COMPRESSION:
The Good, the Bad and the Ugly

HDBaseT Alliance

3855 SW 153rd Drive, Beaverton, OR 97006

Tel +1 (503) 619-3007 | Fax (503) 619-6708

admin@hdbaset.org | www.hdbaset.org

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INTRODUCTION

The use of compression in the global storage and distribution of video media has long been ubiquitous. Compression significantly reduces video file sizes in server storage or packaged media such as DVD and Blu-ray Disc™, and it conserves transmission bandwidth requirements for broadcast services such as digital terrestrial television, cable, satellite, and streaming services. In more recent years, compression has become a standard fixture in professional video with mezzanine approaches utilized during capture and post-production. It is also becoming more common at the delivery end of the pipeline as bandwidth demands increase between source and display devices, with a broad range of applications including medical, Pro AV, industrial, commercial, and residential.

Since the release of HDBaseT technology in 2010, the use of uncompressed transmission has been advocated in relation to the transmission of high-definition AV signals over long distances. This is consistent with the short-length connectivity counterparts to HDBaseT, namely DisplayPortTM and HDMI® technologies. The reasons are simple — maximum image quality and device interoperability with no latency. By comparison, compression may compromise any or all such parameters.

However, the use of compression has become inevitable, and even necessary in some applications as bandwidth requirements exceed native link speeds. The HDBaseT Alliance has ratified a light compression method as an interim solution to support the equivalent of an 18Gbps HDMI signal using HDBaseT version 2.0. However, there are still circumstances by which this can complicate interoperability. HDBaseT 3.0 resolves this with the equivalent of 18Gbps uncompressed, for maximum performance with interoperable and backwards compatible devices. And in the future, combining HDBaseT 3.0 with light compression could even support up to 48Gbps for 8K or high frame rate applications.

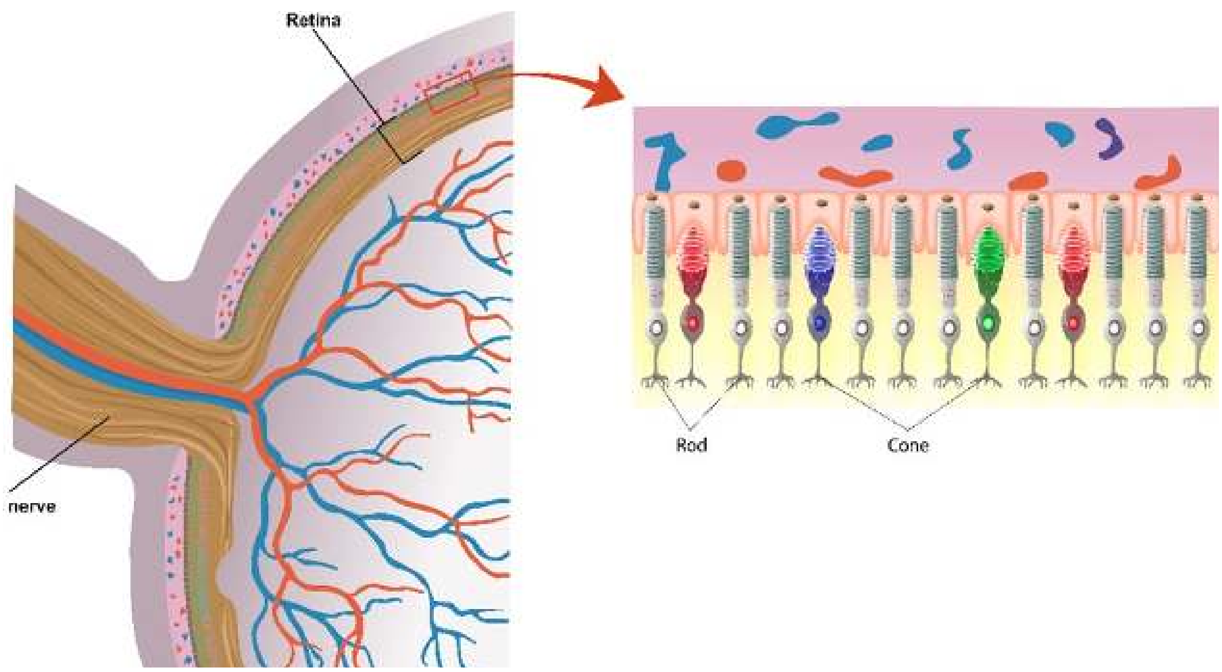
The increasing number of options leads to a question for system designers and integrators: “is the use of link compression good, bad, or neutral, and what should I be using?” In answering this question, it is beneficial to first consider what compression is, and the different types therein.

TYPES OF COMPRESSION

Video compression is the process of encoding digital video in such a way as to yield a reduction in its bit rate. There are many ways to do this, with varying degrees of impact to on-screen video quality and system performance. The most prevalent methods are chroma subsampling— often not thought of as compression even though it technically is— and codec-based algorithms and file containers.

Chroma Subsampling

The human visual system perceives color and grayscale quite differently. The photoreceptors in our eyes' retinas are called "rods", providing monochrome vision and numbering some 120 million cells. By comparison, "cones" that provide color vision only number around 6 million cells, also requiring higher levels of light to be activated. Furthermore, there are three sensitivities of cones that approximate to the three primary colors: red, green, and blue (RGB). Overall, our vision is considerably less sensitive in perceiving color resolution than that of grayscale (contrast).



Video systems are fundamentally based on RGB. Video color standards define RGB primary coordinates, image sensors in video cameras capture scenes in RGB, and all color display technologies— analog and digital alike— reproduce images in RGB. However, RGB is impractical for storage and transmission requirements due its requirement for three full-bandwidth channels.
Several decades ago, a two-fold challenge ensued as color television was introduced; the install base of TVs was predominantly black-and-white (B&W), and transmission bandwidth was limited. An early form of analog component video called Y'UV provided the solutions:

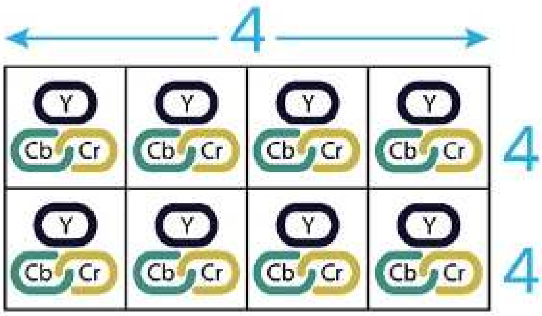
1. Y'UV provisioned a B&W image on one luminance signal, with the color information on separate, concurrent signals. Color TVs could use both, whereas B&W TVs simply used the luminance signal only, and
2. The 2-channel color encoding system could reduce the color resolution— accounting for our vision's lower sensitivity— while maintaining full grayscale resolution. This conserved bandwidth without a noticeable degradation in image quality.

Many years later a higher quality variant of Y'UV emerged, denoted Y'P_bP_r. Described as the "color difference" component video, it is typically identified as the 3x RCA analog video outputs on legacy video sources, such as DVD players.

Y'C_bC_r is the digital, pixel-based equivalent of analog Y'P_bP_r, employing *chroma subsampling*. This works with a sample block of pixels, typically a grid of four pixels wide by two high. Each pixel therein is a subset of the sample, or a subsample. Chroma, meaning color, can be removed from some pixels in the sample to reduce the number of bits. When a display receives the signal, it shares the retained color information across the adjacent pixels to produce a full-color image. The method is represented by three colon-separated numbers, of which there are several permutations. The most common in Pro and consumer video are 4:4:4, 4:2:2, and 4:2:0.

4:4:4

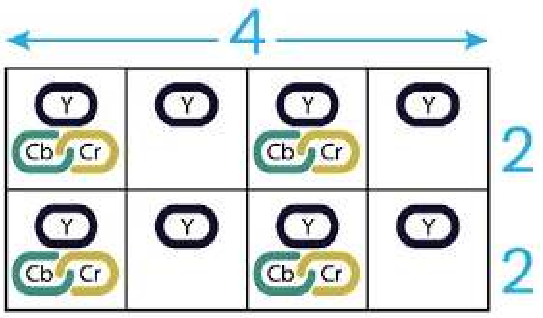
4:4:4 is the full bandwidth, mathematical equivalent to RGB. Converting an RGB signal to 4:4:4 and back again is completely lossless. The meaning of each number is as follows:



- The first number in 4:4:4 represents the sample width in pixels: 4
- The second is the number of color units on the first row of the sample (keeping in mind each C_b and C_r components together count as a single, co-dependent unit): 4
- The third number counts the color units on the second row: 4

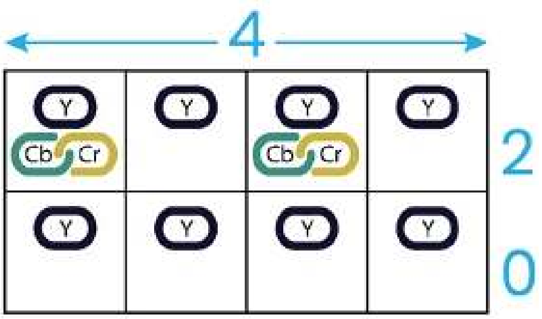
4:2:2

The sample size has not changed, so the first number remains 4. But half the color units are removed on each row, leaving 2 on the first row and 2 on the second. Therefore, 4:2:2. The result across a full picture is a halving of the horizontal color resolution (every second column) while retaining full vertical color resolution (every row). Any detriment to picture quality is imperceptible to most people.



4:2:0

4:2:0 retains the same sample size of 4, and retains 2 color samples on the top row. However, it removes the remaining color information from the second row, resulting in 0 for the third number.



The big advantage of 4:2:0 is that it halves the bandwidth compared to 4:4:4. Doing the basic math:

- 4:4:4 — the 4x2 sample contains 24 components (8 each of Y, C_b, and C_r).
- 4:2:0 — the 4x2 sample contains 12 components (8 x Y, but only 2 x C_b and 2x C_r).

The downside is that 4:2:0 halves both the horizontal and vertical color resolution. The color from one pixel is then shared across its three adjacent pixels, making one larger block of color (2x2 pixels). This can cause "jaggies" on diagonal edges in any given frame, and compromise sharpness and contrast as the intersection of white and black pixels may average to gray, or colors may average to an all-new color. But the good news is that we still generally can't perceive its impact in motion video, especially with today's higher resolutions (as each sample is a proportionally smaller area of the picture) and better video processing.

Codec-Based Compression

Stored and distributed media are invariably subject to codec-based compression. “Codec” is a contraction of **co**de-**dec**ode, indicating the use of an algorithmic process to reduce the number of bits in the video file. It’s worth noting that codec-based compression and chroma subsampling are not mutually exclusive; in fact, it is quite the opposite as compressed media— particularly at consumer level— typically contains 4:2:0 video. The two are used together to yield the greatest reduction in bit rates. However, only one form of codec-based compression can be used at any given time.

Video codecs can be generalized into one of two types: *intra-frame* and *inter-frame:*

- **Intra-frame** compression works one frame at a time, completing one before moving on to the next. This makes it relatively fast, but less efficient in terms of data reduction capacity. Compression ratios vary from as little as 1.3:1, with up to around 20:1 being common. For example, this could reduce a 4K UHD 24fps 24bpp stream from 7.128Gbps to around 350Mbps to work over a 1GbE network.

- **Inter-frame** compression reads several frames ahead, which takes longer but results in far bigger savings in file size and transmission rate. This can yield compression ratios of 300:1 or better. The same 4K UHD example as above could be reduced from a raw rate of 7.128Gbps to under 24Mbps to work over an internet connection.

An important consideration is the impact of compression on image quality. This can be classified into lossless or lossy:

- **Lossless** compression, as the name suggests, produces zero mathematical loss through the process, with a post-compression image being identical to the original. This can only be achieved with very light compression ratios, typically 2:1 or less.

- **Lossy** compression produces an approximation of the original, resulting in some unrecoverable loss. How much is acceptable depends on the application and user expectations. Most contemporary applications are generally described as “visually lossless.”

Visually Lossless Compression

Visually lossless is a highly subjective term. To some it might mean that the video looks fine if viewed in a different room and on a smaller, inferior screen to the original. Clearly that is not ideal. The general expectation is that visually lossless should mean that a user can't differentiate original and compressed media when viewed in comparable conditions, or even side-by-side. Sometimes this might be critical, or potentially even a matter of safety. To that end, the **Federal Agencies Digitization Guidelines Initiative**, a collaboration of several US Government agencies, formally defined "visually lossless" compression as:

> "A form or manner of *lossy compression* where the data that is lost after the file is compressed and decompressed is not detectable to the eye; the compressed data appearing identical to the uncompressed data."

FA DGI

Medical applications describe requirements as **Diagnostically Acceptable Irreversible Compression** (DIAC), meaning the compression will not impact the image in any way that could compromise the diagnostic outcome. Being lossy doesn't in itself matter, as long as the purpose and expected result is defined and served. The alternative within available bandwidth might be a much lower resolution, which could be even more detrimental to picture quality than that of compression.

TYPES OF COMPRESSION

There are many and varied compression codecs, and even more variations and performance levels within each. Here we'll focus on just two intra-frame codecs, JPEG 2000 and DSC, as well as two inter-frame codecs, H.264 and H.265, for comparison.

JPEG 2000

JPEG 2000 (JP2) is an intra-frame codec developed by the Joint Picture Experts Group as a replacement for the original JPEG photo compression codec. It was released in 2000, hence its name. However, in the context of video, JPEG 2000 is typically used as shorthand for **Motion JPEG 2000** (MJ2). Where the original Motion JPEG (MJPEG) delivered every frame as a separate JPEG image, also adding audio, each frame of MJ2 is coded independently using JP2.

The MJ2 process is quite sophisticated, capable of breaking up a frame into macroblocks of any size from 8x8 (like original JPEG) right up to the full image. Many common applications use blocks of 16x16. Image quality can be excellent, while latency is typically in the order of 30ms, or approximately one frame of video (depending on the refresh rate, of course).

DSC

Display Stream Compression (DSC) takes a completely different intra-frame approach. Developed by VESA and originally released in 2014, DSC is a form of line code compression as it slices up each frame horizontally, working with small groups of lines at a time. It is a very lightweight codec, achieving ratios up to 3.75:1, but that makes it extremely fast (latency measured in microseconds) while retaining exceptionally high image quality. Version 1.1 was designed for use with RGB video up to 12 bits per color. The release of DSC 1.2a in 2017 added support for 4:2:2 and 4:2:0 chroma subsampling, and up to 16-bit color with RGB.

H.264

H.264, also known as Advanced Video Codec (AVC) is an inter-frame codec developed by the ITU-T and based on MPEG, part 10. It is the ubiquitous deep compression standard for broadcast and streaming media, and in packaged media such as Blu-Ray DiscTM.

Part of what makes this format so efficient is its ability to read ahead to optimize compression across frame groups. But reading ahead also means it inevitably takes longer; sometimes as low as 100ms, but many examples extend to 200-500ms of latency. That's the trade-off for achieving a much lower bit rate while retaining excellent picture quality.

H.264 works by dividing a series of frames into three types:

- **I-frame**, short for Inter-frame. These are key frames that are encoded in their entirety, and used as a reference for the other types below:
- **P-frame**, or Predicted frame. These delta frames only encode changes that have occurred between the current and preceding frame.
- **B-frame**, or Bidirectional predicted frame. These encode differences between the current frame and the preceding and following frames to optimize quality and compression.

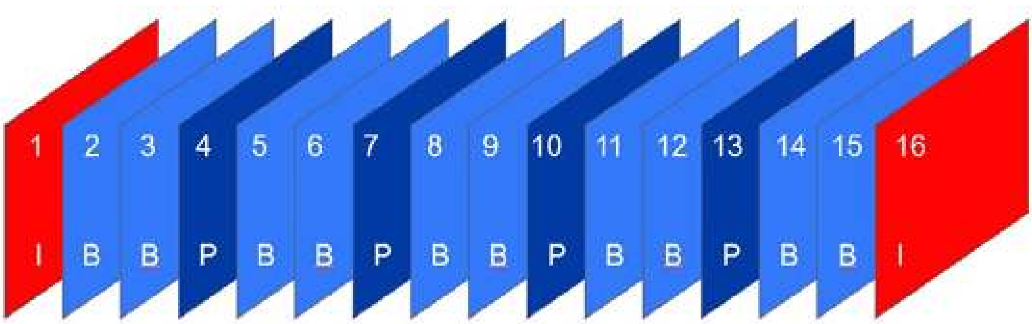


Figure 1 Example of I-, P-, and B- frame sequence used in H.264

Similar to JPEG 2000, H.264 also partitions a frame of video into macroblocks to work with smaller, manageable chunks. H.264 typically uses macroblocks of 4x4, 8x8, or 16x16.

H.265

H.265 is the next generation codec after H.264. Known as High Efficiency Video Coding (HEVC), it achieves comparable picture quality to H.264 but with a much lower bit rate, with savings up to 50%.

Such a significant improvement was made possible by processing information with coding tree units (CDUs) instead of macroblocks. CDUs can be anything from 4x4 up to 64x64 in size. The picture can be partitioned into variable sized structures, so large areas with little variation can be encoded far more efficiently, with smaller blocks used in areas of greater detail and change.

Adoption of H.265 is growing fast, but H.264 still predominates in applications such as broadcast and streaming media. The ITU-T published H.266 in 2020 as the next generation again, to support the fast-evolving media space.

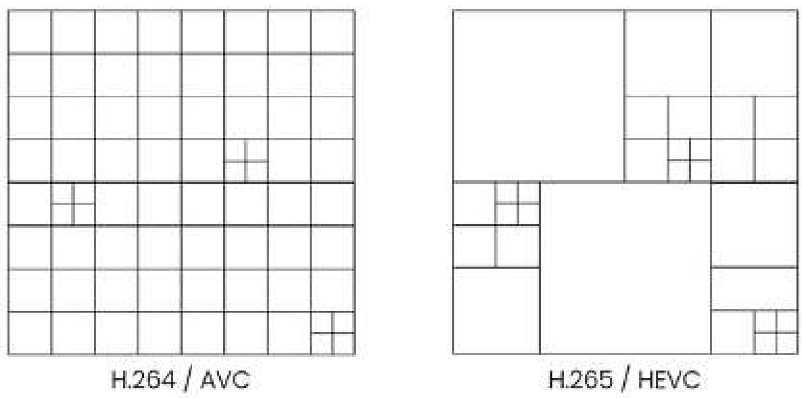


Figure 2 Simplified representation of H.264 macroblocks vs H.265 coding tree units

BALANCE AND COMPROMISE

Compression generally requires a balance between three key parameters:

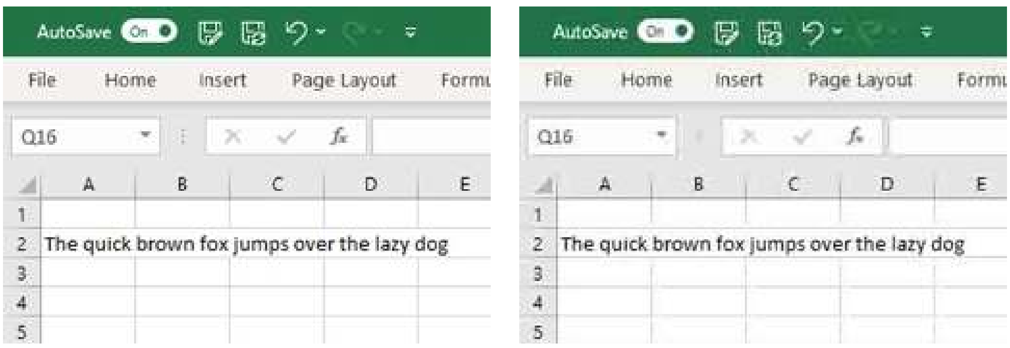
1. Image quality
2. Bit rate
3. Latency

Achieving a combination of high image quality, low bit rate, and low latency is possible but requires a lot of processing; something that usually equates to higher cost. It depends on the application, but pragmatic approaches entail some degree of compromise.

Image Quality

As mentioned earlier, most consumer media is highly compressed for delivery to a user's source device, and only uncompressed from the HDMI output, while computer and gaming sources are natively uncompressed. Video quality from the source output is beyond the scope of this paper; the concern here is how the performance of the source media can be maintained over the link to the display, and the impact of any compression. Two key areas of vulnerability include:

- **Dynamic range** — The advent of deep color and HDR video require a minimum of at least 10 bits per component to be maintained end-to-end through the signal path. This may be incompatible with some compression systems, resulting in inferior black levels and color range.
- **Text legibility** — When transporting signals from a computer, such as spreadsheets, text legibility is important. Block-based compression codecs such as JPEG can result in "ringing" artifacts around the text, and contouring of the edges, resulting in a loss of contrast and sharpness. Codecs that work line by line instead of with blocks are far better at maintaining character edges without artifacts. For example, portable network graphics (PNG) for still images, or DSC for video. Of course, no compression at all is still best for optimal graphics performance and crisp text!



Above: Uncompressed (left) vs high level of jpeg compression with "ringing" reducing quality (right)

Integrator tip

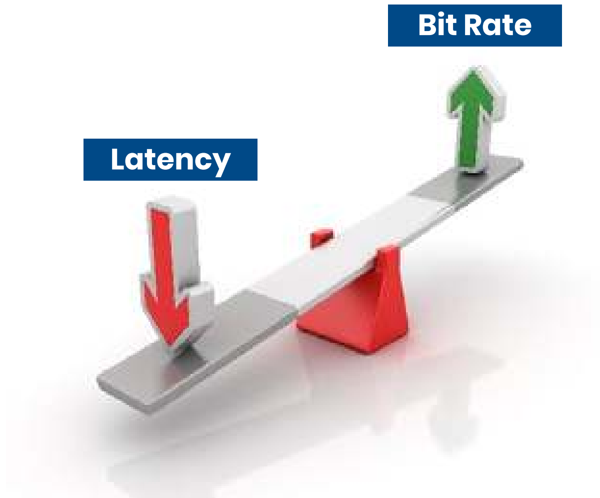
A bigger barrier to text legibility is actually that of video scaling, not compression. For best results, always match the output resolution of the source to the native resolution of the display, irrespective of whether the link uses compression or not.

Target Bit Rate vs Latency

The main compromise with video compression is typically between bit rate and latency. These are usually inversely proportional: to achieve a lower relative bit rate requires higher compression and more processing, in turn increasing latency, and vice versa.

Video latency can impede user experience: delays in keyboard and mouse inputs during conference room presentations, visual response delays using a remote control while navigating on-screen menus, or causing a lipsync error if the audio is reproduced separately before the compressed video transport to the display. Studies have found that we can perceive visual stimuli as low as 13ms, and in fact process entire images at that rate, so latency at or below this level is ideal to be perceived as "real time."

Some manufacturers may quote latency in frames per second. This of course depends on the frame rate in application, but is typically based on 30fps wherein one frame of latency equals 33ms. Some products may carry claims of "no latency" even where latency is indeed a characteristic; this is generally a marketing decision based on a pragmatic view, or perhaps a rounding factor. Whatever the case, it is advisable for system specifiers to identify the maximum acceptable latency in their AV systems, and thoroughly research products for qualified use.



Interoperability

When determining if or how much compression is needed, interoperability is important in ensuring deployed systems will perform predictably and reliably. Primarily, this means that the transmitter (Tx) and receiver (Rx) both need to support the same method. Another significant factor is whether the AV signal contains any embedded metadata from the source that may be incompatible with compression, and require extraction from the signal for separate handling over the transport, and re-embedded in the signal at the other side.

Metadata can be described as "data about data." It contains information about how the display should use the video stream. An example is information about whether the signal is RGB or Y'CbCr colorspace. It is especially important with HDR video as specific metadata provides tone mapping instructions for the display; incorrect or missing metadata can result in errors like skewed colors, or the dynamic range being crushed, or the overall image appearing too dark.

Reliable interoperability is best achieved with adherence to standards, but sometimes even that alone may not be enough; there can still be variations, interpretations, and conflicts between chipsets, etc. System designers and integrators are well advised to seek out not only standards compliance and feature support in video transport systems, but preferably also testing and certification of interoperability.

COMPRESSION IN HDBASET

In developing any video transport, the need for compression is determined simply by comparing required bandwidth to that natively available in the link. From there, the type and amount (ratio) of compression is selected to achieve the desired balance and performance.

For a decade, the native bandwidth capabilities of HDBaseT proved sufficient to support the vast majority of AV transmission requirements. The rise of 4K Ultra HD video didn't in itself trigger the need for more bandwidth in HDBaseT. After all, 4K was introduced with the HDMI 1.4 specification in 2009, before that of HDBaseT. This included sub-30Hz media that still overwhelmingly dominates to this day, such as movies at 24fps. Even the release of the HDMI 2.0 specification in 2013 with its 4K/60 capability was dominated by 8-bit 4:2:0, retaining 10Gbps compatibility for mapping to the 8Gbps link speed of HDBaseT (as HDBaseT removes the 20% TMDS encoding overhead from an HDMI signal).

The factors that DO ultimately push bandwidth demands to beyond the uncompressed capability of HDBaseT versions 1.0 and 2.0 include any combination of at least two of the following parameters:

1. Sources with native RGB/4:4:4 output, such as a computer or gaming console graphics processing unit (GPU), or a source device that converts 4:2:0 media to 4:4:4 output.
2. The presence of HDR video and the need to maintain at least 10 bits per subpixel.
3. Increasing frame/refresh rates beyond 30Hz.

For the most part, these combinations fit within the capabilities of the HDMI 2.0b specification. Its 18Gbps raw capacity actually carries payloads of up to 14.25Gbps, again accounting for the TMDS overhead (17.82Gbps max signal x 8/10 TMDS). This means that an effective compression ratio of no more than 2:1 is needed to support these formats with HDBaseT.

HDBaseT Approved Compression Technology

The very low compression ratio requirement to enable 4K/60 4:4:4 or 4K/60 HDR 4:2:2 to work over an HDBaseT 1.0 or 2.0 link ruled out the need for H.264/265, or even JPEG 2000 (MJ2) compression. After all, those codecs target much higher compression ratios than are needed, and would result in noticeable latency. The HDBaseT Alliance's absolute priority to maintain imperceptible latency led to the selection of **DSC** as the best possible candidate for manufacturers to optionally implement visually lossless compression into HDBaseT products. Latency is measured in mere double-digit microseconds, orders of magnitude below the human perception threshold!

HDBaseT is not alone in endorsing DSC as the preferred, powerful light compression method for AV transmission:

- DSC is part of the DisplayPort 1.4 specification to enable 8K/60 video over an HBR3 32.4Gbps link, DSC features in the HDMI 2.1 specification to enable format support beyond the native 48Gbps link speed, or to reduce cable stress in links below 48Gbps.

Both DisplayPort and HDMI technologies each have their own strict controls to ensure interoperability between supporting devices; the same goes for the implementation of DSC in HDBaseT. The HDBaseT Alliance has also qualified the requirements and methods for manufacturers to use in achieving maximum performance and interoperability of their DSC-enabled HDBaseT products.

It is worth noting that although these three interfaces— HDBaseT, DisplayPort, and HDMI— each separately employ optional DSC, the compressed signal cannot pass from one interface type to another without intermediary decompression.

Third Party Compression

The use of any compression method over HDBaseT other than DSC is NOT approved by the HDBaseT Alliance. However, its use is optional, just as the use of other compression methods cannot be prohibited and manufacturers are free to innovate. The caveat is that the use of any non-approved method will drop the negotiated resolution between two products to 4K60 4:2:0 or 4K30 4:4:4.

As a word of caution, some manufacturers may implement chroma subsampling and bit depth down-sampling to achieve the desired reduction in the overall data rate. For example, a 4K/60 10-bit HDR 4:2:2 signal that requires 17.82Gbps through HDMI might be subsampled to 4:2:0, and the 10-bit signal down-sampled to 8-bit, together enabling the aggregate signal to drop below the uncompressed threshold of HDBaseT 1.0 or 2.0 (equivalent to 8.91Gbps in HDMI). It may then be up-sampled again to emulate the 10-bit 4:2:2 source at the other side, but once half the color and three-quarters of the dynamic range has been discarded, there's no getting them back!

Such solutions may be promoted as uncompressed on the basis that no codec-based compression algorithm is applied, however the impact on image quality could be worse than with codec-based compression, depending on the media. This may be acceptable in some installation settings, so long as all stakeholders are aware and approving of any compromises.

HDBASET 3.0: ASSURING INTEROPERABILITY

Of course, the ultimate in maintaining maximum performance and interoperability between devices is to keep the signal uncompressed in the first place! HDBaseT 3.0 doubles the downstream baud rate from the 500 PAM-16 symbols per second of HDBaseT 1.0/2.0, to 1,000 PAM-16 symbols per second. Each symbol is composed of 4 bits, with signals across all four twisted pairs resulting in a native uncompressed link speed of 16Gbps over a standard Cat 6A cable up to 100m (328 ft). That's equivalent to more than 18Gbps in HDMI, making it fully compatible with all AV formats supported by HDMI 2.0b, and all natively uncompressed.

This also means that any metadata embedded in the signal need not be extracted, vastly improving interoperability. Similarly, 4K/60 media encoded with Dolby Vision standard mode uses a proprietary RGB tunnelling method that is incompatible with link compression, but is compatible with the uncompressed HDBaseT 3.0 link.

HDBaseT 3.0 is also fully backwards compatible with versions 1.0 and 2.0 — any connection between an HDBaseT 3.0 device and an earlier generation device will establish the maximum common features, including AV format support and 5Play capabilities.

PRODUCT TESTING AND CERTIFICATION

The HDBaseT Alliance has long maintained a stringent testing and certification program to assure compliance and interoperability of HDBaseT-enabled products. This includes HDBaseT versions 1.0 and 2.0, both uncompressed or with visually lossless compression (DSC), or the latest technology products utilizing HDBaseT 3.0.

When it comes to video compression, some simple guidelines for certification of HDBaseT products include:

1. Any product certified to support 4K/30 4:4:4 implies 8-bit video, equivalent in bandwidth to 4K/30 up to 12-bit 4:2:2 for HDR, and 4K/60 8-bit 4:2:0. These can be assumed to not use compression.
2. Any product using a non-approved method of compression can only be certified for its uncompressed capability. For example, an HDBaseT extender claiming support for 4K/60 4:4:4 but without using DSC in the approved method can only have their product tested and certified to 4K/30 4:4:4, providing it meets the corresponding performance criteria.
3. Any product utilizing HDBaseT 3.0 can be tested and certified to 4K/60 4:4:4 uncompressed, and is backwards compatible with earlier versions of HDBaseT, as mentioned previously.

FUTURE POSSIBILITIES

With the advent of 8K video, and HDMI and DisplayPort increasing capacity to 48Gbps (HDMI 2.1) and 80Gbps (DisplayPort 2.0) respectively, it is easily conceivable that demand for more than 18Gbps through HDBaseT may arise. The combination of DSC technology and HDBaseT 3.0 architecture can make this a reality.

The flagship formats to work uncompressed through HDMI 2.1 are 8K/30 12-bit 4:4:4, and 8K/60 12-bit 4:2:0, each of which is transmitted at 48Gbps. Applying a 3:1 compression ratio brings this down to 16Gbps, which neatly aligns with the native speed of HDBaseT 3.0. And that's not even taking the HDMI encoding overhead into account (that would further reduce it)! This would also be more than enough for some premium graphics formats such as Apple 6K, which has a raw data rate in the order 40Gbps at 10-bit RGB.

Theoretically, with appropriate signal processing, HDBaseT 3.0 with the maximum capability of DSC (3.75:1 compression) could support up to the equivalent of 67.5Gbps in HDMI FRL, enabling 8K/60 12-bit 4:2:2, or 8K/60 8-bit 4:4:4.

CONCLUSION

Demand for higher video resolution with more bits per pixel is ever-increasing, and bandwidth along with it. When it comes to provisioning this through a video transport, the options are simple: use compression to reduce the bit rate over the link or increase the bandwidth of the system. HDBaseT now makes both available.

The word "compression" may draw some negative connotations, depending on the context. But the reality is that it's everywhere, and with video, picture quality from a vast array of sources is generally very good to excellent. Deep compression is used for the global distribution of video, and more recently, light compression has become a common fixture at either end too — very light "mezzanine" compression at the capture and post-production end before distribution, and now optionally at the last hop from a consumer's source device to a display.

The HDBaseT Alliance conducted exhaustive research and testing to approve Display Stream Compression (DSC) as the best compression codec to enable the equivalent of 18Gbps HDMI signals over an HDBaseT 1.0 or 2.0 link, without the common drawback of latency that accompanies many compression codecs. But this still adds complexity that poses challenges for interoperability. As such, an uncompressed link from the source is still always best.

HDBaseT 3.0 answers this challenge, supporting uncompressed 4K/60 4:4:4 (8-bit), 4K/60 12-bit 4:2:2 with HDR, or 4K/60 Dolby Vision over 100m of industry standard Cat 6A cable, for unprecedented bandwidth, interoperability, and backwards compatibility with HDBaseT versions 1.0 and 2.0. This lifts the ceiling for long-length connectivity for Pro AV, commercial, medical, and consumer video; from conference facilities to places of worship; from classrooms to living rooms.

Furthermore, combining HDBaseT 3.0 with DSC is the key to unlocking 8K video over long lengths of twisted pair cable. It's a very high bandwidth pathway ahead!

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