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REGULAR ARTICLE

Assessment of Optimization Parameters for Video Transmission over Optical Fiber using an H265/HEVC Encoder in Video Streaming Applications

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In this research, we investigated and analyzed the performance of an optical video transmission system. We combined the benefits of HEVC compression techniques and OTDM multiplexing using the Differential Phase Shift Keying (DPSK) scheme. Source and channel coding are separately designed and then cascaded. The intra-prediction module used in HEVC encoder has been implemented using the Matlab tool to show its ability to select the coding prediction threshold and block size using all prediction unit sizes and modes (PUs). The obtained results have been implemented for the second contribution concerning the proposed fiber transmission system using the OptiSystem software. To evaluate the proposed system, several metrics were used, including the signal-to-noise ratio (SNR), Q-factor, and bit error rate (BER). The simulation results show that the optimization criterion led to better performance in terms of transmission quality, in improving Q-factor and minimizing (BER), thus providing a significant resolution reduction of the video stream, which reduces the amount of data before being transmitted on the optical fiber.

Keywords: HEVC, Intra-prediction, Video transmission, PUs, Q, SNR**.**

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1. INTRODUCTION

Attempting to maximize the effective transmission and routing of video data from source to destination, current researchers are thoroughly examining video properties across various networks, necessitating the use of a suitable transport protocol [1-3]. Each network path comprises a series of links, each with its own bandwidth, but other factors also influence network performance. Therefore, it is crucial to minimize error rates in channels by designing a suitable transmission method that allows specific handling of losses between connections on wired and wireless networks, notably compression, which is a viable aspect of video communication.

The HEVC video standard was developed to achieve better compression performance than previous standards, with a potential bit rate reduction of up to 50% for equal perceptual video quality. Thus, the use of HEVC is crucial in video compression as it is well-suited for network transmission. The migration to optical fiber has required several developments as it now represents the most widely used transmission medium in various fields, especially video transmission [4].

Many sectors are increasingly demanding higher video quality and coding efficiency. The compression capabilities of H.264 are no longer sufficient for high-quality video compression [5]. Hence, the emergence of real-time H.265/HEVC coding in 2013 aimed to offer significant compression and performance improvements over previous standards [6-7].

Some researchers have proposed methods based on gradient analysis to reduce the number of candidate prediction modes, thus reducing coding time while maintaining high coding efficiency [8-9]. Others have suggested using edge-related information to reduce computational complexity by decreasing irrelevant prediction modes [10-13]. Furthermore, enhancing the visual quality of intra-frame and inter-frame coded videos has been proposed by improving selective paths in the HEVC coding tree and applying adaptive filtering techniques to each selected path to enhance its quality [14].

Moreover, several studies have shown that combining multiple modulated optical signals into a single optical fiber using OTDM time division multiplexing and differential phase shift keying (DPSK) ensures that the transmitted video covers the greatest distance, minimizing bit error issues and optimizing bandwidth usage [15].

It is noted that in the above works, different approaches, methods, and techniques are used depending on the desired application. In this article, as the first

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part of this work, we present a simulation of the intra-prediction module used in the H.265/HEVC video encoder. This module was implemented using Matlab to demonstrate its ability to select the prediction threshold and optimal block size using all prediction unit (PU) sizes and modes. Several metrics, including peak signal-to-noise ratio (PSNR) and bit rate, are used to evaluate the proposed implementations.

The design and simulation of a new optical system, specifically for transmitting video data streams from the HEVC encoder with the application of these characteristics to maximize bandwidth, were the focus of the second part of this study. Raw video sequences (YUV), transformed into bit streams as data files, were used to create and transmit a video stream. High-level simulation software was used to realize a transmission system based on optical fiber. Both steps (video coding and the transmission system) were carried out independently in simulation mode, and a direct connection between the two simulation environments was attempted using video encoded according to the HEVC standard and several optical connections (with different characteristics).

The paper is organized into four sections as follows:

Section II provides a description of the intra-prediction mode utilized in HEVC encoders, along with detailed explanations of various levels and parameters, as well as the conception steps of OTDM transmission architecture, employing high-level simulation software (OptiSystem software).

In Section III, simulation results are presented and discussed utilizing the data stream generated in Section II. Finally, Section IV encompasses conclusions drawn from the findings and outlines avenues for future research.

2. EXPLORATION OF HEVC ENCODER SETTINGS AND FACTORS FOR SOURCE CODING OPTIMIZATION

The HEVC standard consists of several blocks, Fig.1 Indeed; digital video is characterized and distinguished primarily by its spatial resolution (intra-frame) and temporal resolution (interframe) [16].

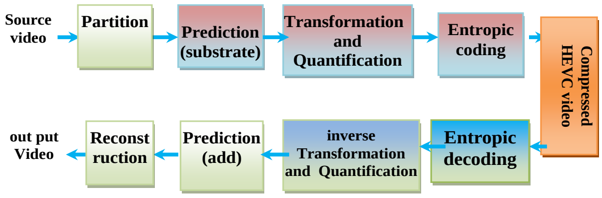
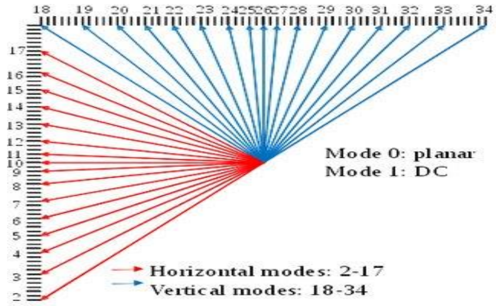


Fig. 1– Block diagram of the H.265/HEVC hybrid codec [16]

The case of video encoders in Intra mode is the main emphasis of this section. With the latter, the video encoder is able to compress each frame separately from the previous frames without using any temporal prediction while looking for the best mode, or the direction with the least block change.

2.1 Theoretical Foundations of Intra-prediction in HEVC and the Proposed Approach

Intra-prediction, in HEVC, is an extension of that in H.264/AVC since both are sample-based spatial predictions [17]. The addition of more concurrent intra-predictors is one of the new standard's enhancements, though. In fact, HEVC has 35 intra-prediction options in total, compared to 9 in H.264, Fig.2. HEVC's intra-prediction modes are divided into 33 spatial directions, a DC (reference pixel average) predictor, and a new predictor called Planar [18].



a) *List of intra predictors for HEVC*

Intra-prediction mode number	Associated name
0	INTRA_PLANAR
1	INTRA_DC
2 . . . 34	INTRA_ANGULAR[i], i=2 . . . 34

b) *The associated name*

Fig. 2 – The relationship between intra predictor mode number and its associated name [17-18]

To improve the intra-coding efficiency, HEVC uses a flexible structure of coding units such as prediction units (PUs) defined with sizes ranging from 4 × 4 to 64 × 64 and many prediction modes [19]. The HEVC intra-prediction algorithm predicts the pixels in the prediction blocks (PBs) of a coding block (CB), using the reconstructed pixels in the available neighboring PBs. There are respectively 33 directional prediction modes which make it possible to improve the prediction but which are difficult to calculate, and 2 non-directional DC and PLANAR modes which are used to predict the homogeneous content area.

One of the open-source databases containing video footage is (UVG: Ultra Video Group), but it's not the only one; there are many more with Full HD (1920 × 1080) or 4K (3840 × 2160) video material as well. The videos that make up the dataset may be divided into two distinct categories: Datasets including slow-motion, complex or smooth-textured, low- or high contrast video sequences; datasets containing fast-motion, low- or high-contrast, and complex or smooth-textured, video sequences. In the present work, five sequences with FHD resolution and 16:9 aspect ratio with 30 frames per second were used. Fig. 3 illustrated the five sequences.

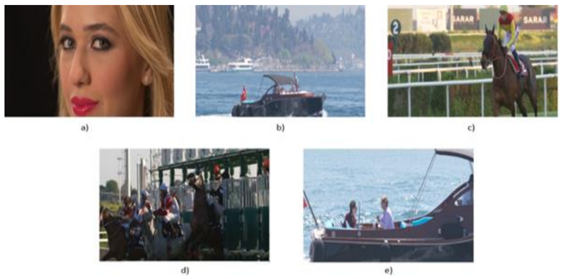


Fig. 3 – Input sequences used: a) Beauty b) Bosphorus c) Jockey d) ReadySteadyGo e) YatchRide

All PU sizes and prediction modes are considered in the proposed study, which is executed using an intra-prediction model using Matlab. The input consists of 1080p (FHD) raw video files that were captured in the YUV format. The approach suggested applies YUV video as input and extracts intra-frames at the conclusion. As a result, the procedure entails playing an RGB color video while also converting it to YCbCr by downsampling it (4:4:4 to 4:2:0) to use less bits. Intra-frame processing is carried out following the division of the blocks into the frame. The intra-frame block is divided into various sizes and processed directly using the standard process in the forward channel of the HEVC encoder. The processed block is then rebuilt using the standard reverse process in the reconstruction channel of the HEVC encoder. Apply each sub-block to all prediction modes, then quantize and adjust the data before encoding it with a context adaptive variable length coder (CAVLC) to produce a compressed bit. Perform a reverse operation in the reconstruction route at the HEVC encoder to acquire a reconstructed picture, and then measure the quality of the image.

The suggested intra-prediction technique is shown in Fig.4. With a 30 frame per second input rate, YUV video is preprocessed by being transformed to RGB and scaled. The generated pictures are then quantized, transformed, and separated into blocks of various sizes, including 4×4, 8×8, 16×16, and 32×32 matrices During intra-prediction, order selection is required so the predicted images are then reordered and a predicted output is obtained.

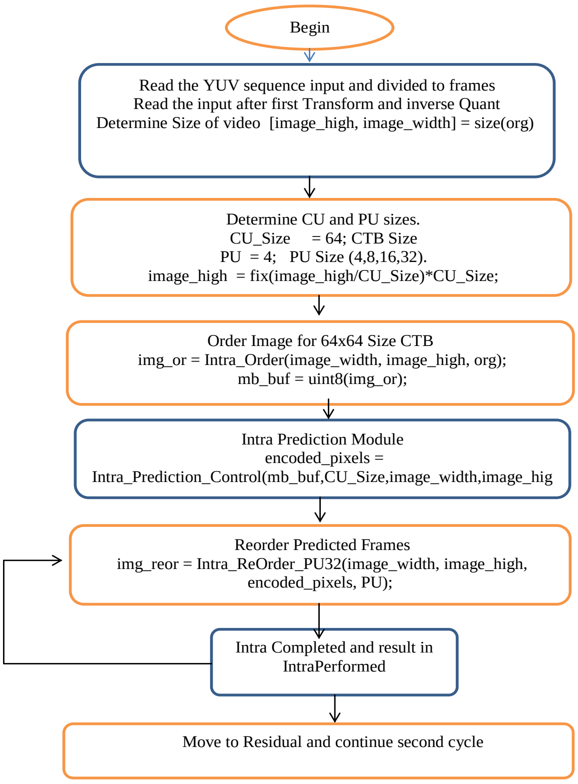


Fig. 4 – Intra-prediction flow diagram for all PU sizes

2.2 Proposed System Architecture for Video Transmission Combining OTDM-DPSK

Figures 5 and 6 depict the architecture of the proposed system under OptiSystem. The YUV video is used as input with a frame rate of 30 frames per second, then it is pre-processed, decomposed into its corresponding images, and only one image is processed at a time. Once converted into bits and saved as a data file (.dat), it is transmitted to the optical transmitter. The signal first passes through a DPSK modulator, then through an OTDM multiplexer, which together maintain the data streams at low rates. On the receiver side, an OTDM demultiplexer reconstructs the data stream which is then demodulated by DPSK. For each user, the bit sequence corresponding to the compressed video file is loaded into a pseudorandom bit sequence generator (PRBS). The non-return-to-zero (NRZ) electrical signal at the output of the PRBS directly modulates a continuous wave (CW) laser diode emitting a wavelength of 193.1 THz, which is an effective way to obtain a well-defined bandwidth and is generally preferable for long distances and high data rates (> 10 Gbps). By integrating the advantages of the DPSK-OTDM system, our implementation facilitates video transmission, achieving optimal bit rates while effectively utilizing bandwidth in various video applications. Through simulations, we successfully validate the efficiency of this system by transmitting and receiving video sequences via the optical channel. Performance evaluation of the system includes Q-factor analysis and assessment of binary error rate (BER) statistics, demonstrating its robustness in variable optical channel conditions.

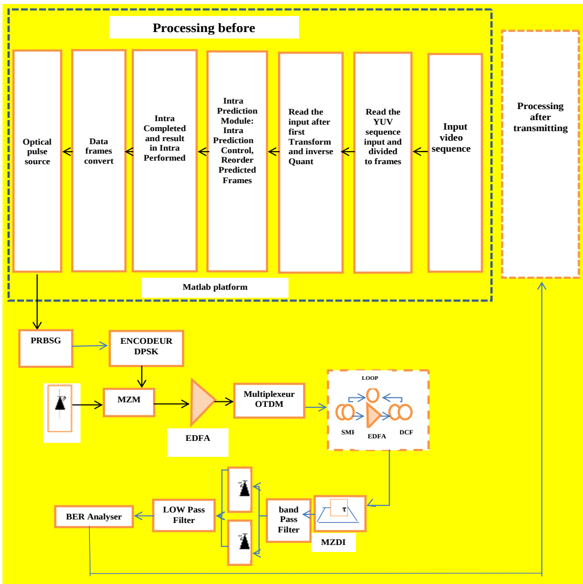


Fig. 5 – Proposed model for optical video transmission system

3. RESULT AND DISCUSSES

A co-simulation approach is utilized, employing OptiSystem and Matlab. OptiSystem manages optical transmission, while Matlab handles simulation execution, analysis, processing, and result presentation. The notion of joint optimization of optical link parameters and codec parameters (prediction, error resistance tools)

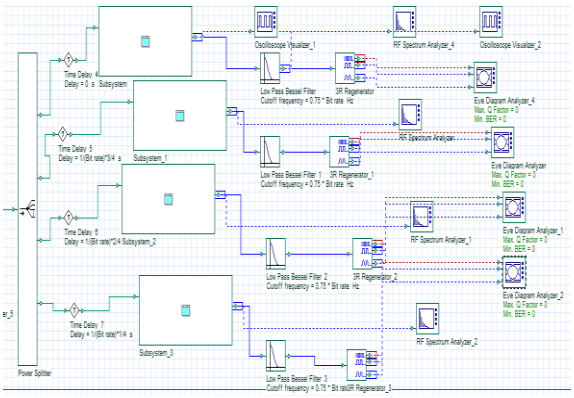


Fig. 6 – Schematic of OTDM Optical Link in Optisystem

has been explored based on the maximum signal-to-noise ratio (PSNR) as an objective measure of video quality, The Bit Error Rate (BER) and the Quality Factor (Q-factor) as the main parameters to define the quality of the optical link.

3.1 Simulation Result of the Intra-prediction Module used HEVC

The simulation was run on a variety of video sequences with various spatial and temporal encodings in order to demonstrate the viability of the suggested methodology. Table 1 displays the various resolutions, scenes, and motion characteristics of these test sequences. The tests performed were done to compare different results and determine which of them gives the most relevant results. The proposed simulation is evaluated against different metrics, namely signal-to noise ratio (SNR), PSNR and bit rate. The 35 prediction mode outputs, comprising DC, planar, and 33 directional modes, are compared in table1. The following formula (1) is used to compute the output's compression ratio:

$$\text{Compression ratio} = \frac{(\text{Input size} - \text{Compressed size})}{\text{Input size}} \quad (1)$$

Table 1– Different compression rates, PSNR and SNR values for Bosphorus video sequence

MODE	Compressed size	Compression Ratio	PSNR (dB)	SNR (dB)
DC	814	-----	22.2755	16.6135
Planar	74,7	90.24	22.3969	18.7382
Mode 1	151	80.28	22.4075	18.7322
Mode 2	139	94.90	22.3963	18.7230
Mode3	125	83.68	22.4197	18.7456
Mode4	123	83.94	22.4164	18.7428
Mode5	125	83.68	22.4141	18.7443
Mode6	110	85.63	22.3989	18.7260
Mode7	111	85.50	22.3869	18.7203
Mode8	110	85.63	22.3947	18.7299
Mode9	110	85.63	22.4290	18.7628
Mode10	351	54.17	22.1072	17.2790
Mode11	329	57.04	22.4766	18.0906
Mode12	870	------	21.9884	17.4275
Mode13	605	21.01	22.3994	18.3868
Mode14	799	-------	22.2832	18.3275
Mode15	535	30.15	22.3761	18.5336
Mode16	754	1.56	22.3071	18.3670
Mode17	149	80.54	22.4401	18.7500
Mode18	752	1.82	22.3418	18.3900
Mode19	530	30.80	22.4171	18.5557
Mode20	797	------	22.3085	18.3338
Mode21	605	21.01	22.4555	18.4218
Mode22	869	-------	22.0126	17.4282
Mode23	329	57.04	22.4984	18.0890
Mode24	351	54.17	22.1124	17.2600
Mode25	78,2	89.79	22.3951	18.7051
Mode26	78,6	89.71	22.3782	18.6897
Mode27	79,0	89.68	22.3746	18.6849
Mode28	70,0	90.86	22.3949	18.6991
Mode29	78,5	89.75	22.4250	18.7323
Mode30	74,7	90.24	22.4015	18.7057
Mode31	75,9	90.09	22.4578	18.7617
Mode32	84,3	88.99	22.4157	18.7213
Mode33	87,8	88.53	22.4128	18.7169
Average compression ratios	59,31			
Average SNR	18,4010			
Average PSNR	22,3575			

Examples of findings that make use of intra-prediction processing are provided in order to assess how they affect the various sequences and the previously indicated qualities. - In static sequences such as Beauty, the average compression ratio is 72.54, the PSNR is 21.4668 dB and the SNR is 11.1340 dB. - In sequences where there is a fast movement on a static background such as Jockey, the average compression ratio is 64.78, the PSNR is 22.2037 dB and the SNR is 13.8171 dB, And for fast movement of multiple objects on a static background like ReadySteadyGo, the average compression ratio is 62.74; PSNR is 21.9087 dB and SNR is 17.4750 dB. As a result, residual predictors can enhance the quality of the image by reducing the quantity of redundant information in the signal. It is clear that less complexity results in easier calculation. Figures 7, 8 and 9 show the complete values of PSNR, SNR and compression ratio respectively for the 35 modes and for the five video sequences used. It can be seen that after the 10th mode, the PSNR, SNR and compression ratio degrade and after the 27th mode, they return to their maximum.

The simulation results show that the proposed algorithm can improve the PSNR and reduce the bit rate of 1080p sequences compared to the state-of-the-art fast intra-prediction decision algorithms (average compression ratio of 64.468%, average PSNR of 21.9842% and an average SNR of 15.2068 dB). By comparing high-resolution video sequences with lower resolutions, it can be concluded that these sequences have higher PSNR values, reduced throughput and considerable SNR gain.

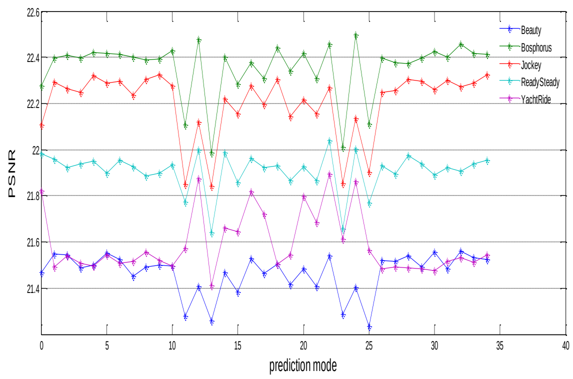


Fig. 7 – PSNR for 35 Intra-prediction modes

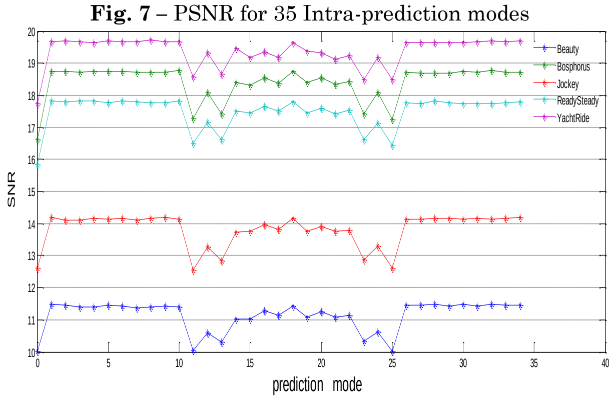


Fig. 8– SNR for 35 Intra-prediction modes

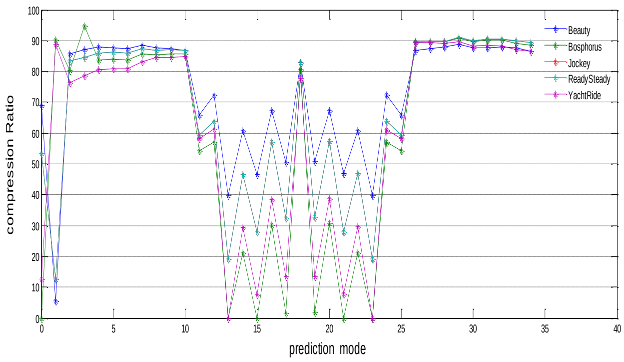


Fig. 9 – Compression ratio for 35 Intra-prediction modes

The simulation results show that the accuracy and efficiency of the proposed intra prediction algorithm is increased in terms of compression ratio in YUV files, compared to the already existing results [18] whose simulation was done on YUV videos of resolution 352 × 256 and 704 × 128 as input data, and resulted in an average compression ratio of 15.3% that seems too low and reached double that of the previous case or It is established at 37.93% for the resolution of 704 × 128. As a result, the average compression ratio increased by 22.6%, while for the 1080p footage, the average compression ratio increased by 49.16%. This leads us to agree with [19] that enhancing the intra-prediction block's input quality can enhance the intra-prediction output as a whole, enabling higher resolution pictures to provide superior intra-prediction output. The simulation results showed that one of the techniques offered by the HEVC encoder to optimize bandwidth while maintaining better video quality is the intra HEVC prediction algorithm used for YUV (1920×1080) video resolutions to achieve more clarity in the compressed images to be transmitted. This can give the possibility of real time coding when combined with architectural, software and algorithmic optimizations in video transmissions over long distances with different means such as optical fiber. Processing can also be done by implementing HEVC in the FPGA and Simulink block.

3.2 Overall Performance Evaluation of OTDM Transmission for Video Sequences

In this part, bit streams file of the Bosphorus sequence encoded using HEVC is used as an input to the optical transmission system. The video is compressed and quantized using the Matlab software to generate the bit Stream. In this simulation we have employed OTDM-DPSK(NRZ) modulation, once the optimization of the injected power, the optimal distance verified and the comparison of the two schemes is done, the following parameters are maintained for the rest of the simulation: OTDM -DPSK-NRZ system, CW laser power = – 19 dB and a distance of 60 km. In the following, the transmission analysis of different videos is presented where the role of the intra-prediction of the coded video in the optimization is shown. The theoretical communication error probability can be calculated from the signal-to-noise ratio (SNR) [22]. There is an inverse relationship between the (SNR) and the (BER).

It can be seen that for:

– Static such as the Beauty sequence. The BER is high for a low SNR.

– Sequences where there is a fast movement on a static background like Jockey as long as the SNR increases the BER decreases.

– a fast movement of several objects on a static background like ReadySteadyGo, it is important to mention that the BER traces are very close.

So for dynamic sequences, the higher the SNR, the lower the graph will be, indicating a lower bit error rate.

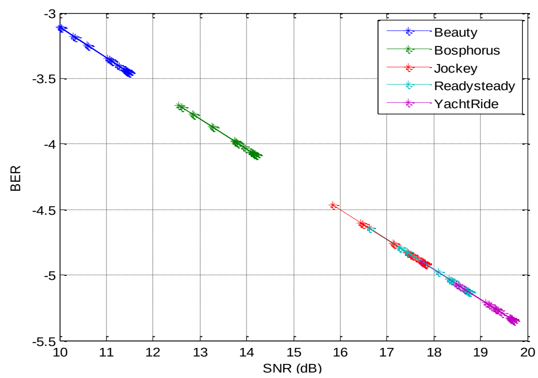


Fig. 10 – BER vs SNR curve for different video scenes

The findings obtained in accordance with Fig.11 corroborate those obtained before since, the lowest binary error rate is achieved for intra-prediction modes lower than the 10th mode and for modes higher than the 27th mode.

In addition, taking into account the performance criteria of the transmission system such as distance, rate, modulation, bandwidth, etc. We studied the impact of the bandwidth of the Bessel filter added in cascade at

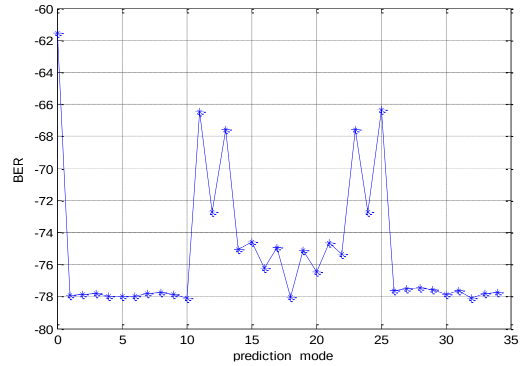


Fig. 11 – BER vs Intra-prediction mode curve for Bosphorus video scene

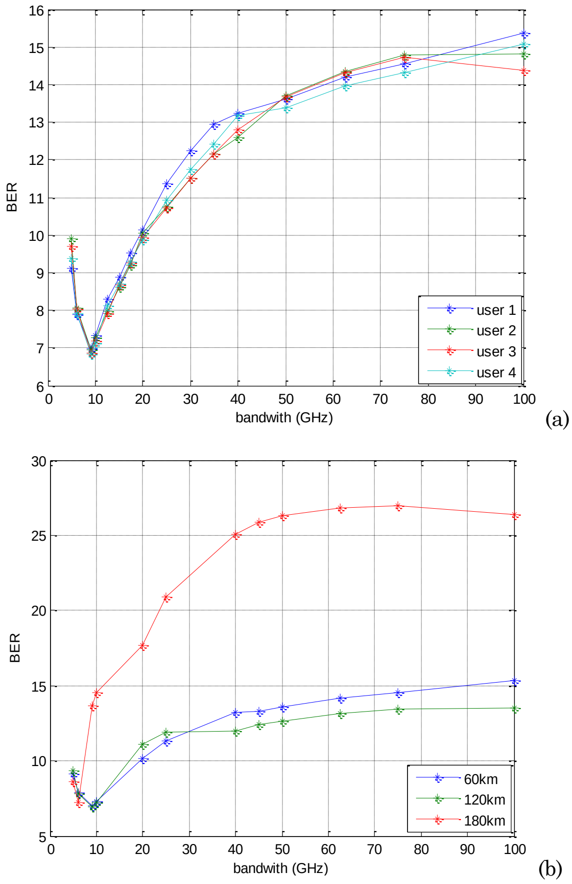


Fig. 12 – BER as a function of filter bandwidth: (a) For different users; (b) For one user for different distances

the receiver on the quality of the received signal. This optical filter is used to reduce the effects of dispersion and time distortion of optical signals transmitted. The BER curve as a function of the bandwidth for different lengths of fiber (60, 120, 180 km), show that for a bandwidth ranging from 5 GHz to 20 GHz we get the best bit error rate (BER). It is also observed that by increasing or decreasing the bandwidth, the quality of transmission degrades beyond these values. However, for the performance of OTDM-DPSK modulation shown in Fig.12, the threshold is respected for dynamic video transmission, 9 dB for 60 km. Fig.12 (a) shows that the bandwidth from 5 GHz to 20 GHz for each user, the DPSK system, enables an effective BER.

Therefore, the BER drops over this frequency range, increasing symbol interference and degrading the link's performance. Higher frequencies do not filter the influence of non-linear effects between channels, while lower frequencies are not suited for passing 30Gbps data speeds. To maximize the quality of the received video, it is crucial to select a suitable bandwidth for the optical Bessel filter. The bandwidth must be both large enough to accommodate all of the video's necessary frequencies and small enough to reduce distortion.

4. CONCLUSIONS

In this work, the performance of an optical video transmission system was studied and analyzed. The advantages of HEVC compression techniques and OTDM multiplexing using the Differential Phase Shift Keying (DPSK) scheme were combined. The source and channel coding are designed separately and then cascaded. Specifically, the simulation was first performed with different intra-prediction modes, the use of which allows for acceptable video quality to be received in modes with higher BER, thus extending the distance for acceptable video transmission quality. Indeed, the use of different modes in different scenes reduces the amount of information which allows the decoder to better reconstruct the altered parts of the image from unaltered blocks. Furthermore, for the performance of the OTDM-DPSK system and for the optimization of the bandwidth exploitation, it seems better with a fiber length of 60 km to 180 km and for a minimum power of – 19 dBm with the NRZ modulation format. However, video compression can be used to reduce the amount of data transmitted over the fiber [20], which could improve the 17 efficiency of optical transmission by reducing network congestion. This improves the efficiency of video transmission over the network and allows more users to share the available bandwidth. In the further work, it is aimed to use machine learning techniques to develop the compression tool such a new intra-prediction mode that will replace or simply complement the conventional intra-prediction, which still fits into the hybrid block-based architecture that is used in many existing video codecs.

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Оцінка параметрів оптимізації для передачі відео через оптичне волокно з використанням кодера H265/HEVC у програмах потокового відео

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У цій роботі були проведені дослідження та проаналізовані продуктивність оптичної системи передачі відео. Були поєднані переваги методів стиснення HEVC і мультиплексування OTDM за допомогою схеми диференційної фазової маніпуляції (DPSK). Кодування джерела та каналу розробляються окремо, а потім каскадуються. Модуль внутрішнього передбачення, який використовується в кодувальнику HEVC, було реалізовано за допомогою інструменту Matlab, щоб продемонструвати його здатність вибирати поріг передбачення кодування та розмір блоку з використанням усіх розмірів і режимів блоку передбачення (PU). Отримані результати були реалізовані для другого внеску щодо запропонованої волоконної системи передачі з використанням програмного забезпечення OptiSystem. Для оцінки запропонованої системи було використано кілька показників, включаючи відношення сигнал/шум (SNR), Q-фактор і частоту бітових помилок (BER). Результати моделювання показують, що критерій оптимізації призвів до кращої продуктивності з точки зору якості передачі, у покращенні Q-фактора та мінімізації (BER), таким чином забезпечуючи значне зниження роздільної здатності відеопотоку, що зменшує кількість даних перед передачею на оптичне волокно.

Ключові слова: HEVC, Внутрішнє прогнозування, Передача відео, PUs, Q, SNR.