{k,l}^i \delta(t - T_l^i - \tau_{k,l}^i) \tag{2.1}$$

where, $\alpha_{k,l}^i$ represents the multipath gain coefficient, T_l^i is the delay of lth cluster, $\tau_{k,l}^i$ is the delay of the kth multipath component relative to the lth cluster arrival time (T_l^i), X_i represents the log-normal shadowing, and i refers to the ith realization.

The modified Saleh-Valenzuela model uses the following definition, and assumes that $\tau_{0,l}$=0.

- T_l=the arrival time of the first path of the lth cluster;

- $\tau_{k,l}$= the delay of the kth path within the lth cluster relative to the first path arrival time, T_l;

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- Λ = cluster arrival rate;

- λ= ray arrival rate, i.e., the arrival rate of path within each cluster.

The distribution of cluster arrival time can be presented by

$$p(T_l|T_{l-1}) = \Lambda\, e^{-\Lambda(T_l - T_{l-1})}, \quad l > 0 \tag{2.2}$$

and the ray arrival time by

$$p(\tau_{k,l}|\tau_{(k-1),l}) = \lambda\, e^{-\lambda(\tau_{k,l} - \tau_{(k-1),l})}, \quad k > 0 \tag{2.3}$$

where, the channel coefficients are defined by

$$\alpha_{k,l} = p_{k,l}\, \xi_l\, \beta_{k,l} \tag{2.4}$$

and

$$20 \log 10(\xi_l\, \beta_{k,l}) \quad \propto \quad N(\mu_{k,l}, \sigma_1^2 + \sigma_2^2)$$

$$|\xi_l\, \beta_{k,l}| \quad = \quad 10^{(\mu_{k,l}, n_1 + n_2)/20} \tag{2.5}$$

where, $n_1 \propto N(0, \sigma_1^2)$ and $n_2 \propto N(0, \sigma_2^2)$ are independent and correspond to the fading on each cluster and ray, respectively. The behavior of the (average) power delay profile is

$$E\left[|\xi_l\, \beta_{k,l}|^2\right] = \Omega_0 e^{-T_l/\Gamma}\, e^{-\tau_{k,l}/\gamma} \tag{2.6}$$

where, Ω_0 is the mean energy of the first path of the first cluster, and $p_{k,l}$ is equiprobable $+/$-1 to account for signal inversion due to reflections. The $\mu_{k,l}$ is given by

$$\mu_{k,l} = \frac{10\ln(\Omega_0) - 10T_l/\Gamma - 10\tau_{k,l}/\gamma}{\ln(10)} + \frac{(\sigma_1^2 + \sigma_2^2)\ln(10)}{20} \tag{2.7}$$

where, ξ_l reflects the fading associated with the lth cluster, and $\beta_{k,l}$ corresponds to the fading associated with the kth ray of the lth cluster. Finally, since the log-normal shadowing of the total multipath energy is captured by the term, ξ_i, the total energy contained in the terms $\alpha_{k,l}^i$ is normalized to unity for each realization. This shadowing term is characterized by

$$20\log 10(X_i) \propto N(0, \sigma_x^2) \tag{2.8}$$

The model derives the following channel parameters as an output [37]

- Mean and root mean square (RMS) delay

- Number of multipath components

- Power decay profile

The model inputs the following parameters [37]

- $\Lambda =$ cluster arrival rate

- $\lambda =$ ray arrival rate i.e., the arrival rate of the multipath components within each cluster

- Γ= cluster decay factor

- γ= ray decay factor

- σ_1 = standard deviation of cluster lognormal fading term (dB)

- σ_2 = standard deviation of ray lognormal fading term (dB)

- σ_x = standard deviation of lognormal shadowing term for total multipath realization (dB)

Four different environments are defined for the indoor UWB channel by Intel, namely CM1, CM2, CM3, and CM4 [36]. CM1 represents a LOS scenario, which is an unobstructed path from transmitter to receiver with broadcasting range less than 4 m. CM2 and CM3 correspond to NLOS scenario, where there are multiple obstructions created by human, furniture, material of room walls, ceiling, between the transmitter and the receiver, with transmitting range less than 4 m and 4-10 m respectively. Finally, CM4 stands for an environment with extreme NLOS multipath channel. Table 2.1 presents the summary of the indoor UWB channel mode.

Table 2.1: INDOOR UWB CHANNEL MODEL SPECIFICATION

Channel Mode	CM1	CM2	CM3	CM4
Environment	LOS	NLOS	NLOS	NLOS
Transmitting Distance	4 m	4 m	4 m to 10 m	-

Table 2.2 lists the model parameters for four different channel characterizations from measurement data by Intel [38].

Table 2.2: INDOOR MULTIPATH CHANNEL CHARACTERISTICS & MODEL PARAMETERS

Target Channel Characteristicse	*CM1*	*CM2*	*CM3*	*CM4*
Mean excess delay (nsec) $(m\tau)$	5.05	10.38	14.18	-
RMS delay (nsec) $(rms\tau)$	5.28	8.03	14.28	25
NP_{10dB}	-	-	35	-
NP (85%)	24	36.1	61.54	-
Model Parameters				
Λ(1/nsec)	0.0233	0.4	0.0667	0.0667
λ(1/nsec)	2.5	0.5	2.1	2.1
Γ	7.1	5.5	14.00	24.00
γ	4.3	6.7	7.9	12
σ_1 (dB)	3.3941	3.3941	3.3941	3.3941
σ_2 (dB)	3.3941	3.3941	3.3941	3.3941
σ_x (dB)	3	3	3	3
Model Characteristics				
Mean excess delay (nsec) $(m\tau)$	5.0	9.9	15.9	30.1
RMS delay (nsec) $(rms\tau)$	5	8	15	25
NP_{10dB}	12.5	15.3	24.9	41.2
NP (85%)	20.8	33.9	64.7	123.3
Channel energy mean (dB)	-0.4	-0.5	0.0	0.3
Channel energy std (dB)	2.9	3.1	3.1	2.7

2.5 Summary

In this chapter, a brief overview of the HD video transmission requirements, coding efficiency comparison of the HD video coding standards, a concise description of the H.264/AVC encoder and the UWB communication channel are presented. Among the advanced features of the H.264/AVC encoder, the GOP length and the quantization parameter have the greatest influence to control the encoded bit rate and the reconstructed video quality. In addition to this, the in-loop deblocking filter plays a significant role on improving objective and subjective video quality. Therefore, these parameters are further studied in the upcoming chapters to achieve a successful HD wireless home entertainment network.

Chapter 3

Methodology

3.1 Introduction

For an effective transmission of the compressed HD video, the channel bandwidth
is critical. To overcome this limitation, in this work, a set of optimum H.264/AVC
encoder parameters is proposed to control the transmitted bit rate while maintain-
ing high quality video at the receiving end. This chapter presents, an overview of
the entire process exercised to determine the optimum parameter settings for the
H.264/AVC encoder at different broadcasting data rate. The performance evalua-
tion process of the achieved parameters is also presented in this chapter.

3.2 Work Flow

The entire work flow is organized into two levels. In the first level, the impact of the key H.264/AVC encoder parameters on the encoded data rate and the decoded video quality are observed. In the second level, a software based end-to-end system is developed to analyze the feasibility of HD video streaming through the UWB communication link using the encoder parameters obtained in the first level. The block diagram of the entire process is given in Figure 3.1. Table 3.1 listed the software used to conduct the experiments. The configuration of the desktop computer used to run the software are presented in Table 3.2.

Table 3.1: Tools Used in the Work

| Software	Purpose of the software	Level
JM 15.1 [39]	H.264/AVC coder	First and second level
Microsoft Visual C++ 2005 version 8.0.50727.42	Run JM 15.1	First and second level
Matlab version 7.0.4.365	Calculate PSNR and generate results	First and second level
YUVTools version 3.0.873	Observe subjective quality of the reconstructed videos.	First and second level
Matlab Simulink	Run transceiver, modulator, demodulator, and the UWB channel	Second level
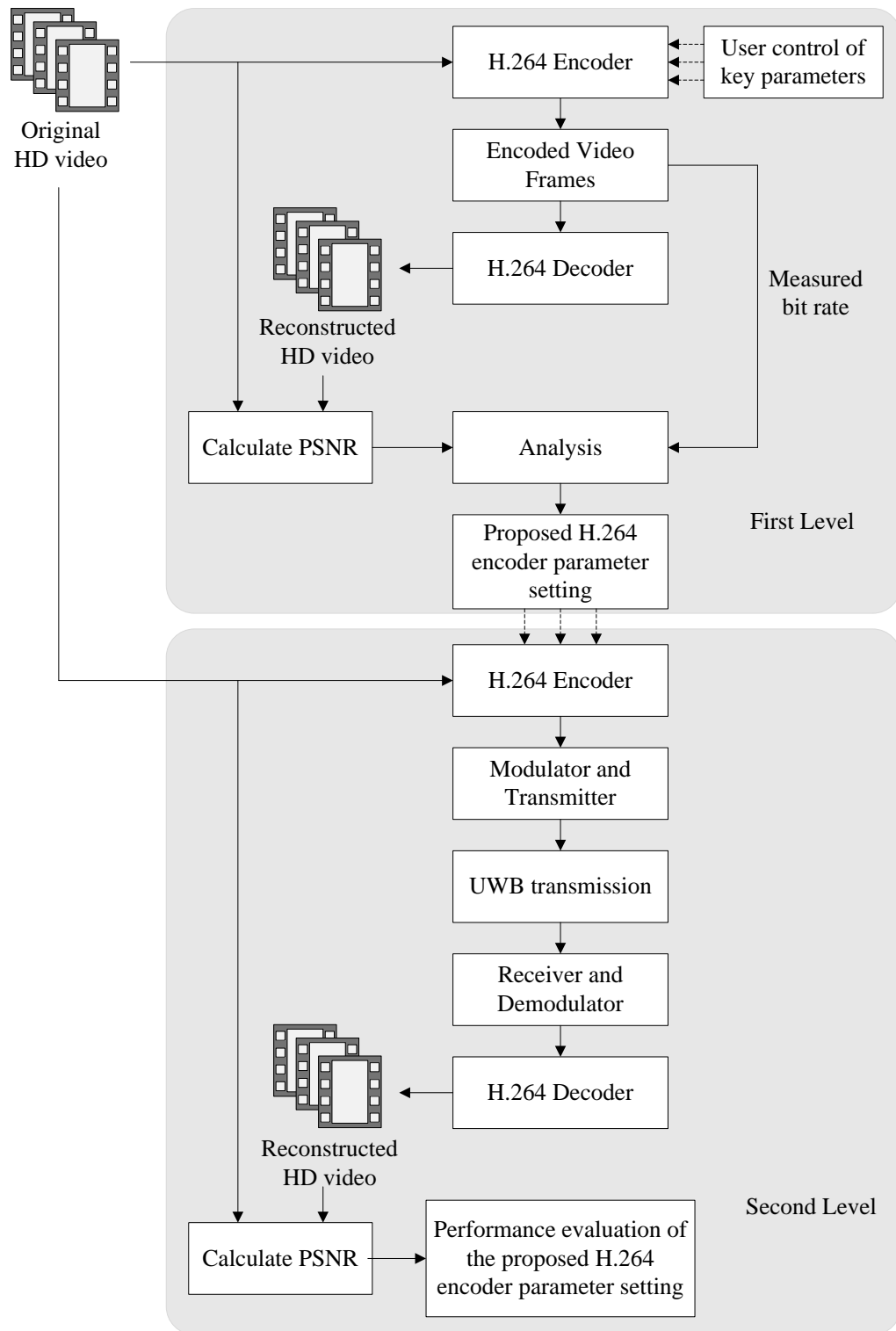
Figure 3.1: Block diagram of the overall work flow

Table 3.2: WORKSTATION CONFIGURATION

Operating System	Microsoft Windows XP Professional Version 2002
Processor	Intel(R) Pentium(R) D CPU
Processor speed	2.8 GHz
Memory	4 GHz Random Access Memory(RAM)

3.2.1 H.264/AVC Encoder Parameter Estimation

In this level, a set of key H.264/AVC encoder parameters value are determined to achieve high compression rate for the HD video at an acceptable video quality. Joint Video Team's reference coding software for the H.264/AVC standard, JM 15.1 [39], is used to perform all the experiments. The block diagram of work flow to determine the encoder parameters settings is presented in Figure 3.2. The subsequent paragraphs demonstrate a brief description of the important blocks of the work flow.

3.2.1.1 HD Video Sequences

Six standard 720p resolution, uncompressed HD video streams are selected to perform simulations. The video sequences include a wide range of low to high motion activities and movements to cover a broad range of video content. Besides, it incorporates both bright and dull colour texture. Table 3.3 provides name, description, and an approximate motion characteristic of each video sequence. In this work, first 31 frames of each video sequence are taken to perform simulations. All the video sequences are in YUV format with progressive scanning at 30 frames per sec-

ond. These video sequences are passed through the H.264/AVC encoder. Figure 3.3

shows the first frame of each video sequence.
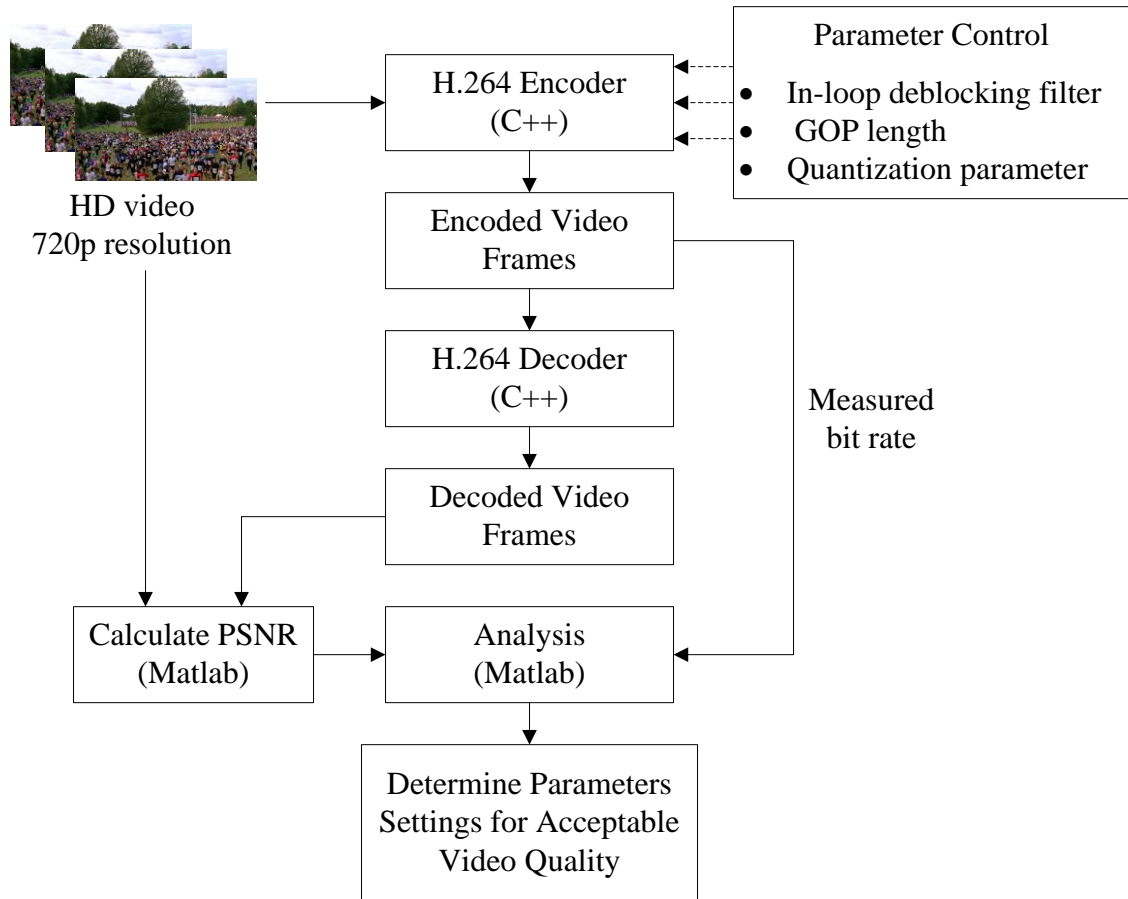
Figure 3.2: Work flow for the encoder parameters settings

Table 3.3: VIDEO SEQUENCE USED FOR SIMULATION

Sequence Name	Video Description	Motion Characteristic
Shields [40]	A gentleman is moving his hand on a series of shields.	Smooth and steady background motion, few object movements, and high spatial detail of objects.
Stockholm [40]	Slow camera motion overlooking the Stockholm city with traffic on road. Gentle wave motion in lake.	Slow background motion, multiple object movement in random direction.
Crowd Run [41]	Front view of a marathon race.	Still background, several fast moving objects in forward direction.
Park Run [40]	A camera follows a person running through the park.	Background and objects moving in opposite direction.
Park Joy [41]	A group of people running through park, front tree motion.	Static background, fast moving objects in opposite direction.
Ducks Take Off [41]	A group of ducks flips their wings to take off.	Still background, fast complex object motion including wave motion.

(a) Shields

(b) Stockholm

(c) Crowd Run

Figure 3.3: First frame of the standard video sequences

(d) Park Run
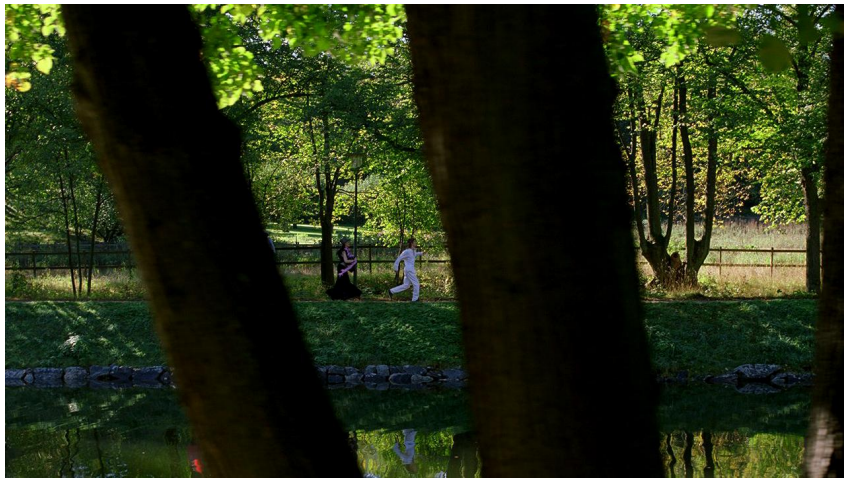
(e) Park Joy

(f) Ducks Take Off

Figure 3.3: First frame of the standard video sequences

3.2.1.2 H.264 Encoder Simulation Environment

The H.264/AVC encoder of the JM 15.1 software is used for video compression. Simulation is carried out by changing the major H.264/AVC encoder parameters, which have greater impact on the encoded bit rate and the reconstructed video quality. Recommended standard setting is applied to the rest of the encoder parameters. Some important simulation settings are listed in Table 3.4. For simulation, high profile and level 4 is selected. This setting supports all HD video resolution (720p, 1080p/1080i) and important features to achieve higher video compression efficiency.

Table 3.4: General Test Condition

Conditions	Values
Profile	High
Level	4
Rate Distortion Optimization	Enabled
Search range	$\pm$ 32
Reference frame number	5
Rate control	Off
Entropy coding	CABAC
Motion vector precision	1/4 pixel
Chroma sub-sampling format	4:2:0
GOP structure	IBBPBBP....

3.2.1.3   Parameter Control

As channel bandwidth is the main constrain, three encoder parameters having higher influence on the bit rate and the reconstructed video quality are selected as encoder controlling parameters. These are:

- In-loop deblocking filter

- Group of pictures (GOP) length

- Quantization Parameter (QP) of I, P and B pictures

At first, the impact of applying in-loop deblocking filter, which is normally used to enhance prediction performance and decoded video quality, on the HD video quality is studied. Simulation is carried out with filter enabled and disabled, and their impact on the reconstructed video quality are monitored. All the other encoder parameters are kept constant throughout the simulation. In next stage, the significance of GOP length to control the data rate is studied. Simulation is performed on all video sequences for the GOP length 4, 8, 16, 32 while maintaining the efficient GOP structure "IBBPBBP...". Finally, the quantization parameter, the main attribute to perform data compression, of I, P and B pictures are controlled to find out the relation among bit rate, video quality and the quantization parameter. The QP value is selected from 22 to 40 in a step of 2. Selection of the precise quantization parameter for all three types of pictures is essential to preserve consistent quality throughout the video sequences.

3.2.1.4   H.264/AVC Decoder and Analysis

The encoded video frames are then transmitted to the H.264/AVC decoder for re-construction. After that, to evaluate the quality of the reconstructed video peak signal to noise ratio (PSNR) [42] is calculated from the original and the decoded video frames. Here, the signal is represented by the original frame and the noise is the difference between the original and the reconstructed frame. The PSNR is defined by equation 3.1.

$$PSNR = 10 \log_{10} \left(\frac{MAX_I^2}{\frac{1}{WH} \sum_{m=1}^{W} \sum_{n=1}^{H} (c_{mn} - \tilde{c_{mn}})^2} \right) \tag{3.1}$$

where, W is the width of the frame, H is the height of the frame, c_{mn} and $\tilde{c_{mn}}$ are the pixel values of the original and the reconstructed video frame respectively, and MAX_I is the maximum possible pixel value of the image. When the pixels are represented using 8 bits per sample, this is 255.

After calculating the PSNR of each frame, average PSNR is estimated to obtain the overall PSNR of the complete video sequence. The PSNR is calculated for both luminance (Y-PSNR) and chrominance (U-PSNR and V-PSNR) components of the video. Luminance (Y) component represents brightness and chrominance (UV) components stand for colour of the video. As human eye is more sensitive to brightness than colour [43], emphasis is given on Y-PSNR to evaluate the reconstructed video

quality. In addition to the objective quality estimation using the PSNR an informal subjective video quality testing is also performed to assess the reconstructed video quality. The subjective video quality [44, 45] is concerned with how a video is perceived by a viewer and the opinion may varied person to person on a particular video sequence. Subjective video quality tests are quite expensive in terms of time and human resources. However, this is the ultimate quality testing process for a video sequence.

Finally, all the experimental data are assessed to determine the optimum parameters settings for the H.264/AVC encoder by observing the relation among the controlling parameters, transmitted bit-rate and the Y-PSNR of different video sequences.

3.2.2 System Software Prototype

In the second level, a performance assessment of the proposed H.264/AVC encoder parameters is performed using a software based end-to-end system. C++, Matlab and Matlab Simulink software are used to develop the entire process. JM 15.1 software is employed for the H.264/AVC encoder and decoder, and this software is developed in C++. The rest of the process is developed in Matlab and Matlab Simulink. The block diagram of the system is given in Figure 3.4.

In this level, the H.264/AVC encoder is set with the proposed parameters obtained in the first level. After that, the test sequences are passed through the encoder to gen-

erate encoded video file (with a .264 extension). Encoded bit streams are extracted from this file using Matlab program, and inputted in the UWB communication channel developed in Matlab Simulink. For the UWB channel, modified Simulink model "UWB Fixed-Point Model (Multiband OFDM)" [46] is used. This model is based on IEEE 802.15.3a multiband Orthogonal Frequency Division Multiplexing (OFDM) proposal (September 2003 version). The snap shot of the Simulink model is given in Figure 3.5. From the output streams of the Simulink model, the encoded file is regenerated using Matlab program. Afterwards, the H.264/AVC decoder of the JM 15.1 software is used to decode and reconstruct the video sequence from the regenerated encoded file. Finally, the PSNR is calculated from the original and the reconstructed video, and the results are verified with the results of the previous level.
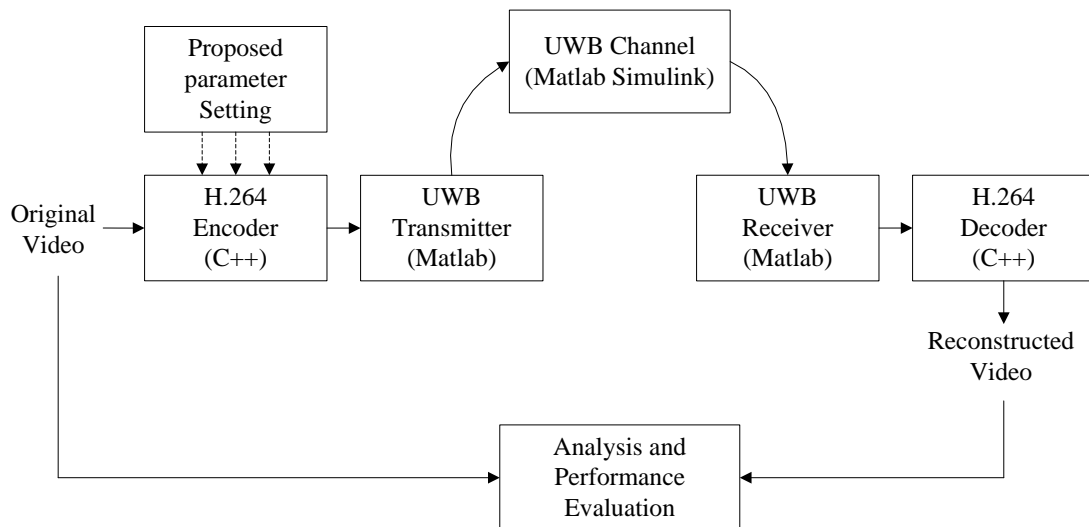

Figure 3.4: Block diagram of the performance evaluation process for proposed encoder parameters
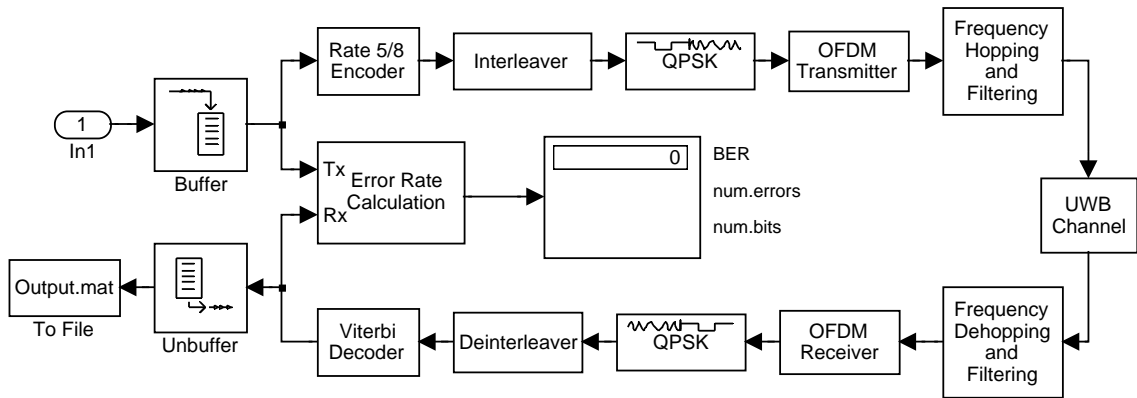
Figure 3.5: Snap shot of the Matlab Simulink model

3.3 Summary

In this chapter, at first, a work flow to determine the optimum parameter settings for the H.264/AVC encoder is presented. After that, a software based performance evaluation process of the encoder parameters is described. This chapter also presents the simulation settings and the controlling parameters of the H.264/AVC encoder. The next chapter presents the simulation results for different settings of the controlling parameters of the H.264/AVC encoder. An overview of the performance evaluation results are presented in Chapter 5.

Chapter 4

Results And Analysis

4.1   Introduction

This chapter presents the simulation results conducted by controlling H.264/AVC encoder parameters, the in-loop deblocking filter, the group of pictures and the quantization parameter of I, P and B-pictures. The analysis of the simulations outcome and their explanation are also presented here.

4.2   Impact of In-loop deblocking Filter

The feature, in-loop deblocking filter of the H.264/AVC coder is used to reduce blocking artifacts in the decoded video sequences to improve visual quality and prediction performance. The blocking artifacts are introduced in video frames due to the block-based coding system of the H.264/AVC standard. Figure 4.1 and Figure

4.2 show the impact of in-loop deblocking filter on chrominance and luminance components respectively of two testing video sequences, Shields and Crowd Run. The Shields sequence is categorized as a slow moving video with fewer activities, where as the Crowd Run sequence is characterized as video with large object movements. Simulation results show that the contribution of in-loop deblocking filter in video quality improvement is insignificant when the bit rate is between 1 Mbps to 12 Mbps, and no significant variation in video quality is observed when the throughput exceeds around 12 Mbps. That means, the effect of in-loop deblocking filter for high bit rate is insignificant, and its impact reduces with the increment of bit rate.

However, subjective quality performance is the ultimate test of any video sequence. Therefore, an informal subjective quality test is performed, and no visual blockiness is observed in the decoded video sequences, which supports the measured objective quality. Figure 4.3 and Figure 4.4 present, the subjective picture quality with deblocking filter enabled and disabled respectively for Shieleds sequence, and Figure 4.5 and Figure 4.6 show that of sequence Crowd Run. This in-loop deblocking filter is considered to be hold one third of the computational complexity of the decoder even with highly optimized filtering algorithm [32]. Hence, disabling the filter for HD videos offers considerable reduction of computational complexity and saves computational times without hampering both subjective and objective video quality. The rest of the experiments are carried out disabling the in-loop deblocking filter.
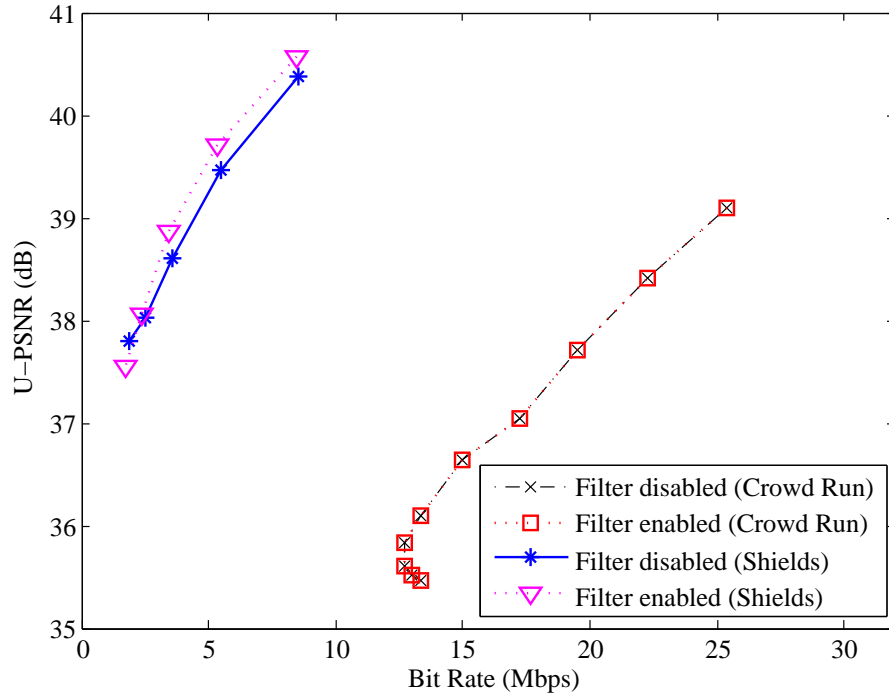
(a) Impact on U colour component
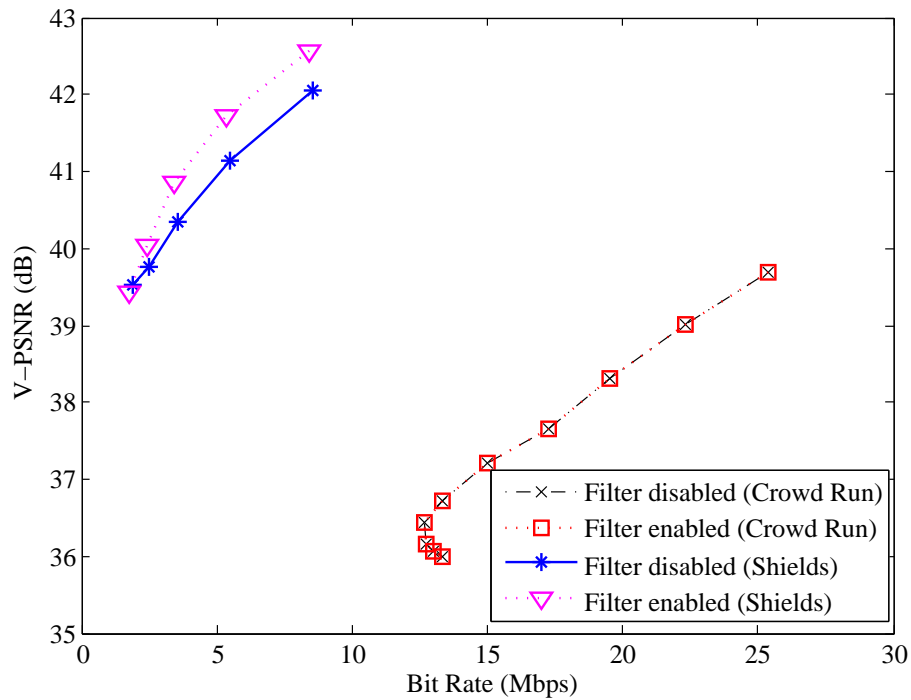
(b) Impact on V colour component

Figure 4.1: Impact of in-loop deblocking filter on chrominance components

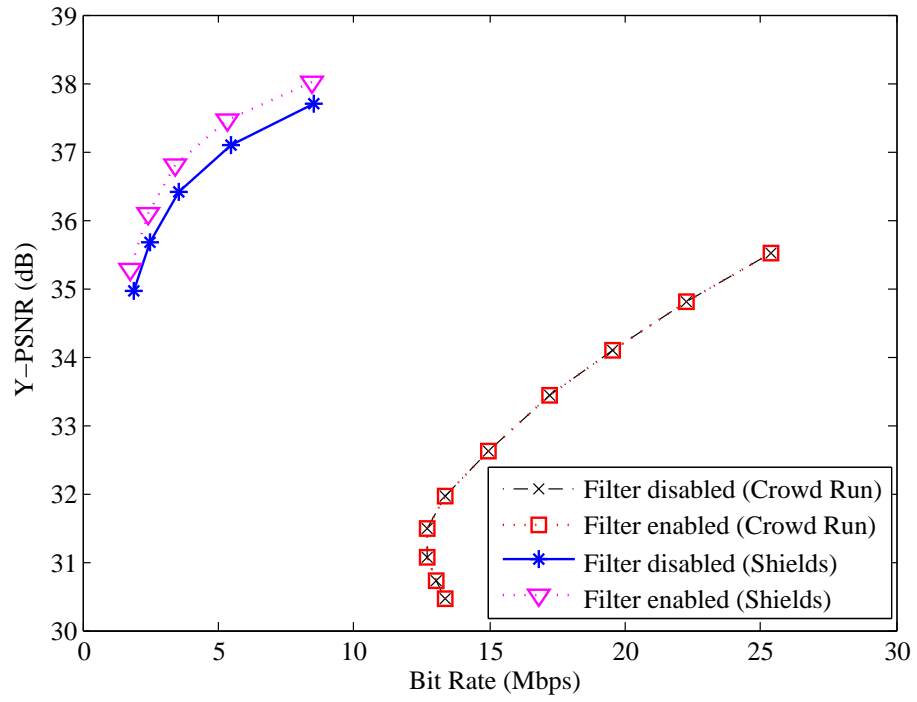**Figure 4.2:** Impact of in-loop deblocking filter on luminance component

Figure 4.3: In-loop deblocking filter enabled (last frame of Shields)

Figure 4.4: In-loop deblocking filter disabled (last frame of Shields)

Figure 4.5: In-loop deblocking filter enabled (last frame of Crowd Run)

Figure 4.6: In-loop deblocking filter disabled (last frame of Crowd Run)

4.3 Impact of GOP

The GOP length and structure combined with the H.264/AVC compression techniques determine video streaming performance in terms of bit rate and perceived quality. In this part, the impact of GOP length variation on the bit rate and the reconstructed video quality (Y-PSNR) is observed with conventional GOP structure "IBBP...". Figure 4.7 to Figure 4.12 present the bit rate verses Y-PSNR plot of video sequences for different GOP length for the variation of quantization parameter of P-pictures.

For Crowd Run, Shields, Park Run, and Stockholm sequences (Figure 4.7 to Figure 4.10), at the same bit rate, the Y-PSNR improved with the increment of GOP length. Here, Shields and Stockholm sequences are slow moving video with less object movements; whereas, Crowd Run and Park Run sequences have large temporal variation. Hence, for these two types of video characteristics, at the same bit rate, the PSNR is improved with the increase of GOP length, and provides sufficiently good PSNR at high GOP length, i.e., 32 or 16. However, for Ducks Take Off and Park Joy sequences (Figure 4.11 and Figure 4.12), at the same bit rate, high PSNR is obtained for GOP length 8 and 16. These two sequences include complex object movements. This concludes, in general, the GOP length can be set to 16 to obtain an acceptable video quality with considerable data compression for HD videos. Similar relation with the GOP length is attained for the variation of the quantization parameter of B-pictures, and it is presented in Figure 4.13 and Figure 4.14.
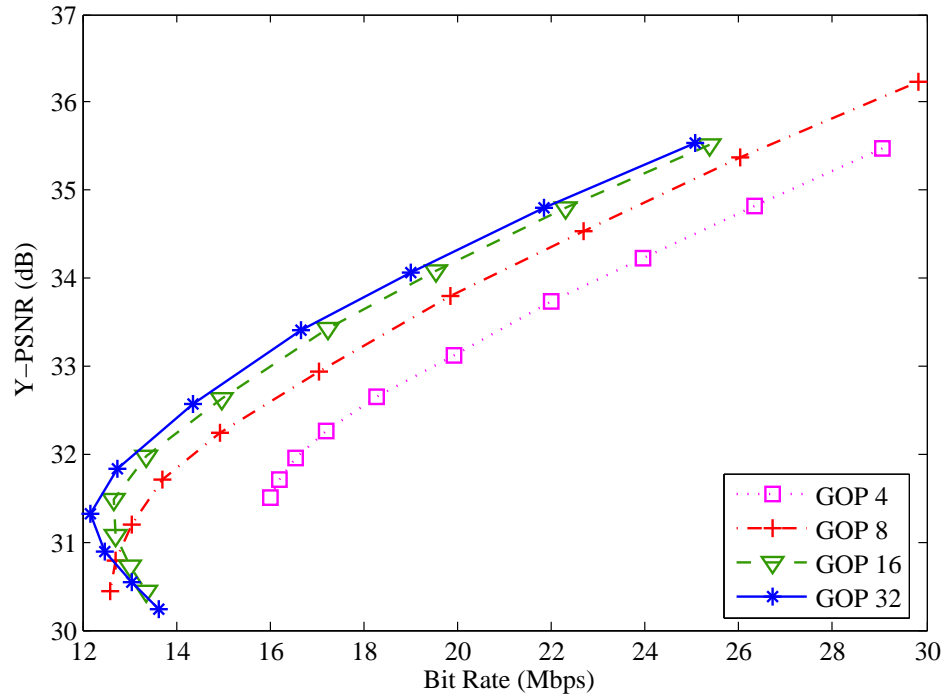
Figure 4.7: Impact of GOP length for QP of P for Crowd Run sequence
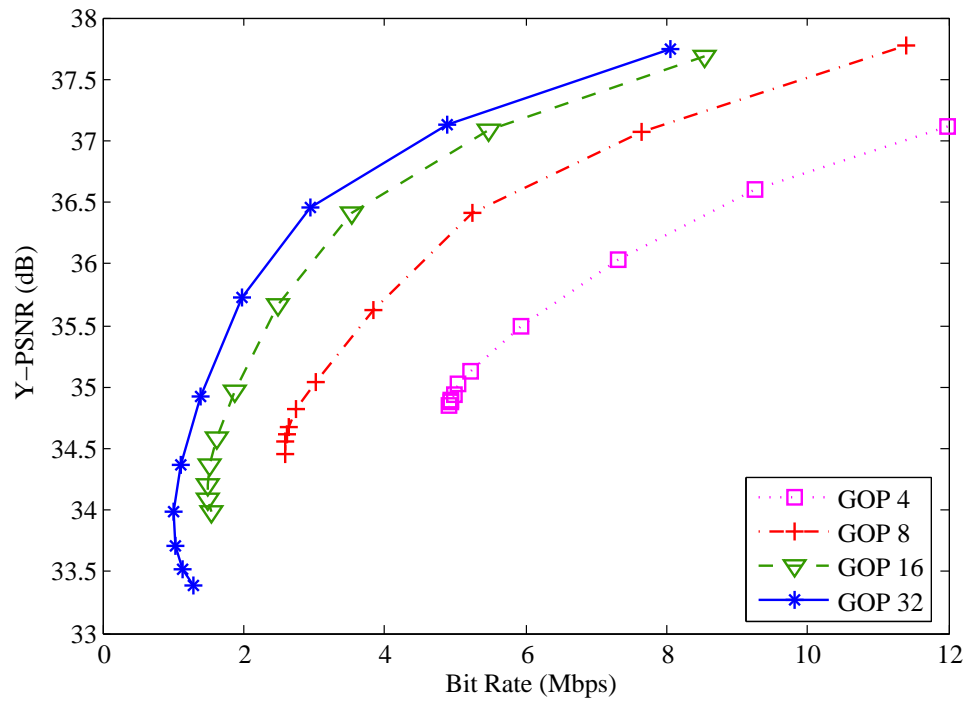
Figure 4.8: Impact of GOP length for QP of P for Shields sequence
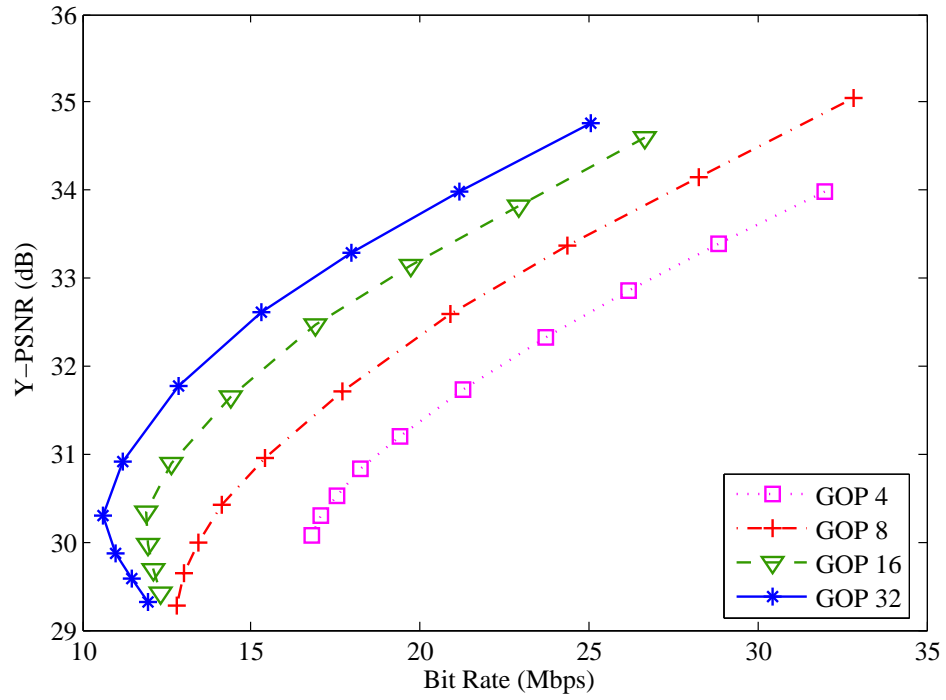
Figure 4.9: Impact of GOP length for QP of P for Park Run sequence

Figure 4.10: Impact of GOP length for QP of P for Stockholm sequence

Figure 4.11: Impact of GOP length for QP of P for Ducks Take Off sequence

Figure 4.12: Impact of GOP length for QP of P for Park Joy sequence

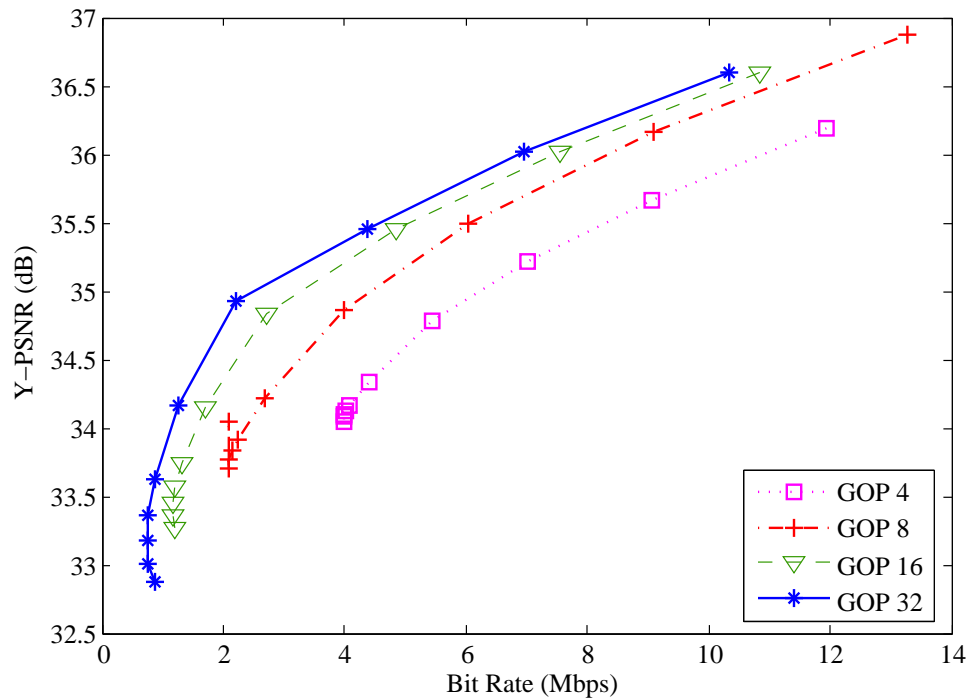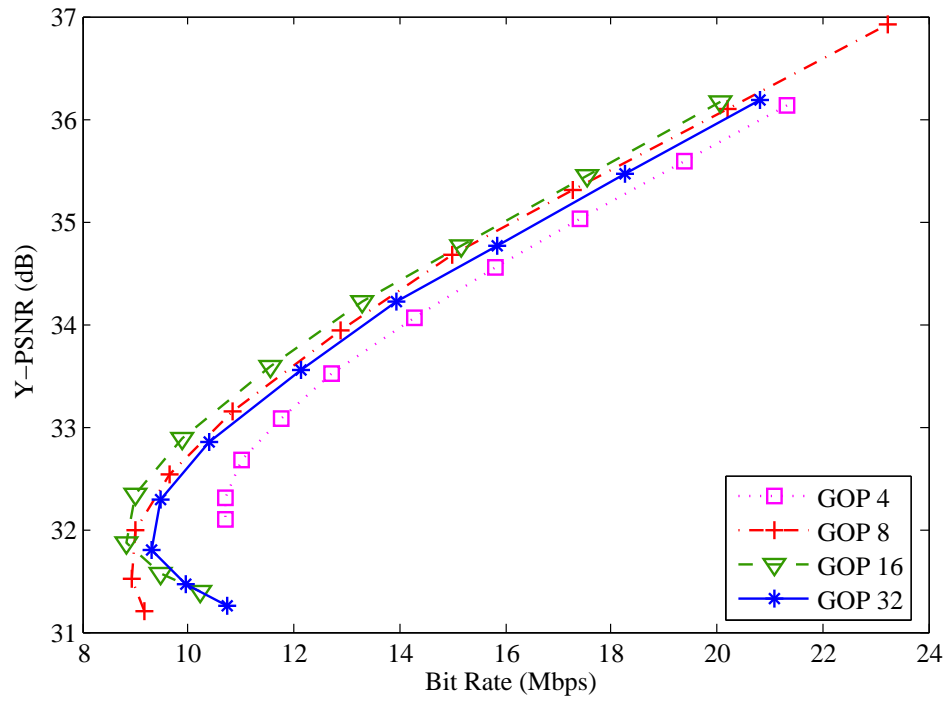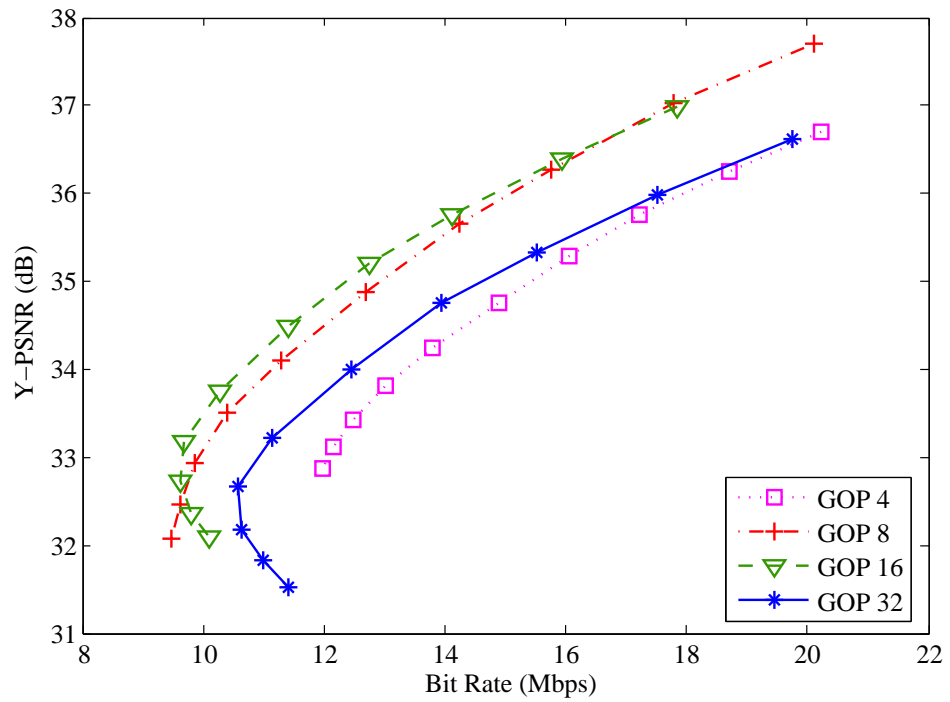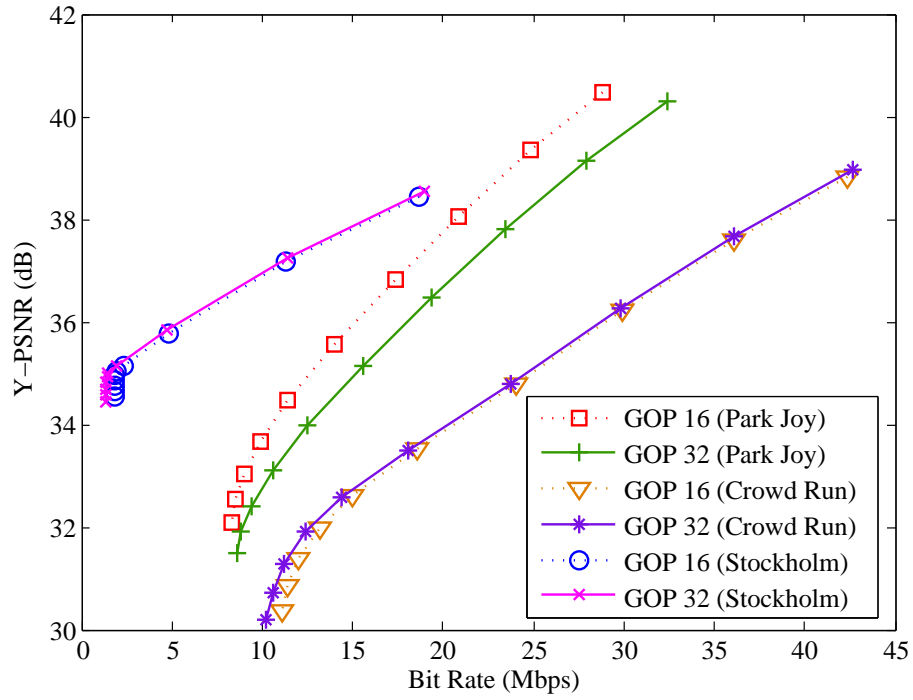**Figure 4.13:** Impact of GOP length for QP of B for Park Joy, Crowd Run, Stockholm sequences
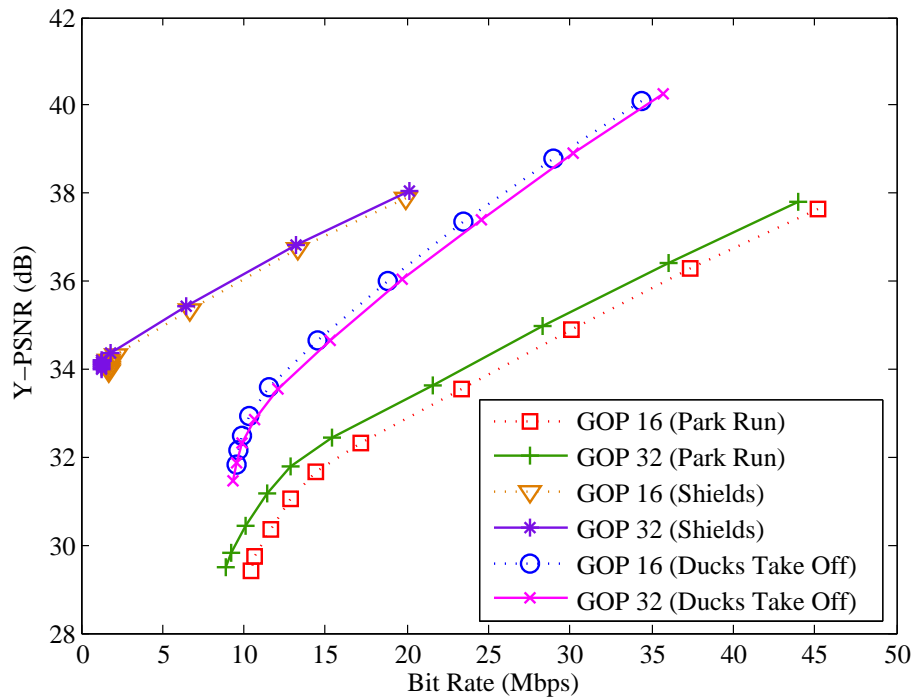
Figure 4.14: Impact of GOP length for QP of B for Park Run, Shields, Ducks Take Off sequences

4.4   Impact of QP

The quantization parameter, which specifies the number of quantization steps, has significant control over the data compression rate. However, the error introduced by the quantization parameter is irretrievable. In this section, the QP for intra and inter predicted frames for various video characteristics are investigated.

4.4.1   Impact on Intra Frames

Intra frame is the base of successive inter frames, and the quality of successive frames depends on the proper selection of the QP for intra frame. Figure 4.15 and Figure 4.16 show the bit rate and the Y-PSNR variation respectively for different QP of I-picture. The QP of P and B pictures are set to 30 and 32 respectively. The later investigation shows the significance of these selections. In GOP based coding, few frames in a group are selected as I-picture to get higher coding efficiency. If the GOP length is high, selection of QP of I-pictures does not provide significant contribution on data compression. However, the overall video quality, and the successive frame quality depend on the appropriate selection of the quantization parameter of I-pictures. Our analysis demonstrates that, for acceptable video quality, the range of QP of I-picture should be from 28 to 34. Within this range the PSNR of luminance component remains above 31.5 dB, which is up to the standard.

Figure 4.15: Bit rate at various QP of I-pictures. QP of P=30, QP of B=32
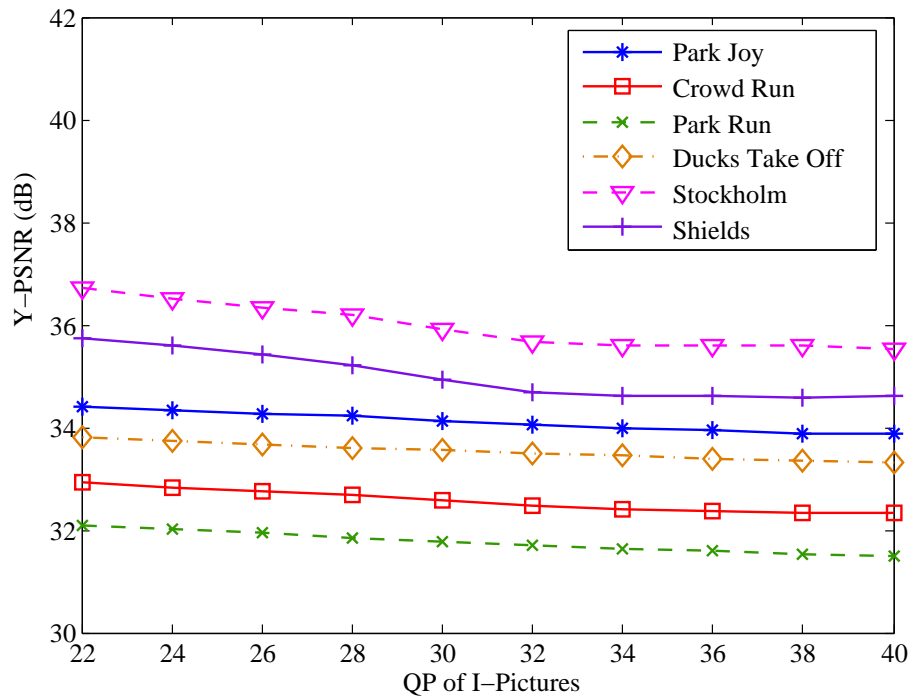
Figure 4.16: Y-PSNR at various QP of I-pictures. QP of P=30, QP of B=32

4.4.2 Impact on Inter Frames

Video clips and movies generally consist of a sequence of individual images having less variation, shown in quick succession. Therefore, using more inter predicted frames, which take the advantage of temporal redundancy between successive frames, allow higher compression rates. The selection of QP for two type of inter frames, P-picture and B-picture are analyzed here.

4.4.2.1 P-picture

The selection of QP for P-picture is very crucial as bit rate differs significantly with the QP value, and the quality of B-pictures depends on the appropriate QP value of P-pictures. Figure 4.17 and Figure 4.18 illustrate the bit rate and the Y-PSNR variation for all video sequences respectively for different QP of P-pictures. The QP of I and B pictures are set to 30 and 32 respectively for the simulation. The QP of I-picture is selected within the QP range proposed in the previous section. Figure 4.17 shows that, the bit rate reduces with the increment of the QP of P-pictures. However, after certain value of QP the bit rate increases with the increment of the QP of P-pictures. Coarse selection of QP of P-pictures reduces the average bit requirement per P-frame, and introduces higher degree of quantization error. As B-picture uses I and P picture as prediction reference, after certain value of QP of P-picture, to maintain the video quality, the bit requirements for Y coefficient of B-pictures increases. This results in, the increment of total bit rate with the increment

of QP of P-pictures after certain value of QP. Therefore, the QP value for P-pictures should be selected near the optimum point where the bit rate in low. According to the result of conducted simulations, the QP of P-picture is proposed to be selected from 28 to 34 for HD video. Within this range, the Y-PSNR remains acceptable, i.e., above 30 dB. Figure 4.19 presents the bit rate vs. Y-PSNR variation of video sequences for QP of P-pictures.
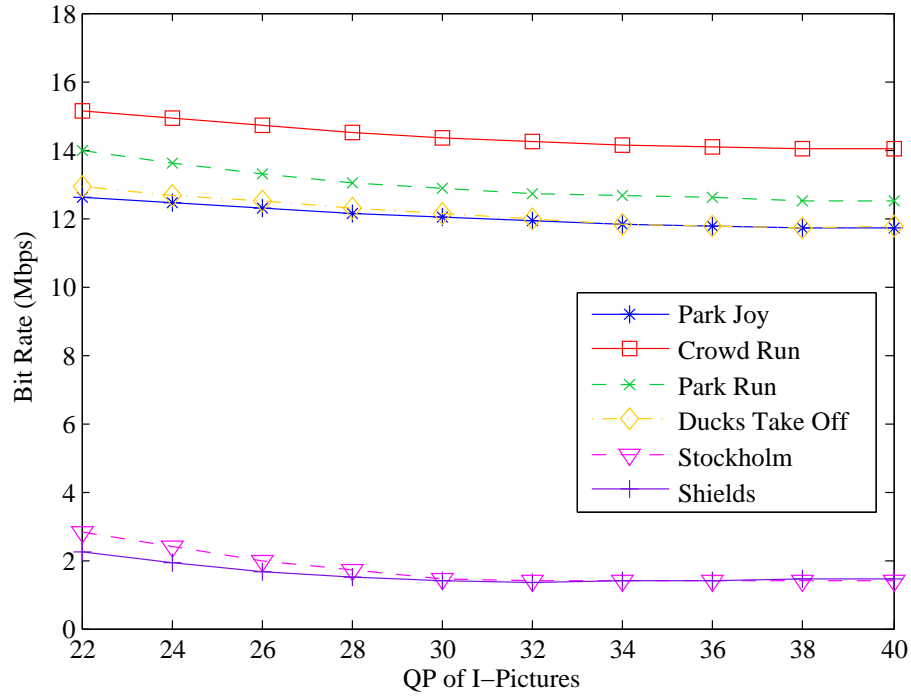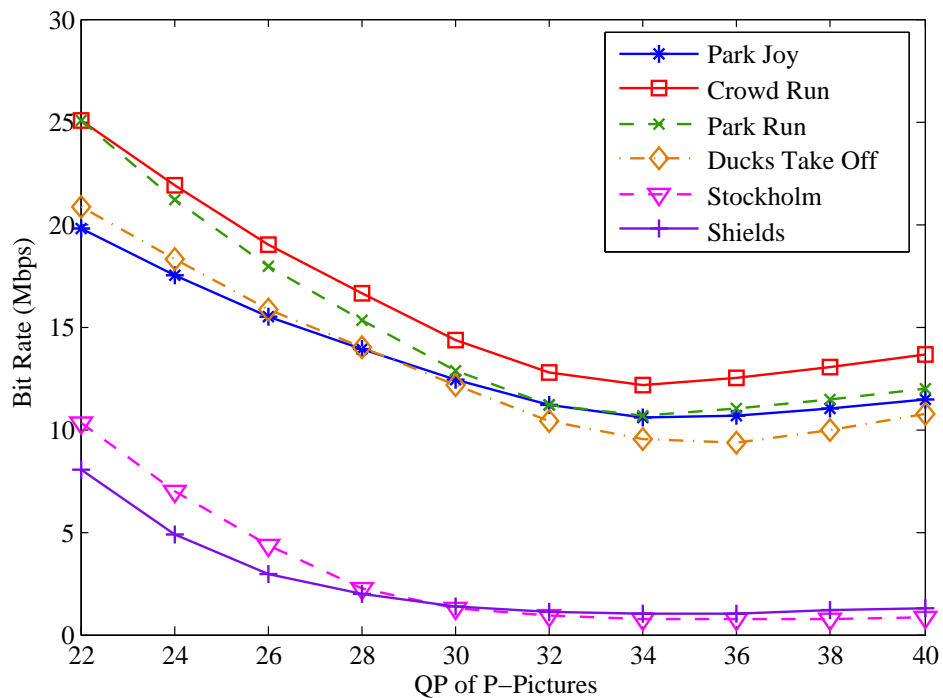

Figure 4.17: Bit rate at various QP of P-pictures. QP of I=30, QP of B=32

Figure 4.18: Y-PSNR at various QP of P-pictures. QP of I=30, QP of B=32
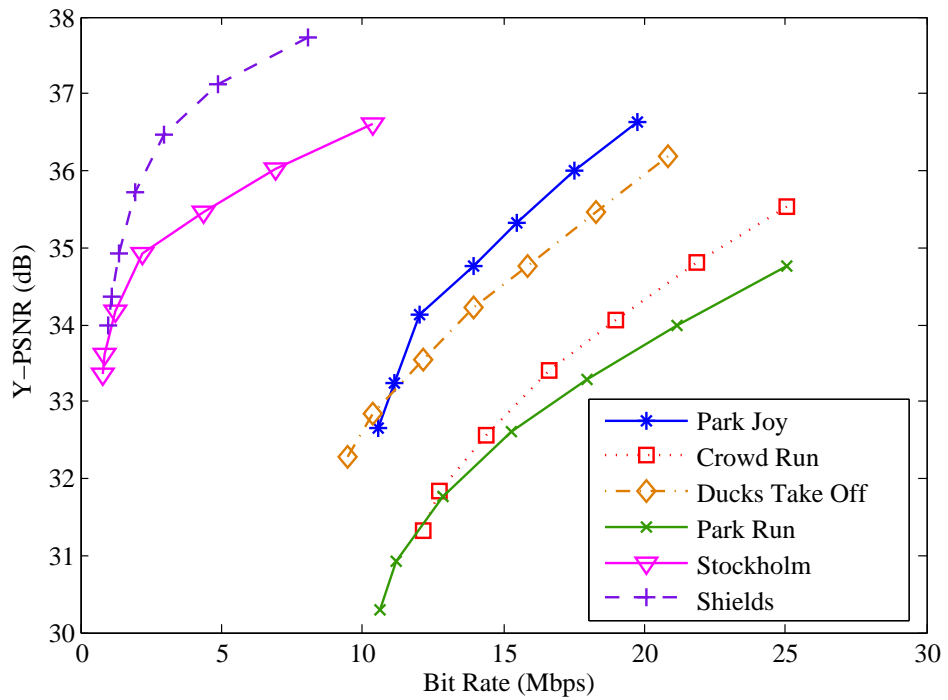
Figure 4.19: Performance of video sequences for QP of P-pictures, QP of I=30, QP of B=32

4.4.2.2   B-picture

Less number of bits is required for coding B-pictures, as it uses bi-directional pre-
diction. Hence, it is a convention to define large amount of B-pictures in GOP to
achieve high compression rates. Therefore, selection of QP of B-pictures is vital to
control overall bit rate. Figure 4.20 and 4.21 present the bit rate and the Y-PSNR
variation respectively for QP of B-pictures. Figure 4.20 shows that selecting QP
value for B-pictures bellow 28 increases the bit rate significantly. Therefore, QP
value for B-pictures for HD video transmission is proposed to be selected between
30 to 36 to have an acceptable video quality (above 30 dB PSNR) at reduced data
rate. Figure 4.22 presents the bit rate vs. Y-PSNR variation of video sequence for
QP of B-pictures.
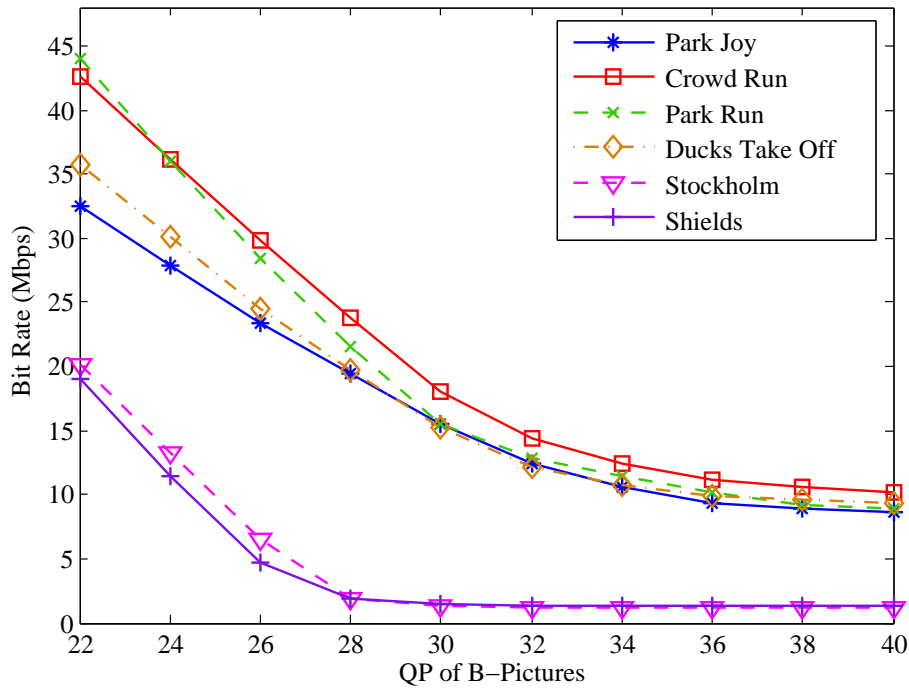
Figure 4.20: Bit rate at various QP of B-pictures. QP of I and P-pictures=30
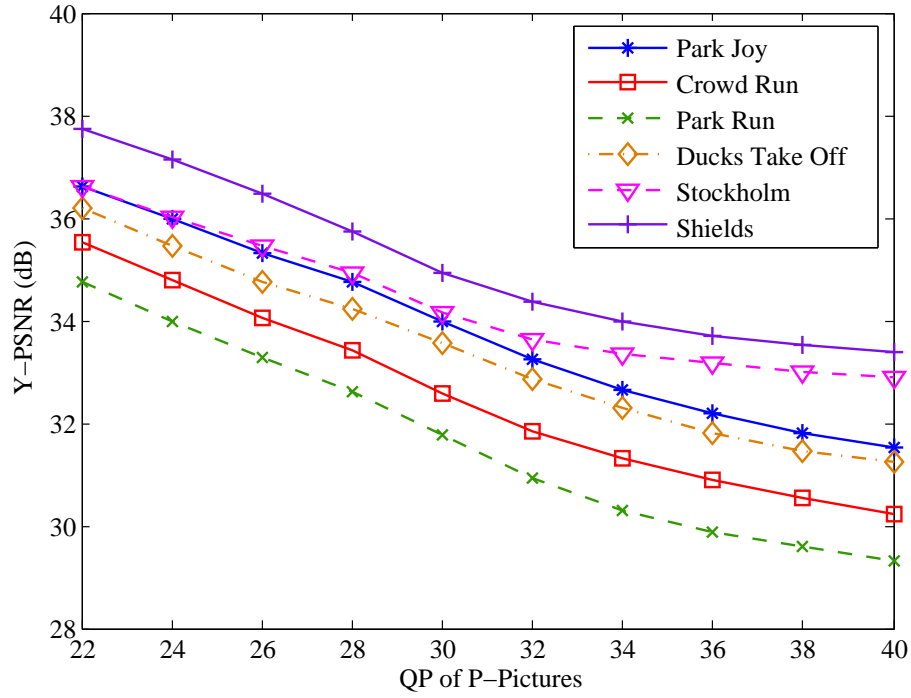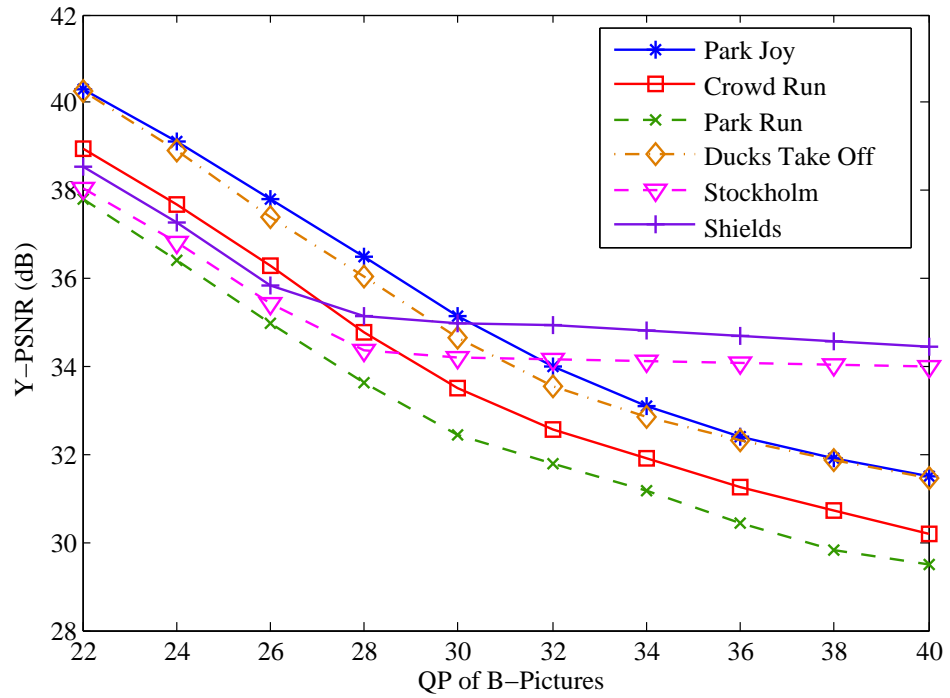
Figure 4.21: Y-PSNR at various QP of B-pictures. QP of I and P-pictures=30
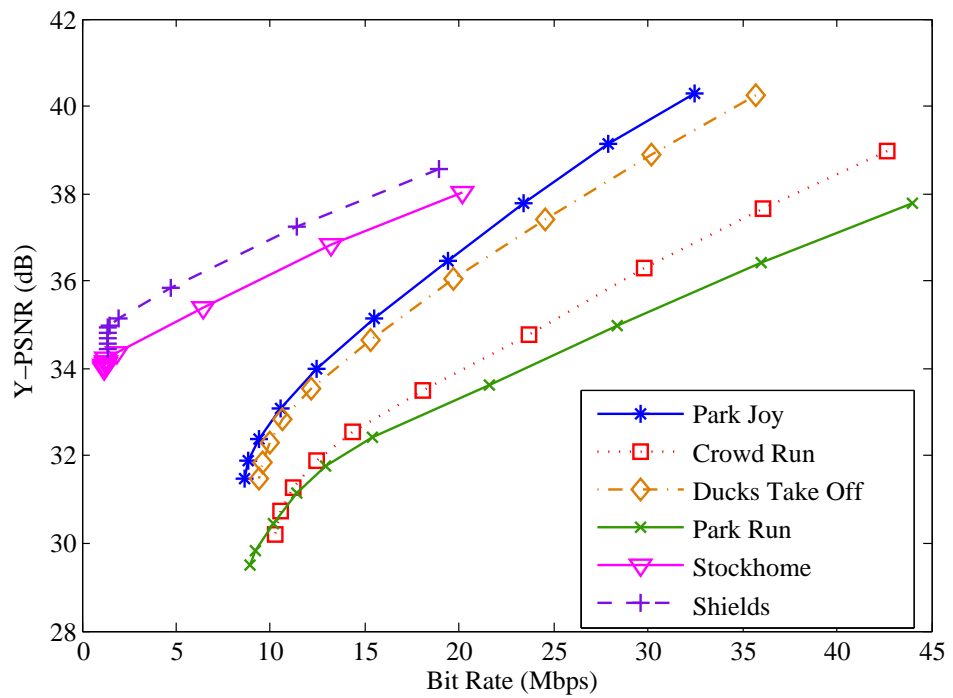
Figure 4.22: Performance of video sequences for QP of B-pictures, QP of I and P-pictures=30

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4.5   Proposed Encoder Parameters

Based on the results of extensive simulations, a set of key H.264/AVC encoder parameters is proposed to enhance HD video compression efficiency. Table 4.1 listed the proposed parameters settings. This generalized parameters settings are independent of video content and motion activities. Figure 4.23 presents the Y-PSNR of consecutive frames for all video sequences with the proposed generalized encoder parameters settings.

Table 4.1: PROPOSED PARAMETER SETTING FOR HD VIDEO

Parameter	Values
In-loop deblocking filter	Off
GOP length	16 (Structure: IBBPBBP....)
QP of I-picture	28-34
QP of P-picture	28-34
QP of B-picture	30-36

In Figure 4.23, only the first frame (frame 1) is intra predicted and the quantization parameter for this frame is selected to 30. The next two frames (frame 2 and 3) are used B-pictures during compression, and for these frames the QP is defined 32. The fourth frame (frame 4) used P-picture during encoding process and the QP for P-picture is selected to 30. The remaining sequence continues following the same pattern "BBPBBP...". Figure 4.23 shows that very smooth frame to frame Y-PSNR variation is obtained for two sequences, Shields and Stockholm. These two sequences are slow moving and have very few object movements. The less temporal variation

between neighbouring frames makes the prediction and reconstruction process more effective, and provides a smooth Y-PSNR variation between successive frames. The rest of the video sequences include large complex object movements. Therefore, different curve pattern is obtained for these sequences. However, for these sequences, the frame to frame variation of Y-PSNR is not significant, and the maximum Y-PSNR variation for conjugative frame is noticed 2 dB.
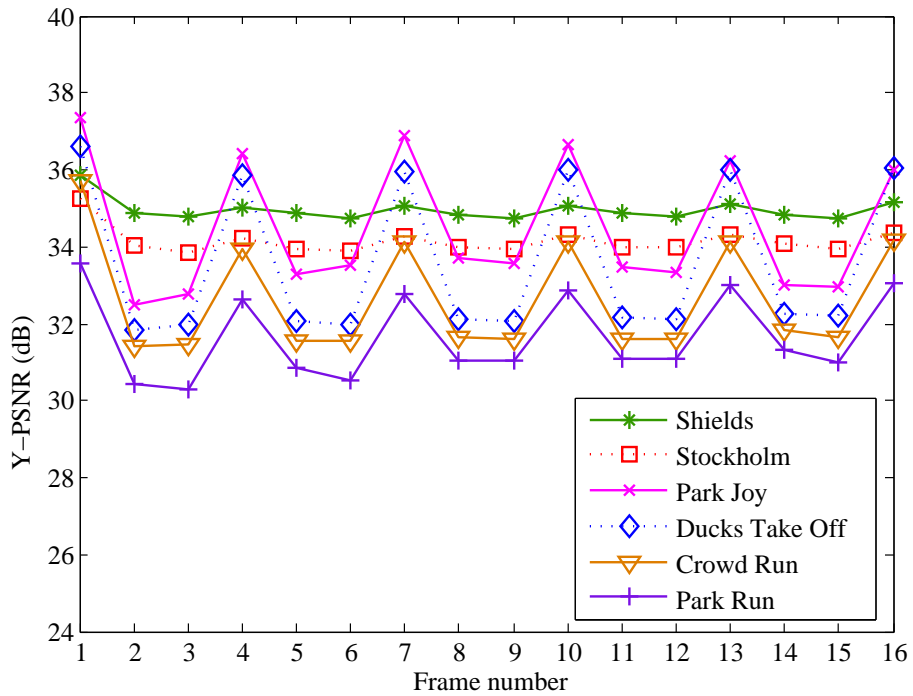
Figure 4.23: Y-PSNR for successive frames of video sequences

Due to the algorithm of prediction technique maximum error is expected to accumulate at the end frame of a GOP structure. Therefore, last frame of two decoded video sequences (Park Run and Crowd Run) is presented in Figure 4.24 and there are no visually noticeable artifacts or blurriness is observed in the images.

(a) Sequence: Park Run

(b) Sequence: Crowd Run

Figure 4.24: Last frames of decoded video sequences

An advanced version of H.264/AVC encoder parameters settings is proposed in Table 4.2 for fine tuning. These parameters settings are dependent on motion activities of video sequences, and specifically designed for the condition where the motion characteristic of the video sequence is known. Depending on the motion activities, the video sequences are categorized into three groups, and the parameters settings for individual group is demonstrated. These parameters settings can be applied to any HD advertisement displaying in shopping mall, any exhibition or conference.

Table 4.2: VIDEO CONTENT ORIENTED PARAMETER SETTING

Video sequence characteristics	Smooth and steady background motion, very few object movement	Random complicated object movements	Static background, large object movements
Video Sequences	Shields, Stockholm	Park Joy, Ducks Take Off	Crowd Run, Park Run
GOP length	Higher than 16	16, 8	Higher than 16
QP of I	28-34	28-34	30-34
QP of P	30-36	30-34	32-34
QP of B	30-36	30-34	28-34
Estimated bit rate	1.5-3 Mbps	10-12 Mbps	12-15 Mbps

4.6 Summary

In this chapter, some simulation results are presented and finally a list of generalized parameters settings for the H.264/AVC encoder is proposed to control bit rate of HD video sequences while maintaining acceptable video quality. An advanced set of H.264/AVC encoder parameters focusing on different motion activities of video sequences is also presented here. The next chapter presents the performance evaluation of these proposed parameters settings.

Chapter 5

Performance Evaluation

5.1   Introduction

This chapter presents the software prototype of the overall system and the performance evaluation of transmitted data. In previous chapter, a set of H.264/AVC encoder parameters is proposed for HD video transmission over the UWB communication channel. Prior to practical implementation of these parameters it is essential to perform software based performance assessment. Therefore, a software based transmitting and receiving system including the UWB channel, which is closely matches with the real indoor wireless environment, is used to assess the performance of the proposed parameters settings. The assessment results are also presented here.

5.2 UWB Channel Setup

The performance evaluation of the parameters is performed by using the UWB channel model developed by the IEEE 802.15.3a standardization group. As the goal of this research work is to provide an indoor wireless solution for home entertainment, the channel model CM3, which symbolize a NLOS channel up to 10 m distance is used to perform simulations. This channel model has 100 channel realizations [36]. The impulse response of the UWB channel used to conduct the simulations is given in Figure 5.1. The simulation is carried out considering ideal synchronization between transmitter and receiver. Quadrature Phase Shift Keying (QPSK) modulation [47] scheme is used and the noise environment is considered Additive White Gaussian Noise (AWGN) [48]. AWGN is a commonly accepted thermal noise model for communication channels, which uses in addition to multipath fading, interference and other noises. The noise is additive, and has flat and constant power spectral density and Gaussian distributed amplitude. The noise channel is linear and time invariant. Table 5.1 illustrates the simulation parameters for software performance assessment.

Table 5.1: SIMULATION MODEL SPECIFICATION

Modulation	QPSK
Synchronization	Ideal
Channel mode	CM3
Noise environment	AWGN
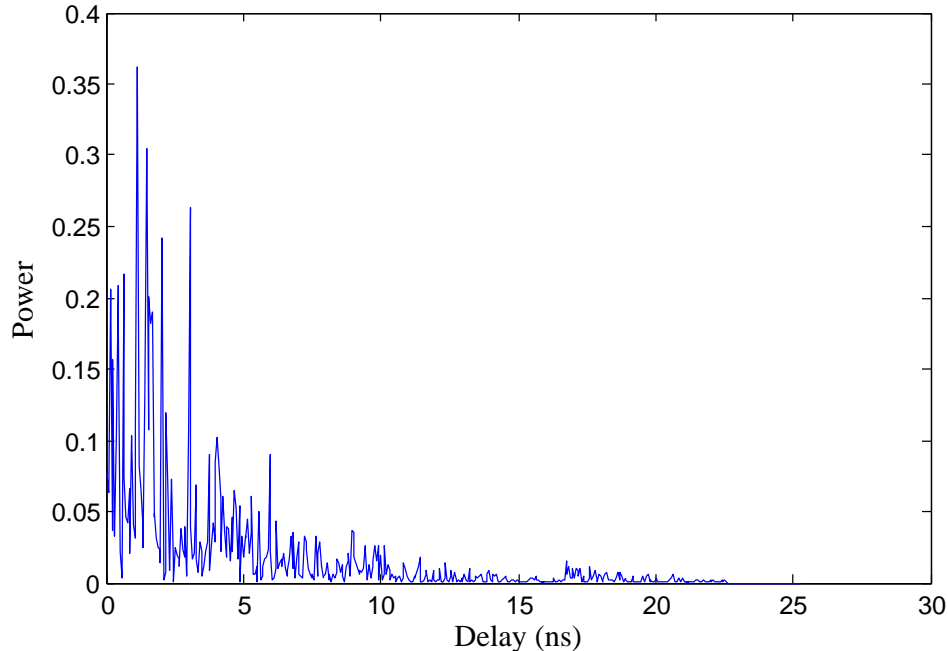
Figure 5.1: Impulse response realization of the channel

5.3 Simulation Results

All six video sequences are transmitted through the software based UWB communication channel. Due to the memory constrain of the computer used for conducting the experiments, maximum 16 encoded frames of two sequences, Shields and Stockholm, can be passed through the UWB channel. For other four sequences, the bit streams of 4 encoded frames are transmitted. The quantization parameter for I and P pictures are set to 30 and that of B-picture is set to 32. Simulation is conducted for different E_s/N_o, symbol energy to noise power density ratio, and the bit error rate is calculated. E_s/N_o [49] is an important parameter in data transmission when data are transmitted as symbol over the communication link. E_s/N_o is defined by equation 5.1.

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$$\frac{E_s}{N_0} = \frac{E_b}{N_0} \log_{10} M \qquad (5.1)$$

where, M is the number of alternative modulation symbols, E_s is energy per symbol, E_b is energy per bit and N_o is the noise power spectral density.

The bit error rate is the ratio of number of received binary bits that have been altered due to noise and interference, to the total number of transferred bits during a specified time period. For QPSK modulation scheme and AWGN channel, the BER is defined by equation 5.2.

$$BER = \frac{1}{2} erfc \frac{E_b}{N_0} \qquad (5.2)$$

where, E_b is energy per bit, N_o is the noise power spectral density and $erfc$ is the complementary error function and it is defined by equation 5.3.

$$erfc(z) = \frac{2}{\sqrt{\pi}} \int_z^\infty e^{-t^2} \, dt \qquad (5.3)$$

Table 5.2 presents the simulation results for six video sequences.

Table 5.2: SIMULATION RESULTS

Video Sequence	No. of encoded frame	Bits in encoded streams	E_s/N_o	No. of error bits	BER
Shields	16	1,003,544	14	37	3.686×10^{-5}
			15	2	1.992×10^{-6}
			16	1	9.962×10^{-7}
Stockholm	16	906,184	14	70	7.722×10^{-5}
			15	4	4.413×10^{-6}
			16	0	0
Park Joy	4	1,984,728	14	86	4.333×10^{-5}
			15	15	7.556×10^{-6}
			16	1	5.038×10^{-7}
Ducks Take Off	4	1,904,936	14	89	4.672×10^{-5}
			15	23	1.207×10^{-6}
			16	2	1.050×10^{-6}
Crowd Run	4	2,655,840	14	124	4.668×10^{-5}
			15	7	2.635×10^{-6}
			16	0	0
Park Run	4	2,835,776	14	157	5.536×10^{-5}
			15	34	1.199×10^{-5}
			16	8	2.821×10^{-8}

5.4 Analysis

When transmitting multimedia, i.e., graphics, audio, video, and hypertext, over an unreliable error-prone channel, several error resilience methods are used to control and reduce channel induced errors. As assessing the HD video transmission feasibility over the UWB communication channel is the main objective, only the encoded HD video streams are transmitted, and no error correction method is applied in this work. This rises the bit error rate, and introduces error in decoded video sequences. Table 5.2 shows that, for all sequences BER is above 10^{-5} for E_s/N_o above 15, which gives an allowable amount of bit error. The bit error amount can be further lessened by using error resilience methods. As the maximum transmitting power for the indoor UWB channel is limited by the FCC, an acceptable decoded video quality can be achieved after transmitting the video over the UWB channel as long as the E_s/N_o is greater than 15.

For an uncompressed HD video, bit errors in one frame only affect that frame. However, for the compressed video frames, where the coder uses inter-frame compression, the error occurred in one frame may propagate to other frames. In this work, due to memory constrain the simulation is limited to single group of pictures. Therefore, single error bit in the GOP causes the successive frames to be distorted. This problem can be controlled considerably by incorporating an advanced error correction scheme. Figure 5.2 shows the last frame of decoded video sequence (Stockholm), where there is no error bit in receiving data stream.

Figure 5.2: Last frame of decoded video sequence (Stockholm) with no bit error

Figure 5.3 presents a video frame, where error is occurred in intra predicted frame. This error affects the decoding process during the reconstruction of intra predicted frame, and continued to propagate through the rest of the macroblocks from the point of initiation. Afterwards, the error continues to propagate in succeeding inter predicted frames up to the end of GOP. In Figure 5.3, macroblocks with error are marked by white line.

Figure 5.3: Decoded sequences (Stockholm). Error in intra predicted frame

Figure 5.4 to Figure 5.7 present successive video frames of another sequence, where error is occurred in an inter predicted frame. It affects only the macroblocks where the error occurred and the succeeding dependent frames on that macroblocks. Figure 5.4 presents the starting frame of the GOP, and it is an intra predicted frame without any bit error. Figure 5.7 presents the inter predicted frame (P-picture) where bit errors occurred, and it is marked by white box. Figure 5.5 and Figure 5.6 are inter predicted frames (B-pictures) and it is dependent on Figure 5.4 and Figure 5.7 for reconstruction. Therefore, these two frames are affected by the error in Figure 5.7. The error macroblocks are marked by white lines.

Figure 5.4: First frame of decoded sequence, no error bit

Figure 5.5: Second frame of decoded sequence, error in inter predicted frame

Figure 5.6: Third frame of decoded sequence, error in inter predicted frame

Figure 5.7: Forth frame of decoded sequence, error in inter predicted frame

5.5　Summary

In this chapter, software based performance evaluation of HD video transmission over the UWB communication link using the proposed H.264/AVC encoder parameters is performed. For simulation, UWB channel model developed by the IEEE 802.15.3a standardization group is used, and CM3 indoor channel mode is used. The quality of the transmitted video sequence is satisfactory as long as the BER is low. The scenario, where the degradation of video quality due to the bit error is introduced by the channel, is also demonstrated in this chapter.

Chapter 6

Conclusion and Future Research

6.1 Summary of Accomplishments

For successful transmission of high-definition video over the UWB communication channel, in this work, at first, exploration of appropriate data compression scheme is performed. Literature review of different video coding standards, which supports HD video resolution, Motion-JPEG2000, MPEG-2, MPEG-4 Part 2, and H.264/AVC, is performed to choose an appropriate coding scheme depending on their features and compression efficiency. The H.264/AVC standard outperforms rest of the coding standards. Therefore, this video coding scheme is chosen in this work.

After the selection of H.264/AVC coding scheme, an exploration of the H.264/AVC encoder features is carried out. This results, summarization of some encoder features, which have greater control over the encoded bit rate and the decoded video quality. Theses, encoder features are: the in-loop deblocking filter, which is used to reduce

blocking artifacts in the decoded video and thereby improves the visual quality; the group of pictures length, which contributes both in data compression and quality enhancement; the quantization parameter of I, P and B pictures, the most vital parameters to manage the bit rate and the decoded video quality.

Simulation is carried out by using JM 15.1 software to find out optimum settings of the encoder parameters - the in-loop deblocking filter, the group of pictures length, the quantization parameter of I, P and B pictures. Finally, a parameter setting for the H264/AVC encoder is proposed for transmitting HD video over the UWB communication link for indoor applications. The encoder parameters are investigated for:

- general setting, which supports both fast and slow motion video and independent of video content.

- video content dependent setting, which allows fine tuning and higher perceive video quality.

The proposed generalized H.264/AVC encoder parameters settings for HD video is targeted for movies, satellite broadcasting, live video telecasting, and other real time applications, such as, recoding and displaying video at the same time using HD video camcoder, where the video includes complex motion activities and color texture. However, the video content dependent H.264/AVC encoder setting is designed for prerecorded video, where the motion characteristic of the video is known. These

HD video content dependent setting can be applied for fine tuning any advertisement displaying in several spots in a commercial place like shopping mall, business conference, any commercial or informative video displaying again and again in a social program or public gathering.

Finally, a software based performance evaluation of theses proposed parameters settings is performed. For performance assessment, "UWB Fixed-Point Model (Multiband OFDM)" Simulink model based on IEEE802.15.3a multiband OFDM proposal is used. The results are quite satisfactory as long as the symbol energy to noise power density ratio, E_s/N_o, is above 15. Six standard HD video sequences, with different motion characteristics are used to perform all the simulations. With the proposed parameters settings, maximum 20 Mbps data rate is achieved at 33.5 dB Y-PSNR.

6.2   Future Research

In this section, some recommendations for future work as an expansion of this research work are presented. These recommendations are beyond the scope of this thesis work, and left for the researchers who wish to continue the exploration. The recommendations are as follows:

- This thesis work is limited to using 720p resolution HD video, which uses progressive scanning. In future, the proposed parameter settings can be applied

to higher resolution HD videos, such as, 1080p (1920×1080) and 1080i, both for progressive and interlace scanning to observe their performance.

- In this thesis UWB communication channel is used as wireless transmitting link. In future, other wireless technologies, such as, the Wireless Home Digital Interface (WHDI), the WirelessHD, and the IEEE802.11n, can be studied to evaluate their performance as HD video transmitting medium.

- For performance assessment of the proposed parameters, in this work, CM3 UWB channel mode, which resemble NLOS indoor scenario with 4 m to 10 m transmitting distance, is used and a few channel responses are selected for simulation. Therefore, there is plenty of scope to extend this work by exploring other channel mode (CM1, CM2 and CM4) using all 100 channel responses and thereby obtaining a comprehensive result.

- Finally, hardware implementation of the entire transmitting and receiving system can be done by using Hardware Description Language (HDL). Afterward, this HDL code can be synthesized on a Field Programmable Gate Array (FPGA) board, and using the UWB transmitter and receiver HD video can be broadcasted over the UWB communication channel. The experiments for practical HD video transmission over the UWB channel can be conducted for different indoor arrangements, LOS and NLOS, and for different transmitting and receiving distance.

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