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Towards Efficient and Reliable Video Communication: A Survey on Scalability, Error Protection, and Multicasting

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Abstract

Efficient and reliable video communication is required to maintain high-quality and uninterrupted streaming in order to minimize bandwidth usage and to tackle network variability. Scalable Video Coding (SVC) introduces efficiency for video communication by introducing a base layer and a set of enhancement layers, while Unequal Error Protection (UEP) can provide high protection to important layers while having low redundancy for less important layers/bits/frames. Moreover, scalable video transmission's efficiency can be further improved by multicasting a video to multiple recipients simultaneously over a network efficiently, where each user can adapt to network conditions. As existing surveys do not concentrate on discussing the improving efficiency and reliability of video communication by multicasting scalable video communication focusing on UEP, we review these factors individually and in combination. We first gathered 113 original research studies using qualification criteria searched using electronic libraries, leveraging an elaborative process. As per the review, video scalability has been achieved using temporal scalability, spatial scalability with spatial resolution, quality scalability using quantization steps, and slice grouping for region of interest scalability, while UEP is achieved using transceiver, packet level, bit level, and cross-layer methods. Moreover, simulcast, multiple access techniques, multi-resolution modulation, and antenna heterogeneity have shown to be the promising SVC multicasting techniques. Review analysis shows that from reviewed work, 10.3% provide H.265-based scalability, 19.2% use transceiver UEP, and 7.7% use simulcast. Finally, we conclude our review by discussing the advantages and challenges of the concept of SVC-UEP video communication and then presenting guidance to overcome them.

A. Introduction

In the modern world, video communication has become one of the critical elements of day-to-day life, as it enables real-time, face-to-face interactions across distances, enhancing connectivity, collaboration, and access to information in both personal and professional contexts [1]. However, if raw video frames are transmitted, it demands a huge communication bandwidth, which may be infeasible to be supplied for very high-resolution videos like ultra-high definition [2]. Therefore, in order to improve the efficiency, video encoding has been introduced that basically attempts to reduce the redundancies within video frames and between consecutive frames in order to represent the original information with a lower size of information [3]. However, efficiency must be maintained such that video quality is not compromised, such that it should significantly reduce video file sizes while maintaining high visual quality, enabling efficient storage and transmission over bandwidth-constrained networks [4]. Video coding is essential in resource-demanding video communication like panoramic video transmission [5].

Scalable Video Coding (SVC) introduces efficiency for video communication by introducing a base layer and a set of enhancement layers, where a part or whole of the enhancement layers can be dropped/omitted at the transmitter or the video decoder based on the demands of the communication [6]. This approach is different from transcoding, where the received bit stream is re-encoded to improve the quality of the video [7]. The advantage of SVC is that it offers better efficiency and flexibility than transcoding by enabling a single encoded stream to support multiple resolutions and quality levels without the need for re-encoding [8]. Furthermore, video scalability is achievable using hierarchical temporal scalability, spatial scalability with spatial resolution, quality scalability using quantization steps, and slice grouping for region of interest scalability [9].

Error detection and correction schemes for video communication have been put forward to improve the reliability of video communication and reduce the degradation of video quality under challenging communication conditions, where the received video data can contain errors [10]. The errors can be accumulated in multi-hop routing scenarios [11], compared to one-hop communication [12], due to packet losses leading to a higher requirement of error detection and correction. There exist numerous error correction schemes related to video communication, like error-resilient tools such as reference picture identification [13], spare picture signalling [14], gradual decoding refresh [15], scene information signalling [16], error concealment [17], etc. However, the major focus of this paper is reviewing unequal error protection, which is a forward error correction [18]-based method to provide high protection to important bits while having low redundancy for less important bits [19].

Multicasting a video stream involves sending a video to multiple recipients simultaneously over a network, efficiently using bandwidth without sending individual streams to viewers. In this scenario, simulcast is a technique for simultaneous transmission of a set of differently encoded video streams that have different bit rates, spatial, temporal, and quality characteristics, which has shown similar quality to that of serial SVC [20]. Discrete Sequence-Code Division Multiple Access (DS-CDMA) [21] has shown data rate loss in user-specific spreading and is thus less suitable for high-throughput desired applications, while Interleave Division Multiple Access (IDMA) has been an effective multiple access technique in multiuser environments that distinguishes different users' different interleavers at the transmitter without spreading and at the receiver [22]. Moreover, some have even used multi-resolution modulation to multicast layered, scalable video to multiple users [23], while others have used antenna heterogeneity in wireless video multicast by using a scalable video multicast system allowing receivers with diverse numbers of antennas to decode from a solo transmission [24].

Now, let us compare our review with existing studies. The study in [25] has inspected the error resilience and error control methods in video streaming with respect to two case studies. The review paper in [26] summarizes the application of multi-access edge computing for video streaming, considering caching and computing aspects. On the other hand, the review [27] surveys SVC, transcoding, and streaming methods. However, none of these surveys focus on reviewing the efficiency and reliability of video communication by improving efficiency by multicasting scalable video, where the reliability can be improved by focusing on unequal error protection. Thus, this review provides a valuable contribution to existing literature by reviewing the precedingly mentioned aspects.

Figure 1 shows the branching diagram of this survey.

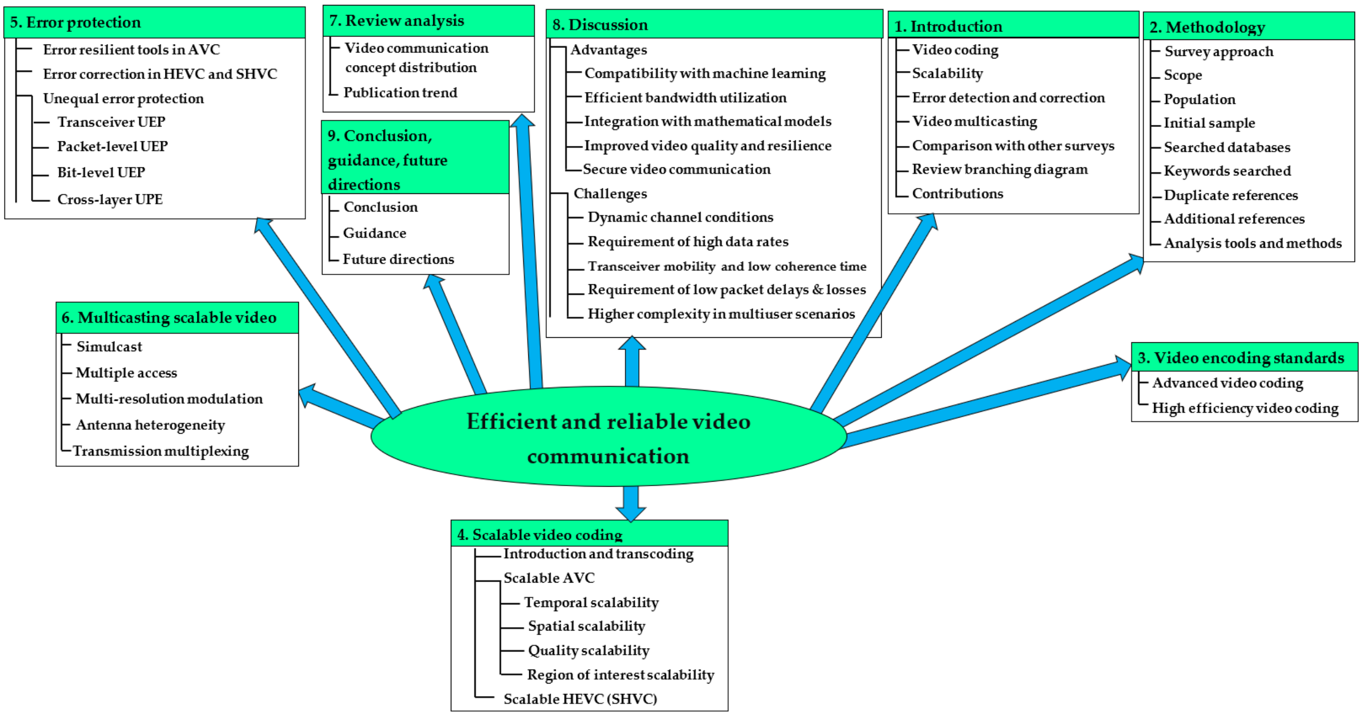

Figure 1: Branching diagram of efficient and reliable video communication survey focusing on scalability, error protection, and multicasting.

1.1 Contributions of the review

- We first review video coding standards (Section 3).

- Scalable video coding is discussed with respect to several parameters and video coding standards (Section 4).
- Error protection in video communication is discussed, specifically focusing on unequal error protection (Section 5).
- Study on prevalent multicasting on scalable video (Section 6).
- Analyze the review with respect to different parameters (Section 7).
- Advantages and challenges of video communication are discussed (Section 8).
- Guidance and future directions for efficient and reliable video communication are discussed (Section 9).

B. Methodology

This review paper summarizes the original research work on efficient and reliable video communication, focusing on scalability, error protection, and multicasting, leveraging an elaborative process [28]. Therefore, all original research papers and web documents published on video communication, including video coding, scalable video, video error protection, and video multicasting, represent the sample space. From the sample space, we extracted 116 references constituting research papers and web docs using qualification criteria given beneath.

We inspected the Google Scholar publication query engine, ScienceDirect scientific data vault, ACM Electronic-library, Wiley Electronic-library, MDPI online searching tool, and IEEE Xplore online technical content explorer. Frequently utilized searching phrases were "Video communication" OR "Video coding" OR "Scalable video communication" OR “Video error protection” OR “Video multicasting”.

There were several norms for refining the articles. First, it had to be an English language document, and secondly, it has to have a high relevance to the searching criteria. Also, we prioritized journal publications over conference and preprint papers. Still, we weren’t biased towards any publisher and extracted articles in the period of 1985 and 2025.

We identified that 3 papers were duplicates, so that initial sample was cut down to 113. Using 48 other references, we referred to definitions of concepts related to video communication. Next, we compared our study with 3 other surveys, getting the final count of publications to 164.

Where possible, we used tables to summarize the reviewed literature with important aspects related to video communication. Further, we drew graphs leveraging MS Excel to evaluate factors related to the reviewed efficient and reliable video communication.

Ethics are inadmissible since this review is related to video communication.

C. Video encoding standards for live streaming

3.1. Advanced video coding (H.264)

Both HEVC and AVC codecs function through comparing different blocks of a video frame to identify those that are redundant in the same frame (intra-coding) or between subsequent frames (inter-coding) to replace them with a small amount of information describing the original pixels [29]. H.264 has been able to reduce bit rates better than former standards like H.261, H.262, H.263, and MPEG1-MPEG-4 by having a higher video compression efficiency. Previous standards were intended for applications such as video telephony (H.261), video CD (MPEG-1), and standard TV broadcast (H.263, MPEG-4). AVC is used for applications in heterogeneous networks, such as packet switched networks, wireless sensor networks [30], mobile networks, cable networks, etc. [31].

H.264 operates by handling video frames leveraging a block-intended, motion-compensation-driven video compression technique, which is used in inter-coding to predict another frame using a reference frame and motion vectors. These components are referred to as Macroblocks (MBs) that generally comprise 16x16 pixel specimens, which can be split into 8x16 and 16x8 transform blocks and can be broken down further into 4x4, 4x8, 8x4, and 8x8 blocks known as prediction blocks [32]. Macroblock and sub-macroblock sub-division in H.264 is depicted in Figure 2.

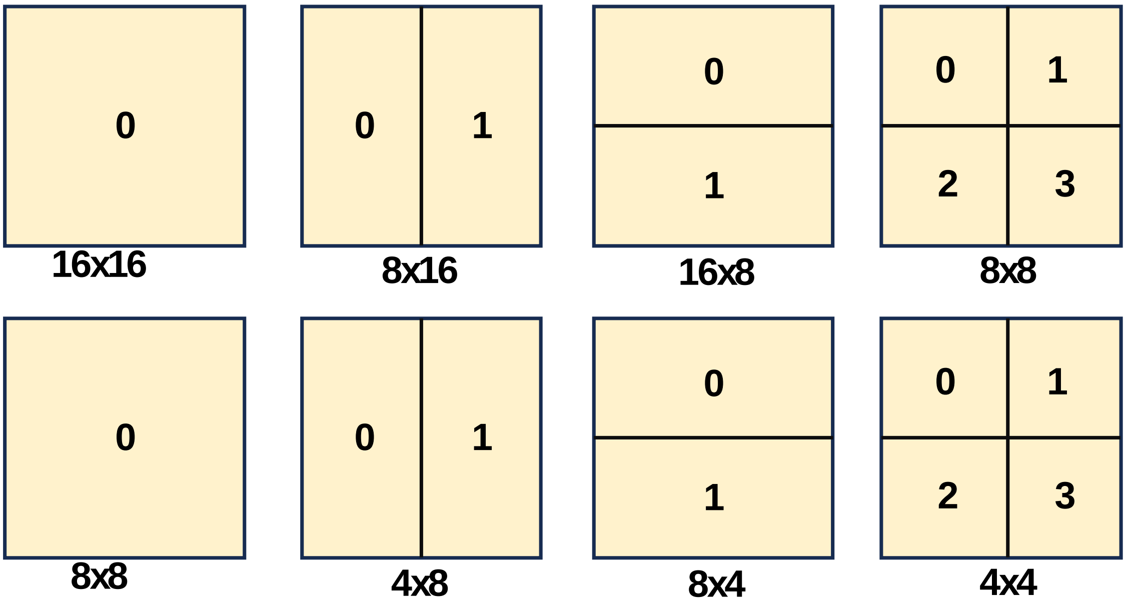

Figure 2: Macroblock and sub-macroblock sub-division in H.264.

Improved motion compensated prediction, transform coding, entropy coding, the adaptive deblocking filter, along with resilience to errors and network cordiality, are some of the characteristic features of AVC that highlight it compared to predecessors such as H.263 [31]. The transform coding is used for spatial reduction of the prediction error signal. H.264 uses low-size integer transforms, such as Hadamard transforms, which include low-complex operations compared to the discrete cosine transform utilized in previous standards. H.264 uses both low-complexity Context Adaptive Variable Length Codes (CAVAC) and relatively complex Context Adaptive Binary Arithmetic coding (CABAC) for entropy coding [33]. Because of the transform coding and motion compensation, block artifacts can appear, which get severe under less quantization. So, a mandatory adaptive deblocking is employed for H.264 in slice or block edge or sample level to enhance the quality [32].

3.2 High efficiency video coding (H.265)

In contrast to H.264 MBs, H.265 handles information in units known as Coding Tree Units (CTUs), having the largest block size in which information is processed. MBs can spread over from 4x4 to 16x16 block sizes, whereas CTUs can span up to 64x64 blocks, enhancing their capacity to optimize data compression. Selecting a substantial block size in flat and homogeneous areas of a frame and deciding on a compact block size in regions of intricate detail and dynamic movement is used to achieve an efficient code [34]. In particular, HEVC has 64x64, 48x64, 64x48, 64x32, 32x64, 64x16, 16x64, 32x32, 32x24, 24x32, 32x16, and 16x32 blocks known as Coding Units (CUs), which are not available in H.264. Larger size CUs have enabled better compression than AVC, but it can also elevate the encoder/decoder latency, the memory demands, and the computational burden of the encoder operation [35]. Due to the high compression efficiency, the bandwidth and storage requirements have been reduced by more than 50 percent compared to AVC [36]. The required bandwidth for 4K broadcasts using HEVC and AVC are 15 Mbps and 32 Mbps, respectively, which can be considered as one of the main achievements of HEVC [29]. Therefore, it is much more bandwidth efficient to use HEVC for UHD live streaming than AVC.

An improved version of motion vector signalling using skipped and direct motion inference and adaptive motion vector prediction is used in HEVC. Quarter sample precision and higher tap filters are used in HEVC for better motion compensation compared to AVC. The inter-picture prediction has 33 modes in comparison with 8 modes in AVC. The entropy coding is done using CABAC like AVC, but with increased throughput, compression, and reduced memory requirements. The deblocking filter is also similar to AVC but has been simplified by incorporating parallel processing [37]. So, the hardware requirement at the encoder is higher, at the same time the decoder requiring less processing power to extract that data.

Parallel processing can be enabled in HEVC either by using tiles or Wavefront Parallel Processing (WPP). Parallel processing computing techniques speed up the computations and support advanced extensions. Tiles are sub-pictures consisting of a set of CTUs to be processed independently in a frame. On the other hand, WPP involves parallel processing within a slice where each row is parallelly processed with a 2 CTU lag between consecutive rows [35]. Another new feature known as dependent slice segments allows information related to a wavefront entry point or tile to be conveyed in a different Network Abstraction Layer (NAL) unit that will aid in reducing the encoding delay [37].

Table 1 conveys a summary of literature on video encoding standards.

Table 1: A summary of literature on video encoding standards.

Encoding standard	Prevalent literature	Approaches	Performance
Advanced video coding	Applications [29], block architecture [32], characteristics [31], and entropy coding [33]	Adaptive deblocking filter, entropy coding, motion-compensated prediction, and transform coding	Enhanced quality, and low prediction error
High efficiency video coding	Coding units [35], coding comparison [36], and parallel processing [37].	Large block sizes (coding tree units), wavefront parallel processing, dependent slice segments, and motion vector signaling	High computational complexity, better compression, and low bandwidth and storage requirements

D. Scalable video coding

In SVC, a low-quality/resolution/frame rate Base Layer (BL) and a set of Enhancement Layers (ELs) are created, and all or some of the ELs can be discarded at the transmitter or at the receiver based on the channel condition or based on the requirement of decoders.

An alternative way of quality improvement without using SVC is transcoding, which is rejected for UHD-supportive video transmission based on the following reasons. Decoding a received bit stream and then re-encoding using a complex process at the receiver, such as using down-sampling to improve the video quality, is known as transcoding. But transcoding increases the complexity of the receiver, introduces a much higher delay compared to SVC, has a higher bit rate requirement, and leads to a lower spatial resolution [38].

4.1 Scalable video coding in AVC

Scalable video will also aid in applying unequal error protection to more important layers/frames [39]. SVC will ensure that if at least the encoded BL is correctly decoded at the receiver, the video is watchable without interruption, even though it is at a low quality. This scalability is cumulative, which means that BLs are required to decode ELs at the decoder. SVC emerged as an extension of the H.264 video coding standard. AVC has two layers known as the Video Coding Layer (VCL) and NAL. VCL contains source-coded content of the video. NAL may contain either VCL information or non-VCL information such as supplemental enhancement information. NAL includes a header for VCL or non-VCL information [40].

AVC uses 52 quantization step sizes defined by the Quantization Parameter (QP). The coding and display order of pictures are independent. The scalability of AVC is achieved in 4 ways given by temporal scalability, spatial scalability, quality scalability, and Region of Interest (ROI) scalability [41]. Each of the ways in which scalability can be achieved is briefly given below.

4.1.1. Temporal scalability

This means that the video encoding contains a set of layers (hierarchy) of decodable pictures known as hierarchical B pictures, which are the basic elements that aid temporal scalability. They are identified using temporal layer identifiers beginning from 0 for the base temporal layer and incrementing by 1 for the other temporal enhancement layers. In SVC, a sequence of pictures, including one or more base layer pictures, is known as a Group of Pictures (GOP). Hierarchical prediction for B pictures can be used to achieve motion-compensated prediction for temporal enhancement layers [42]. The temporal base layer should have relatively the highest information since other temporal layers are predicted from it. Therefore, temporal enhancement layers are quantized with a higher QP than the base temporal layer [43].

4.1.2. Spatial scalability

Spatial scalability is associated with spatial resolution. Every spatial layer is recognized using a dependency identifier assigned 0 to the base spatial layer and incremented by 1 for each consecutive spatial enhancement layer, similar to the temporal layers. An access unit consists of several spatial layers at a given time instant [44]. Inter-layer inter prediction can be used within an access unit for spatial prediction, which involves motion and residual prediction [45]. Inter-layer intra prediction is spatial enhancement layer macroblocks being predicted from intra-coded macroblocks in the reference layer. In inter-layer motion prediction, reference layer blocks are up-sampled and motion vectors are amplified by a factor of 1.5 or 2. In residual prediction, the residual signal of the appropriate macroblock in the reference layer is up-sampled which is known as block-based filtering [45]. Due to these prediction techniques, effective video coding rate can be reduced [41].

Figure 3 shows the temporal and spatial scalability concept in H.264.

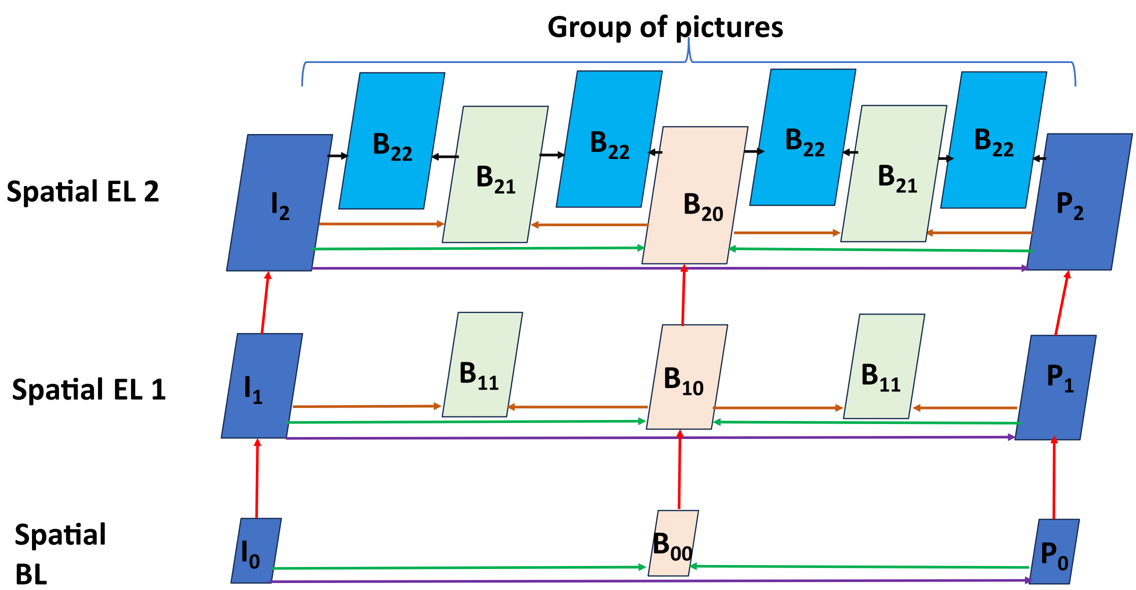

Figure 3. Temporal and spatial scalability in H.264.

4.1.3. Quality scalability

This is also called SNR scalability, where the quality layer is recognized by a quality identifier. Residual texture signal in a spatial layer having the same temporal and dependency identifier is re-quantized with a small quantization step without up-sampling [9] to create a quality enhancement layer. AVC uses Medium Grain Scalability (MGS) with key pictures. Key pictures are the pictures at the beginning and end of a GOP in which motion parameters cannot differ between enhancement and base quality layers. Quality layer enhancement layers are contained in NAL units, which can be discarded if required. The highest quality layer reference is utilized for motion-compensated prediction [41]. The base quality layer of a particular dependency layer is typically used for inter-spatial layer prediction.

4.1.4. Region of interest scalability

ROI is a selected area in a picture of a video selected for enhancement. In the AVC SVC extension, scalability can be achieved for ROI patterns composed of macroblocks using the concept of slice grouping [46].

4.2. Scalable video coding in HEVC

The scalable extension of HEVC is known as Scalable HEVC (SHVC). There exist some differences in the SVC extension of AVC and SHVC. AVC incorporates combined decoding of enhancement and base layers. A layer is identified by the layer ID in the NAL header where a layer can differ in terms of spatial resolution [47]. In contrast, in AVC, there were temporal layers with different temporal IDs. HEVC has temporal sub layers instead of temporal IDs. HEVC has a common syntax for NAL headers for extensions unlike in AVC [48]. HEVC uses multi-loop encoding and decoding compared to AVC, which uses single-loop decoding. In SHVC, up-sampling in spatial scalability is not restricted to factors of 1.5 and 2 [47]. Together with the temporal, spatial, quality, and ROI scalability, SHVC assists bit depth and Color Gamut Scalability (CGS). In SHVC, bit depth varies from 8 to 12 bits, which is the number of bits a pixel is represented with. Bit depth scalability refers to a BL having a lower bit depth than an enhancement layer having a higher bit depth. Color gamut level represents the width of the spectrum of colors [49]. CGS scalability refers to using a narrower color gamut in the base layer and wider color gamuts in ELs. In HEVC, the base layer can be coded leveraging a non-HEVC codec as well [50].

Table 2 conveys a summary of literature on scalable video coding.

Table 2: A summary of literature on scalable video coding.

Encoding standard	Prevalent literature	Approaches	Performance
Advanced video coding	Temporal [42], [43], spatial [44], [45], quality [9], [41], and region of interest [46].	Hierarchical B pictures, motion compensated prediction, base and enhancement layers, spatial prediction, residual prediction, block-based filtering, medium grain scalability, and slice grouping	Support UEP, cumulative scalability, and motion vectors are amplified by a magnitude of 1.5 or 2
High efficiency video coding	Syntax hooks [47], non-HEVC base layer [50], and extensions [48].	Non-restricted factors for up-sampling, temporal sub-layers, bit depth and color gamut scalability, and multi-loop encoding	Bit depth varies from 8 to 12 bits

E. Error protection for video transmission

Transmission errors can occur in video communication; specifically, their probability is high in challenging communications like wireless communication. Error-tolerant coding methods have been suggested for video transmission to hide the errors that can occur in the channel in order to reduce the degradation of video quality at the receiver side [51]. For instance, in the H.264 video codec, there are numerous error-resilient tools such as reference picture identification [13], spare picture signalling [14], gradual decoding refresh [15], scene information signalling [16], etc. SHVC inherits most of these features from AVC-SVC, while some features, such as data partitioning and macroblock ordering, are not inherited [37]. Error concealment is hiding bit errors of the picture from the user's view as if no errors have occurred in order to improve the user's perceptual video quality, such as motion copy [17], weighted boundary matching approach [52], downhill simplex approach [53], and concealment using block partition decisions [54]. These concealment strategies should be done during source encoding/decoding. But such techniques do not guarantee high video quality at the user end under high communication errors. They can be used in combination with other error correction strategies.

Unequal Error Protection (UEP) [19], [55] has been introduced to provide high protection to important bits while having low redundancy for less important bits. Forward error correction (FEC) attempts to correct errors after the source encoder at the transmitter and before the source decoder at the receiver. FEC-based UEP has been one of the key significant research areas for scalable video transmission. In literature, FEC-based UEP has been achieved in four major ways. They are given in the following subsections:

5.1. Transceiver unequal error protection

This is protecting more important layers or bits by varying parameters such as transmission power level, modulation, etc., without using FEC. Adaptive Hierarchical Quadrature Amplitude Modulation (HQAM) [56] of non-uniform key frames and predicted frames of AVC was used in [57]. HQAM uses multilevel QAM to achieve bit-level UEP [58]. In [59], Kim et. al. have proposed a joint UEP using FEC and a Multiple Input Multiple Output (MIMO) system, where MIMO was switched between 3 modes of spatial diversity (transmission and reception of the same information through multiple transmitter and receiver antennas), spatial multiplexing (transmission of different information at the same time using multiple transmit antennas), and hybrid mode, which achieves both spatial multiplexing and spatial diversity. The diversity gain is high in spatial diversity that increases the link reliability achieved by deploying multiple antennas at both transmitter and receiver sides. In spatial multiplexing, the throughput is high, causing high spectrum efficiency rather than using a single antenna and a single link. Spatial multiplexing gain is high in high-scattering environments where there is multipath propagation that increases the frequency-selective fading of the wireless communication channel [60]. The hybrid mode is equipped with Orthogonal Frequency Division Multiplexing (OFDM). Use of an Inverse Fast Fourier Transform (IFFT) at the transmitter and FFT at the receiver and sending independent data with tones having the symbol period higher than the delay spread of the channel; OFDM transforms the frequency selective channel into a combination of parallel flat fading sub-channels by eliminating Inter Symbol Interference (ISI) [60], [61].

A remarkable turning point in MIMO took place with the idea of Spatial Modulation (SM) [62], which increased the throughput and energy efficiency [63]. In SM, part of a block of transmission data is used to select one of the antennas (known as space shift keying), and the rest of the bits are modulated and transmitted from the selected antenna. However, SM assumes a flat fading channel with a line-of-sight channel. By modifying the SM model, Space Time Shift Keying (STSK) involves selecting a Linear Dispersion Code (LDC) instead of transmitter antennas using a set of input data bits, and the rest of the bits are modulated and multiplied with the LDC and mapped to antennas [64]. This scheme is able to achieve both multiplexing and diversity gains. Further, enhancing the STSK; Multi

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Set Space Time Shift Keying (MS-STSK) was proposed in [65], which has SM and selects an antenna set (antenna combination) each of size M out of total available antennas based on part of input data for transmitting a STSK codeword dispersed in M dimensions. A phase shift is associated between each antenna set to reduce the correlation between common antennas among different antenna combinations. Therefore, implicit information is carried by the index of the antenna set selected [65]. Authors in [66] recently have used MS-STSK for transceiver UEP of video transmission. In order to tackle ISI in non-line-of-sight channels that are frequency selective, an OFDM-aided STSK system was proposed in [67], [68]. In OFDM-MS-STSK, a set of single-carrier analog beamforming antenna arrays is selected instead of a set of antenna elements. A set of STSK symbols are mapped to a set of OFDM subcarriers at the same time [69]. Each subcarrier is mapped to a selected transmit antenna array by the multi-set encoder.

Non-Orthogonal Multiple Access (NOMA) has been proposed for future 5G wireless networks and intelligent networks [70] due to its higher throughput, reliability, and spectrum efficiency over the orthogonal multiple access schemes [71]-[80]. Moreover, downlink NOMA has been shown to satisfy ultra-reliable low latency communication requirements [73]. In NOMA, information is transmitted in the same time, frequency, and space in which users are differentiated either by power domain [78]-[80] or code/pattern domain [74], [75], [77]. NOMA can allocate more power to base layers and use successive interference calculation to decode stronger power signals first, making it easier to decode enhancement layers [79]. Also, these systems can be designed such that users with superior channel conditions are allocated lower power and vice versa. For MIMO NOMA systems, the interference from multiple users has to be cancelled at the receiver, and that process has been complex due to the correlation among different users at the receiver [71], [72] by using techniques such as Successive Interference Cancellation (CSI) and Parallel Interference Cancellation (PIC).

5.2. Packet-level forward error correction-based unequal error protection

One promising technique for achieving UEP in video transmission was to consider I frames as more important frames while giving less protection for bidirectional and predicted frames [81]. Motion vector size is one of the measures of motion energy [82]. Error protection can be done using these motion vectors of macroblocks at the time of source encoding.

Motion energy is the energy required for displacement among two adjacent frames [82]. A slice-level motion energy-based FEC (ME SLICE LEV) was considered in [83]. A modified approach for two-level error protection using a threshold value for motion energy known as the ME FRAME LEV method was presented in [84], which was more efficient in coding and transmission and required less processing time than ME SLICE LEV due to the consideration of only one slice per frame. By further improving the frame-level system given in [84], which categorizes a frame as high importance or low importance by comparing the total motion energy of high-motion-energy blocks and low-motion-energy blocks, a system was presented in [82]. A macroblock has high motion energy if its ME, calculated by the product of the motion vector and block size, is greater than the threshold energy level calculated from neighbors and vice versa [84]. The threshold energy is the average motion energy of neighbors of a macro-block. An unequal distance method to calculate the threshold was presented in [83]. A multi-level scheme was introduced in [85] that calculates the threshold of a macroblock based on the average value of motion energy of neighboring macroblocks using either the equal distance method or an arc method. Motion energy of a macroblock determines the level of distortion that occurs in case of transmission errors (if the motion vector is lost, etc.). The higher the motion energy, the higher its importance. It was proved by Sina et. al. in [85] that the arc method provides the highest correlation of a given macroblock with its neighbors. A four-level importance of the frames for the preceding method has been decided by considering the changing rate of ME of each macro block compared to the previous frame so that UEP can be applied at 4 levels. Figure 4 shows diverse neighboring macroblock considerations in motion energy calculation for UEP.

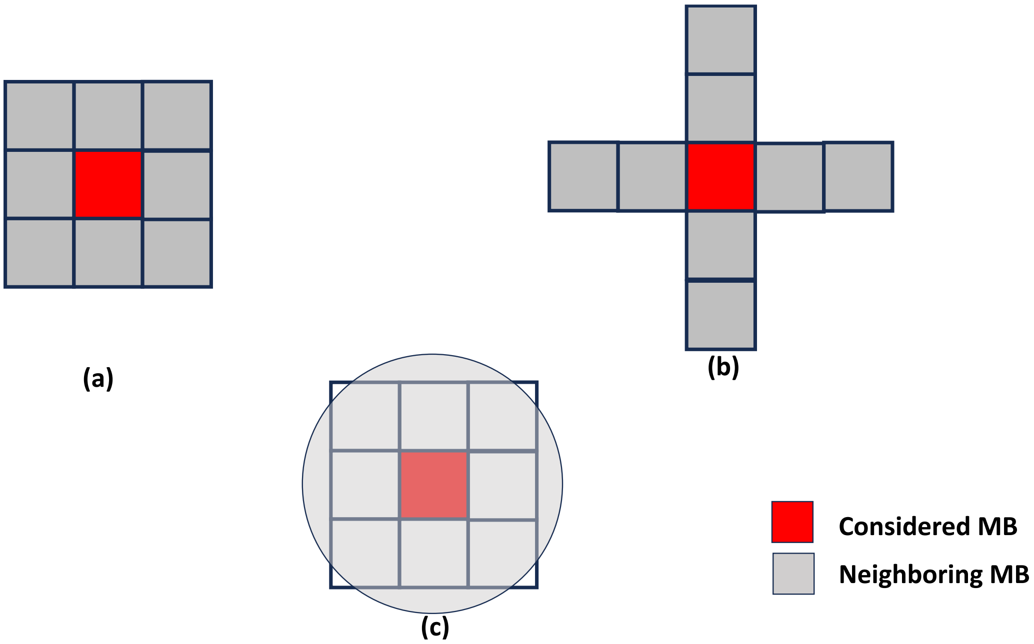


Figure 4: Neighboring macro-block considerations for motion energy calculations in UEP (a) Square (b) Diamond (c) Circular.

More recently, S. Vafi et. al. in [86] have proposed two UEP techniques for HEVC-encoded video frames. Since the non-homogeneous areas tend to be broken down into smaller coding units by the HEVC encoder, one method compares the number of Coding Units (CUs) in a frame with the average CUs of the video to decide the frame importance. The other method is the motion energy-driven UEP, which is somewhat different from the schemes proposed in [83] and [87]. That is because in this technique, CUs are considered instead of macroblocks in AVC. The sum of individual motion energies of CUs of a frame is obtained and compared with the average of such calculated frames of the video sequence to find the importance in contrast to previous techniques proposed for AVC, where individual macroblocks were separated based on importance by considering their motion energy and the threshold value obtained from neighbor blocks, and at last decides the importance of the frame based on the number of high- or low-important macroblocks present in the frame. They have extended the protection to 4 levels by considering the first quartile, average, and third quartile of the video frames. Each of the previously mentioned techniques considers the motion energy of a macroblock or a coding unit. But the individual motion energy of each pixel within such a block can be different from each other. Since in HEVC, the CUs can be as large as 64x64 and as small as 4x8, such two blocks with the same motion vector magnitude will have different significance. That is because, according to the rate distortion criterion and space-time homogeneity, the encoder chooses smaller coding units for areas with high texture and complex motion [88], [89]. Inaccuracies in motion vector prediction significantly impair the gross quality of the decoded video [88]. Hence, small CUs have higher significance than large CUs with the same motion energy since the Motion Density (MD) of the smaller CU is high [90]. Motion density is like motion energy per unit area. It has been proved in [90] that Peak Signal to Noise Ratio (PSNR) performance of UEP using motion density for HEVC is better than UEP using motion energy.

5.3. Bit-level forward error correction-based unequal error protection

Channel coding has been a remarkable field of study in the past few decades to find capacity-approaching codes with less encoding and decoding complexity. Convolutional codes were one of the earliest error-correcting codes [91] that shifted input bits one by one and encoded them, which could not reach channel capacity. By parallel concatenation of two convolutional encoders, turbo codes were first proposed in [92]-[95], which can approach channel capacity. Another class of codes is the Low-Density Parity Check Codes (LDPC) [96]-[98], which are block codes with a sparse parity check matrix that are capacity-approaching codes. Polar codes [99]-[102] constructed using channel polarization transform were the first codes that were proved to approach channel capacity when the code length is very high. Each of the previously mentioned major forward error correction techniques has pros and cons such that they should be chosen based on the desired application. When it comes to UHD video transmission, the complexity, energy efficiency, latency, and Bit Error Rate (BER) under different Signal to Noise Ratio (SNR) are some of the major parameters that should be considered. Authors in [103] performed an analysis of the BER of polar, LDPC, turbo, and convolutional codes across various information block sizes and code rates, covering a range of numerous instances of reliability and high throughput. According to it, the BER performance of LDPC and turbo codes is the highest under both low and high SNR values. BER performance of polar codes is worst under very low SNR ratios despite its better performance in high SNR values. Since the SNR values of a wireless mobile channel can get low values, the choice of polar codes is thus less appropriate for video communication. On the other hand, the convolutional encoder has the worst performance under high SNR values, and an error floor develops. Therefore, the choice of convolutional encoders has also been less in the literature of video communication. The remaining LDPC and Turbo codes have similar BER performance, complexity, and convergence. The choice of LDPC or Turbo codes for high-speed data communication has been a debate over the last decade [104]. In that context, high-throughput non-binary channel coding techniques such as non-binary LDPC codes [105], [106] and non-binary turbo codes [107] have been proposed. Code lengths for videos are generally greater than 1000. At such code lengths, the error correction performance of LDPC and Turbo codes is still similar [104]. But the energy, area efficiency, and information throughput for LDPC codes are high while the computational complexity is lower than those for turbo codes, according to the survey done in [104].

Binary Quasi-Cyclic (QC) LDPC codes have been proposed for the 5G new radio and are already used in Wi-Fi and WiMAX due to their high efficiency, lower complexity, and parallel decoding structure [108]-[113]. QC-LDPC codes have structured LDPC codes of girth higher than 4, and the parity check matrix is formed by a series of circulant matrices, enabling efficient encoding and decoding with minimal complexity through the use of shift registers [110]. QC-LDPC codes not allowing a girth of 4 ensures good performance with a low error floor [114]. Non-binary LDPC codes introduced by Davey and Mckay have been proven to show significant improvement over binary LDPCs for a binary Gaussian channel model [115]. In [105], it has been proved that the BER performance of non-binary QC-LDPC codes has been lesser than both binary QC-LDPC codes and turbo codes over multi-path fading channels. Furthermore, some authors have chosen to employ the non-binary LDPC codes proposed by authors in [105] for UEP.

5.4. Cross-layer unequal error protection

The source coding and channel coding are not completely separate in cross-layer UEP. Joint Source Channel Coding (JSCC) is a cross-layer error protection method that considers both the application layer and the physical layer. In other words, JSCC involves error protection applied considering source coding as well. A cross-layer scheme with adaptive channel selection in the application layer using CSI and the video layer, a physical layer power allocation technique based on CSI and the video layer, and different Modulation and Coding scheme selection (MCS) with the objective of maximizing system utility has been presented [116] for a MIMO system. An improved model compared to [116] by allocating multiple spatial channels for transmitting a video layer along with additional application-level FEC is found in [117]. A cross-layer UEP has been achieved in [118] by using Reed-Solomon codes in the application layer and HQAM in the physical layer. Optimized cross-layer communication strategies and protocol frameworks for transmitting control information and enhancing multimedia delivery across both wireless and wired IP networks have been presented in [119]. It transfers control information, such as source-significant information, source a priori information, channel state information, network state information, source a posteriori information, and decision reliability information, between various layers of the Open System Interconnection (OSI) model and is applied for streaming of SVC streams with the objective of maintaining an efficient data rate and maximizing perceived video quality [119]. Application layer video characteristics, such as time and quality of SVC video and PSNR as wireless channel fading information (physical layer), are considered to maximize the average PSNR of users in [120], which schedules users in the time domain, and the rate of each user is matched by a frame dropping strategy.

A generic application-datalink-physical cross-layer UEP scheme is given in [122] that incorporates Automatic Repeat Request (ARQ) and estimates the loss visibility with the objective of achieving long-term video quality constrained by playback buffer conditions using aggregate channel statistics. In order to minimize the transmission delay and high computational resources required for finding optimization parameters for each varying channel condition, a pre-computed lookup table-based cross-layer error protection technique has been proposed in [123]. In [124], Tseng et. al. recently proposed a cross-layer resource allocation system that considered a multiuser MIMO OFDM system with the objective function of maximizing average PSNR of all users for infinitesimal bandwidth increments by using an optimal subcarrier assignment or user grouping system where the power allocation is achieved using the water filling method.

Table 3 conveys a summary of literature on unequal error protection.

Table 3: A summary of literature on unequal error protection.

UEP aspect	Prevalent literature	Approaches	Performance
Transceiver	HQAM [57], [58], joint UEP using FEC-MIMO [59], NOMA-HEVC [66], STSK [67], [68], and NOMA [71]-[80].	Adaptive hierarchical quadrature amplitude modulation, Multiple input multiple output, Multiset-space time shift keying, beamforming, interference cancellation, and power allocation	High diversity gain, high throughput, and higher complexity due to the correlation among different users at the receiver
Packet-level FEC	I frames [81], ME SLICE LEV [83], ME FRAME LEV [84], ME [82], prioritization [87], multi-level scheme [85], HEVC [86], and motion density [90]	High importance for I frames, slice-level/frame-level motion energy, unequal distance method, arc method, coding units obtained to determine importance, and rate distortion criterion and space time homogeneity	High coding efficiency, less processing time, higher motion energy associated with higher importance, small CUs have higher significance, and better PSNR for MD than ME
Bit-level FEC	Non-binary LDPC codes [105], [115], [106], non-binary turbo codes [107], binary QC-LDPC [108]-[113], and efficient LDPC [114].	Non-binary codes, higher code lengths, and QC LDPC codes have girth higher than 4 and circulant matrices	Similar BER performance, complexity and convergence among LDPC and Turbo, energy and area efficiency, information throughput high for LDPC, and parallel decoding
Cross layer	Power allocation [116], application layer FEC [117], RSC-HQAM [118], cross layer communication [119], PSNR [120], ARQ [122], lookup table [123], and MU_MIMO [124]	Reed Solomon codes, joint source channel coding, adaptive channel selection, SVC transmission, automatic repeat requests, and wireless channel fading information	Efficient cross layer communication, maximize system utility or PSNR, and maintain efficient data rate and video quality

F. Multicasting scalable video

In SVC, a multi-layered video bit stream is composed as a serial bit stream by the HEVC encoder. This bit stream should be forward error correction encoded and transmitted either serially or parallelly. Simulcast involves the simultaneous transmission of a set of differently encoded video streams that have different bit rates, spatial, temporal, and quality characteristics. Whether to use serial or parallel transmission of different video layers has been a research question over the years [125]. Simulcast is less bandwidth efficient due to parallel transmission when more layers are required to be transported. Serial transmission is shown to be less efficient when one resolution is targeted on average [125]. Authors in [126] have stated that time for reconstruction of video using different quality layers simulcasted from a transmitter consumes more time, with a factor of about 1.5 to 2.0, than serial transmission for mobile video communication. Authors in [20] show that simulcast achieves similar quality as serial SVC even without coding overhead. By incorporating simulcast into SVC, the TV channel switching delay can be reduced [127]. Simulcasting has outperformed serial transmission of SVC with respect to link utilization and has demonstrated improved scalability in high-capacity links [128]. Authors in [129] prove that when the receivers have low SNR in an MIMO system, the simulcasting outperforms serial transmission, and when SNR increases, both techniques show similar performance. More importantly, by employing simulcast, layered video streams can be incorporated into MIMO techniques to obtain diversity and multiplexing gains to increase the transmission reliability. Moreover, channel information, video preference information, device information, and the number of antenna arrays allocated for each user can be obtained, and an optimized decision can be taken whether the video layers are simulcasted or serially transmitted for each user or group of users in adaptive simulcasting. Multi-hop multicasting of video can occur in ad hoc networks like vehicular ad hoc networks [130] and software-defined networks, where direct communication between the source and destination is not feasible [131]. Figure 5 shows 3 instances of possible multicast trees in a network of 3 nodes.

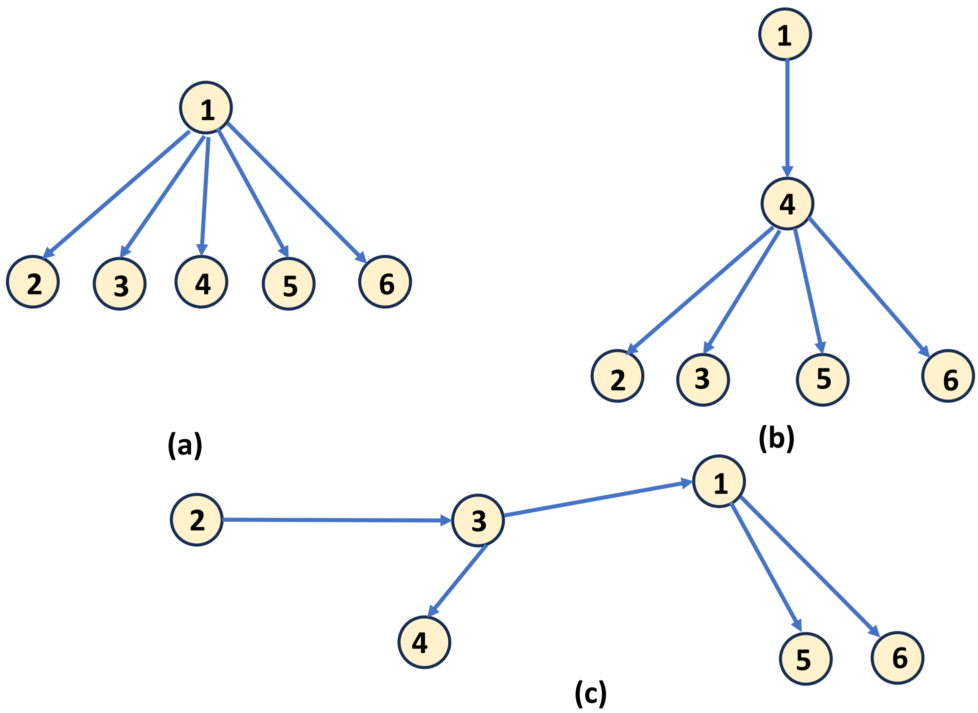


Figure 5: Multicast tree instances in a network of 6 nodes (a) 1-hop (b) 2-hop (c) 3 hop.

Discrete Sequence-Code Division Multiple Access (DS-CDMA) is a candidate for multiple access in NOMA systems [21]. But due to the data rate loss in user-specific spreading involved in DS-CDMA, it is less suitable for high-throughput desired applications. Interleave Division Multiple Access (IDMA) has been an effective multiple access technique in multiuser environments that distinguishes different users' different interleavers at the transmitter without spreading and at the receiver using a chip-by-chip multiuser detector [22], [132]. In [133], authors have proposed a grouped OFMD-IDMA technique to group users by dividing OFDM subcarriers among different user groups with less decoding complexity. IDMA has been proposed for massive MIMO uplink for accurate CSI transfer [134]. In [135], authors have proposed IDMA to be used in 5G systems by proposing a low-complex multiuser detection algorithm without using a deinterleaver to reduce the latency of the conventional interference cancellation by a factor of 0.5.

In [23], authors have used multi-resolution modulation to multicast 2-layered scalable video to multiple users. The said system assumes that the bit ratio between BL and EL is one, and only one EL is transmitted so that limitations exist in the given system.

Authors in [24] use antenna heterogeneity in wireless video multicast by using a scalable video multicast system allowing receivers with diverse quantities of antennas to decode from a single transmission, with rebuilt video quality enhancement proportional to the number of employed antennas. In such a system, only a single transmission with a scaled video exists, and the number of decoded video layers depends on the number of antennas of the user. This scheme is not applicable for users requesting different videos (different TV channels), etc.

Very recently, a system that broadcasts/multicasts scalable multiple videos in which dedicated user streams are inherently represented on the indices of the transmit antenna combination that are multiplexed on the same transmission has been given in [136]. A QOE-driven SM and NOMA unified framework for multi-user video transmission was recently proposed for scalable video transmission [137].

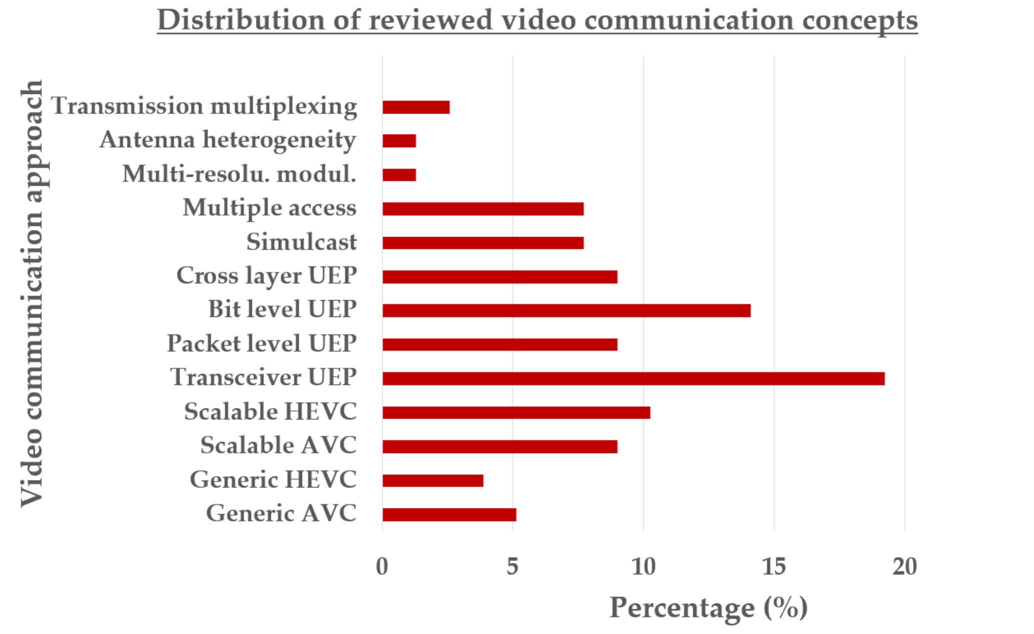
Table 4 conveys a summary of literature on scalable video multicasting.

Table 4: A summary of literature on scalable video multicasting.

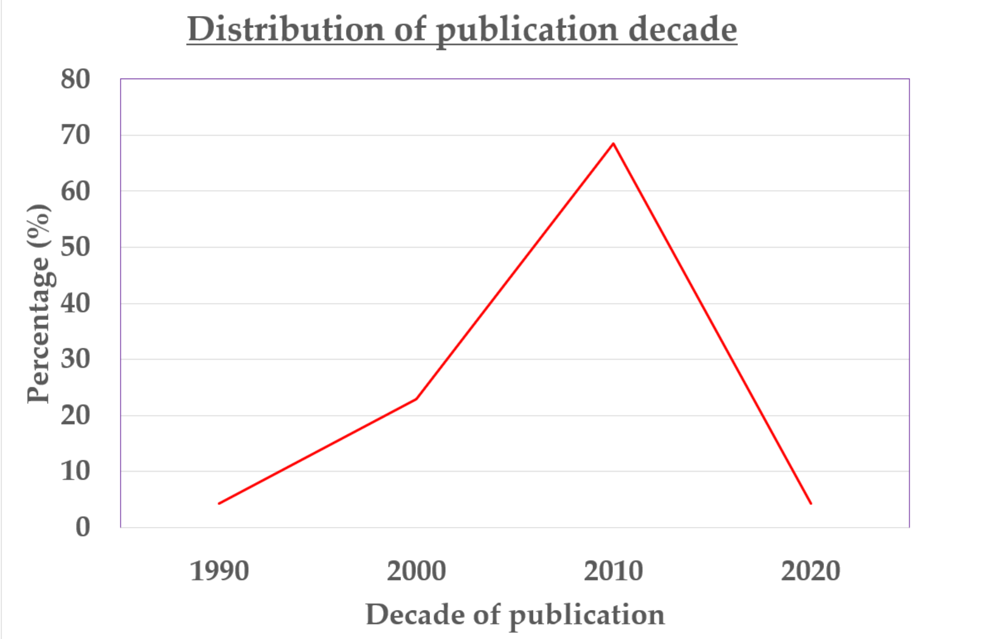
Multicasting technique	**Prevalent literature**	**Approaches**	**Performance**
Simulcast	IPTV [125], mobile video [126], partitioned [20], TV [127], best effort [128], and wireless [129]	Parallel transmission of layers, control channel switching delay, and can be integrated with MIMO techniques	Less bandwidth efficient with more layers, more reconstruction time, and similar quality as serial SVC
Multiple access	DS-CDMA [21], IDMA [22], [132], grouped OFMD-IDMA [133], massive MIMO [134], and 5G [135]	IDMA distinguishes different user's different interleavers, chip by chip multiuser detector, group users by dividing OFDM subcarriers among different user groups in OFDM-IDMA, and uplink CSI transfer	Data rate loss in DS-CDMA, and low complex multiuser detection with low latency
Multi-resolution modulation	MRM-SVC [23]	Multicast 2 layered scalable video to multiple users	Limitations exist
Antenna heterogeneity	Wireless video multicast [24]	Receivers with diverse quantity of antennas to decode from a solo transmission	The rebuilt video quality rises with the quantity of deployed antennas
Transmission multiplexing	Spatial modulation [136], and NOMA-SM [137]	Generalized spatial modulation, and non-orthogonal multiple access	Driven by quality of experience

G. Review analysis

Figure 6 illustrates the percentages of different video communication concepts and publication volume variation with time for works reviewed in this paper.



(a)



(b)

Figure 6: Review analysis (a) video communication concept distribution (b) publication trend.

As depicted in Figure 6a, from the reviewed literature, 5.1% are generic AVC, 3.8% are generic HEVC, 8.9% are scalable AVC, 10.3% are scalable HEVC, 19.2% are transceiver UEP, 8.9% are packet-level UEP, 14.1% are bit-level UEP, 8.9% are cross-layer UEP, 7.7% use simulcast, 7.7% use multiple access techniques, 1.3% use multi-resolution modulation, 1.3% use antenna heterogeneity, and 2.6% use transmission multiplexing. Finally, when evaluating the evolution of literature related to efficient and reliable video communication, it is observable that publications have begun in the 1990s, achieved a peak in the 2010s, and declined by the 2020s.

H. Discussion

8.1. Advantages

8.1.1. Compatibility with machine learning techniques

Machine learning includes regression, focusing on predicting continuous numerical values based on input data [138], while classification involves categorizing data into predefined discrete classes or labels [139]. For instance, DVLC is a deep convolutional neural network-based approach for block-adaptive resolution coding for video coding that replaces conventional video encoders and decoders [140]. Survey in [141] suggests that deep learning has been extensively utilized for video anomaly detection, especially in the video surveillance application. There exist numerous applications of machine learning in video communication, like real-time object identification from video streams by techniques like big data analytics [142] and alert generation. However, all of these applications are possible if the video communication occurs reliably and efficiently by using proper video encoding and error protection.

8.1.2. Efficient bandwidth utilization

In multicasting SVC with UEP, UEP ensures that base layers are critically protected, which provides baseline video quality for all users while providing better quality for users with high bandwidth. Specifically, multicasting with SVC will allow receivers with different network conditions to adapt to their available bandwidth without needing multiple unicast streams. For instance, application layer video characteristics such as time and quality of SVC video and PSNR as wireless channel fading information (physical layer) are considered to maximize the average PSNR of users in [120]. If video communication occurs in a multi-hop scenario, load-balanced video communication can be utilized to disseminate video information in an optimally balanced approach utilizing existing bandwidth [121].

8.1.3. Integration with mathematical models

Mathematical models that model concepts mathematically [143] can be used to develop concepts related to video coding and error correction. For instance, in [144], a perceptual model is developed to estimate perceived video quality considering the video codec and bitrate. Similarly, another work analyzes the quality of video streams in LTE networks using sigmoid functions and blockiness in H.264 video coding [145]. Further, some studies [146] suggest that Markov models can be utilized to represent packetization of errors in AVC video transmissions. Thus, there is enough evidence to suggest that mathematical models can be leveraged to raise the efficiency and reliability of video coding.

8.1.4. Improved video quality and resilience

UEP prioritizes error protection for the most essential video components that can ensure smooth baseline video playback even under challenging conditions. In multiuser scenarios, this ensures critical video components are better protected. On the other hand, users with higher capabilities and who have good channel conditions can improve the video quality by correctly decoding enhancement layers. Authors in [24] have shown that video quality in multicasting can be improved by an increment in the number of receiver antennas. Authors in

[20] have shown that simulcast achieves similar quality as serial SVC even without coding overhead, making it ideal for multicasting scalable video.

8.1.5. Secure video communication

Recent video communication systems have utilized the blockchain technology [147] to provide a decentralized system for access control and authentication, where each video session can be recorded as a transaction in the blockchain. Smart contracts can be deployed in an energy-efficient approach for data transmission [148] such that video transmission session key exchange and session management are automated. If video communication occurs through multiple hops, blockchain-based routing can be effectively utilized to secure the video communication due to the non-tamperable nature of blockchain [149].

8.2. Challenges

8.2.1. Dynamic channel conditions

Wireless communication channels are susceptible to path loss due to power dissipation along the propagation path, shadowing effects owing to absorption, scattering, reflection, diffraction, and multipath propagation effects due to reflected signals. The path loss is severe in millimeter wave channels, so antenna arrays have to be employed at transceivers to increase the gain, and blockages can arise from humans, rain, or other objects for millimeter waves [150]. The channel properties tend to vary quickly when there is relative motion between the transceivers, reducing the channel coherence time. Therefore, mobile devices have channels that undergo time-varying frequency-selective channels [151]. The channel coherence time under mobile conditions is typically lower than a GOP, so that decision taken in the application layer is based on aggregated channel characteristics [122]. Mobile communications inherently have limited bandwidth. Since the coverage of mm waves is low, mobility causes significant and rapid load fluctuations in the base station [150]. These conditions can be even more challenging for SVC with UEP. Specifically, if UEP adapts to fluctuating channel conditions to adapt its protection level, its highly dynamic nature can bring in challenges to this process.

8.2.2. Requirement of high data rates

Video communication demands considerably higher data rates for high-resolution video transmission even after video encoding. Moreover, after incorporating error protection, the data rate demand even increases more. Even though bandwidth-efficient high data rates can be achieved through MIMO communication [152], it incurs additional costs. In [153], unequally protected layered video transmission has been transmitted using open-loop space-time-coded OFDM. It has incorporated spatial multiplexing and diversity through space-time coding, while using OFDM to tackle frequency selective fading. But the system has been designed as an open loop since the transmitter is unaware of the Channel State Information (CSI). CSI can be estimated using a training sequence (pilot symbols) that are known to the receiver [154].

8.2.3. Transceiver mobility and low coherence time

Due to the mobility of transceivers, the wireless channel parameters change quickly. Therefore, an optimized burst of video layers can be transmitted inside a coherence time period. Optimized parameters should change after that time and be recalculated. If coherence time is short, high throughput for enhancement layers is required. This demands video transmission's optimization of parameters within a short period of time, making the communication more complex. It demands frequent channel estimation at the receiver and sends additional overhead to the transmitter if adaptive transmission takes place.

8.2.4. Requirement of low packet delays and losses

Packet delay and packet loss can seriously degrade the Quality of Service (QoS) of the video transmission [155]. Specifically, delays in receiving the base layer can delay the decoding of the enhancement layers. A delay or loss in the base layer can significantly challenge the decoding of enhancement layers, degrading the quality of the video. UEP itself can introduce additional overhead and delays by increasing the processing requirement in more important layers. The real-time requirements of video communication can be challenged when error protection consumes too much time for the encoding-decoding process.

8.2.5. Higher complexity in multi-user scenarios

A multiuser MIMO system can be achieved by allocating a set of OFDM subcarriers for a particular user [156]. For achieving multiple access in Digital Video Broadcasting (DVB), a multiuser OFDM system has the flexibility to adjust resources such as subcarriers, bitrate, and transmission power [157] or use beamforming [158], [159], which are optimization problems. In that context, user clustering is allocating users for subcarriers in OFDM at different time slots based on resources available [158]. These systems bring in additional complexity in video transmission, and this, combined with scalable video coding and UEP, can make the whole system much more complex.

I. Conclusion, guidance, and future directions

This review studied original research work on improving the efficiency and reliability of video communication by utilizing the concepts of multicasting, scalable video, and error protection. After introducing basic concepts, we studied scalable video in terms of temporal scalability, spatial scalability with spatial resolution, quality scalability using quantization steps, and slice grouping for region of interest scalability. Further, we concentrated on unequal error protection and reviewed it extensively, considering transceiver, packet level, bit level, and cross-layer aspects, and discussed simulcast, multiple access techniques, multi-resolution modulation, and antenna heterogeneity as SVC multicasting techniques. Moreover, close studying revealed that the majority of frameworks have opted for temporal scalability, transceiver UEP, and simulcast. Finally, we disclosed advantages and challenges in applying the concept of SVC-UEP video communication.

As per challenges spotted, the following guidance can be stated to overcome them.

- To address dynamic channel conditions, SVC can prioritize base layer transmission in multicasting and use UEP to strongly protect the base layer with higher redundancies compared to the enhancement layers. Under severe multipath fading and drastic channel conditions, adaptive modulation and coding and hybrid automatic repeat requests can be deployed.
- SVC itself provides a solution for high data rate demand by allowing users to decode only the layers they support. MIMO with adaptive channel selection can be used to combat high data rate demand. In [160], each MIMO sub-channel for each SVC layer at receiver antennas is estimated at the receiver, and the SNR of each layer at the receiver is calculated. That SNR is fed back to the transmitter as partial channel information. Then the transmission of different layers by each antenna will be switched based on the SNR order of each layer and layer importance, known as Adaptive Channel Selection (ACS). An alternative strategy is to adaptively control the transmission power of each antenna to minimize the channel distortion [129], [161].
- By feedback of average channel SNR to provide the best SNR channel to the base layer, optimally allocating remaining power under a total power constraint, and adjusting enhancement layer data rate by adaptive modulation of M-ary QAM and then reallocating power for changed modulation, MIMO SVC for AVC has been transmitted in [162] to achieve a given QOS (BER) to combat against low coherence time and transceiver mobility. Ensuring fairness by providing a base layer for all users and allocating the rest of the resources by power allocation, changing the modulation order to achieve network efficiency; a multiuser resource allocation framework was presented in [163].
- UEP can protect critical packets, reducing unnecessary packet retransmission that can cause additional delays. Moreover, multicasting can potentially reduce congestion-induced delays. Throughput has been optimized (by code rate adjustment) while minimizing distortion (by reducing PSNR degradation) based on historical information of video frames of a GOPs for MIMO free space optical SHVC video transmission system in [164]. Moreover, low-latency protocols can be incorporated to reduce additional delays.
- Even though SVC coding in a multiuser scenario combined with MIMO can bring in additional complexity, multicasting SVC reduces the complexity by a large margin by removing the requirement for single streams for each user, where each use can adjust to individual user capabilities.

Future research activities may incorporate machine learning to predict user behavior and video importance in real-time based on data to update UEP strategies in SVC. In emerging wireless technologies and 5G and beyond, there exist even tighter video communication requirements, so that the application of SVC-UEP in these systems should be investigated in more detail. Furthermore, it will be beneficial to investigate the application of multiaccess edge computing to enhance SVC with UEP to provide localized processing and caching to end users.

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