**History of video codec:**

Historically, video was stored as an analog signal on magnetic tape. Around the time when the compact disc entered the market as a digital-format replacement for analog audio, it became feasible to also store and convey video in digital form. Because of the large amount of storage and bandwidth needed to record and convey raw video, a method was needed to reduce the amount of data used to represent the raw video. Since then, engineers and mathematicians have developed a number of solutions for achieving this goal that involve compressing the digital video data.

In 1974, discrete cosine transform (DCT) compression was introduced by Nasir Ahmed, T. Natarajan and K. R. Rao. During the late 1980s, a number of companies began experimenting with DCT lossy compression for video coding, leading to the development of the H.261 standard. H.261 was the first practical video coding standard, and was developed by a number of companies, including Hitachi, PictureTel, NTT, BT, and Toshiba, among others. Since H.261, DCT compression has been adopted by all the major video coding standards that followed.

The most popular video coding standards used for codecs have been the MPEG standards. MPEG-1 was developed by the Motion Picture Experts Group (MPEG) in 1991, and it was designed to compress VHS-quality video. It was succeeded in 1994 by MPEG-2/H.262, which was developed by a number of companies, primarily Sony, Thomson and Mitsubishi Electric. MPEG-2 became the standard video format for DVD and SD digital television. In 1999, it was followed by MPEG-4/H.263, which was a major leap forward for video compression technology. It was developed by a number of companies, primarily Mitsubishi Electric, Hitachi and Panasonic.

The most widely used video coding format, as of 2016, is H.264/MPEG-4 AVC. It was developed in 2003 by a number of organizations, primarily Panasonic, Godo Kaisha IP Bridge and LG Electronics. H.264 is the main video encoding standard for Blu-ray Discs, and is widely used by streaming internet services such as YouTube, Netflix, Vimeo, and iTunes Store, web software such as Adobe Flash Player and Microsoft Silverlight, and various HDTV broadcasts over terrestrial and satellite television.

AVC has been succeeded by HEVC (H.265), developed in 2013. It is heavily patented, with the majority of patents belonging to Samsung Electronics, GE, NTT and JVC Kenwood.

**H.264:**

In the year of 2003, H.264 was formed by Motion Picture Expert Group (MPEG). H.264 is otherwise denoted as MPEG-4 part-10. It is an Block Oriented motion compensation based video compression standard. Block Oriented Motion compensation can be done by doing motion compensation on each block level of each frame. Motion compensation is an algorithm which is used to describe the transformation of reference picture to the current picture. Reference picture may be a previous or future picture.

Encoding process carried out by three important steps: Prediction, transform and encoding. Compressed bitstream can be achieved by encoding process. While decoding is an complementary process of encoding which involves decoding, inverse transform and reconstruction of video stream.

Prediction uses macroblock (small unit of frame within the frame of size about 16x16 displayed pixel). Prediction is a process of subtracting the current data from the previous coded data to form a residual. In the coded data either from a current frame (Intra prediction) or other frame which is already encoded and transmitted (Inter prediction).

Intra prediction is carried out by comparing current macroblock with the previous macroblock within the frame. The macroblock used in the intra prediction had size either 16x16 or 4x4. Inter prediction is carried out by comparing macroblock of current frame with the macroblock of previous frame that detects the similar region. In this manner video streams had been compressed in H.264.

The macroblock can span 4x4 to 16x16 block sizes which makes more bandwidth and bit rate for transmission and compression. H.264 allows only 16x16 pixel macroblocks which are to small to be efficient with the video above 1080p resolution. So here we go for H.265 or HEVC standard for video stream compression.

**H.265:**

In the year of 2004, HEVC development was started by ITU (VCEG) as a successor of H.264. In 2007, MPEG started research on the same direction. In the year of 2010 MPEG collaborates with the ITU in the development of HEVC standard. The collaborated team is called as JCT-VC (joint collaborative team for video compression). In January 25, 2013 the technical content of HEVC was finalized and on April of same year, it was formally declared as a standard.

HEVC provides 64x64 pixel macroblocks which is now called as coding tree unit (CTU) allowing for greater encoding efficiency at higher resolution. Improved variable block size segmentation, improved intra prediction, improved motion vector prediction (displacement prediction on different frames), improved motion compensation and additional filtering steps called sample adaptive offset(SA0).

SAO filtering increases the signal processing on the encoder side which leads to less computation on decoder side. High efficiency(HE), Random Access(RA), Low complexity(LC), Low delay(LD).

**LITERATURE SURVEY**

This paper[1] presented the joint proposal by Tandberg, Nokia and Ericsson that was partially adopted by JCT-VC in the initial test model under consideration as the low complexity operating point. Simulation results[1] show that the proposal achieves a bit rate reduction of around 20%-30% when compared to H.264/AVC High profile. For high definition resolutions of 720p and 1080p, the proposal[1] requires around 35%-50% less bit rate than H.264/AVC at the same subjective quality measured using MOS. The coding efficiency improvement is achieved with very low complexity, which makes the proposal[1] especially suitable for resource constrained use-cases.[1]

The new HEVC standard was developed and standardized together by a ITU-T VCEG and ISO/IEC MPEG. It had several advanced video coding technologies which was based on conventional block-based motion compensated hybrid video coding concept and along some important differences relative to previous standard. It reduces 50% bit rate for analogous perceptual quality relative to the performance of previous standard [2].

Sample adaptive offset, namely as SAO, was proposed to reduce the distortion between reconstructed pixels and original pixels. The bit rate reduction is about 1.3% in HE-RA, 2.2% in HE-LD, 1.8% in LC-RA, 3.0% in LC-LD, 3.3-6.3% in Cb component and 3.9-7.6% in Cr component by the proposed SAO for HEVC. In SAO for chroma, the encoding time and decoding time is almost unchanged and also it is adopted in HEVC WD-4.0 and HM-4.0. In proposed SAO system, the encoding time is roughly unchanged and decoding time is increased by 1-3% and also it is adopted in HEVC WD-3.0 and HM-3.0 [3].

SAO locates after deblocking and is a new in-loop filtering technique which reduces distortion between the original samples and reconstructed samples. SAO can improve video compression in both expected and biased measures with acceptable complexity in the system [4].

In the proposal[5], combine different edge classes as one new edge class that can remove error in different directions. In this paper[5], we analyze the performance of each edge offset class, and find that single directional edge pattern is not efficient enough to remove artifacts for the CTBs, which contain multiple edges in different directions[5].

In the proposal [6], bitmaps are used in the statistics collection of data and to find offset directly, avoiding iterations of multiple values in order to determine the best offset. The SAO estimation architecture is classified into two modules as statistic collection module and parameter determination module. The statistical collection module requires 256 cycle for luma and 64 cycles for Cb and Cr respectively. The parameter determination module requires 64 cycle to process each component of each CTB. This proposed SAO estimation algorithm tends to provide good BD rate performance. Negligible hardware complexity achieves high performance by this algorithm [6].

In this paper [7], we proposed class combination for edge offset, pre-decision for band offset in SAO. Class combination is for calculating the four EO in the same time. BO pre-decision decrease the offset category from 29 to 4. These two proposal successfully decreased the processing time with some efficiency loss. We also proposed [7] offset merge separation algorithm for saving the efficiency loss by restrict the range of merge offset on CTB level. Experiment results show that our purposed algorithm could reduce SAO encoding time by about 38% with only 0.16% BD-rate gain and 0.001 dB ΔPSNR loss[7].

In the proposed dual clock architecture [8], to address the separate data flow of Statistics collection(SC) and Parameters Determination(PD) by separately driving SC and PD at high and low speed clock respectively. Two clock frequencies with a relationship of dividend M eliminate the extra hardware and implementation cost. Coarse range selection(CRS) and accumulator bit width reduction(ABR) further reduce the circuit area with no change in the coding efficiency. The architecture which is proposed occupies 51k logic gates with high speed clock of 1.3 GHz and low speed clock of 217 MHz [8].

The proposed SAO architecture [9] is implemented in Verilog HDL at RTL level and synthesized with UMC 90nm library. The purposed design can be used for decoding 4k x 2k videos @30fps which has substantial applications. In future the hybridization of dataflow and parallel architecture can be explored for SAO filter [9].

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| S.No. | Year | Title | Author | Improvement | Issues with the proposed system |
| 1 | 2010 | Low Complexity Video Coding and the emerging HEVC Standard | Kemal Ugur, Kenneth Andersson, Arild Fuldseth, Gisle Bjøntegaard, Lars Petter Endresen, Jani Lainema, Antti Hallapuro, Justin Ridge, Dmytro Rusanovskyy, Cixun Zhang, Andrey Norkin, Clinton Priddle, Thomas Rusert, Jonatan Samuelsson, Rickard Sjöberg, Zhuangfei Wu | Emerging of HEVC and the Bit rate reduced by 20-30% compared to H.264/AVC | Encoding time increases |
| 2 | 2012 | Overview of the High Efficiency Video Coding (HEVC) Standard | Gary J. Sullivan, Jens-Rainer Ohm, Woo-Jin Han, Thomas Wiegand, | Bit rate is reduced by 50% relative to the performance of previous standard | Distortion rate is not optimized |
| 3 | 2011 | Sample Adaptive Offset for HEVC | Chih-Ming Fu, Ching-Yeh Chen, Yu-Wen Huang, Shawmin Lei | Distortion rate and bit rate is reduced in various components | No improvements in Filtering process |
| 4 | 2012 | Sample Adaptive Offset in the HEVC Standard | Chih-Ming Fu, Elena Alshina, Alexander Alshin, Yu-Wen Huang, Ching-Yeh Chen, and Chia-Yang Tsai, Chih-Wei Hsu, Shaw-Min Lei, Jeong-Hoon Park and Woo-Jin Han | New in-loop filtering technique is introduced to reduce distortion | Offset determination is not optimized |
| 5 | 2013 | Improved Sample Adaptive Offset for HEVC | Hong Zhang, Oscar C. Au, Yongfang Shi, Wenjing Zhu, Vinit Jakhetiya, Luheng Jia | Improved Edge offset determination technique | Selection of offset is not optimized |
| 6 | 2014 | Fast SAO estimation algorithm and its VLSI architecture | Jiayi Zhu, Dajiang Zhou, Shinji Kimura, Satoshi Goto | Bit map is used to improve offset selection | Offset determination time is more |
| 7 | 2014 | Low complexity SAO in HEVC base on class combination, pre-decision and merge separation | Gaoxing Chen, Zhenyu Pei, Zhenyu Liuy and Takeshi Ikenaga | Introduced techniques like Class combination for edge offset and Pre-decision for band offset | Time for Statistics collection and parameter determination is still high |
| 8 | 2017 | A dual-clock VLSI design of H.265 sample adaptive offset estimation for 8k ultra-HD TV encoding | J. Zhou, D. Zhou, S. Wang, S. Zhang, T. Yoshimura, S. Goto | separate clock architecture for statistics collection and parameter determination | Hardware architecture requires more size for implementation |
| 9 | 2017 | Area efficient dataflow hardware design of SAO filter for HEVC | Kaustubh Shukla Baldev Swamy, P.Rangababu, | SAO implemented in Verilog-HDL at RTL level and synthesized with UMC 90nm library | Band offset calculation can be improved |