WHITE PAPER

4K over 1 Gbps Video Distribution

Exploring the Challenges and Solutions

The rapid increase in commercially available display resolutions is driving demand for video distribution and switching solutions that can accommodate the bandwidths required for those resolutions. Unfortunately, for applications that require video distribution beyond a single room, there are very few existing standards that can accommodate this bandwidth, and those that do have strict cable requirements or require the use of optical fiber. However, by compressing the video using JPEG2000, the bandwidth can be significantly reduced, allowing it to be transmitted using standard category cable and switched over a user's existing IP network.

This paper explores the challenges of and solutions for 4K video distribution by exploring the following points:

- The bandwidths required for uncompressed UHD distribution are large enough that they limit the number of options available for video distribution and these options all require the use of dedicated cabling.
- Distributing 4K video at bandwidths less than 1 Gbps allows for the use of standard Ethernet cable and switches at distances up to 300 ft using standard Cat 5e cable.
- Distributing 4K video at bandwidths less than 1 Gbps requires compression.
- Modern intraframe codecs, such as JPEG2000, allow for low-latency, high quality video compression.

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INTRODUCTION

Professional video applications are demanding higher resolutions and frame-rates in order to preserve fidelity and optimize the user experience. Specifically, 4K (2160p60), with a full-color bandwidth of 12 Gbps[1], is replacing 1080p60, with a full-color bandwidth of 3 Gbps, as the professional resolution of the future. This presents a challenge since none of the current distribution technologies (Gigabit Ethernet, 10 Gigabit Ethernet, 3G-SDI, and HDBaseT) support full color sampling at 2160p60 resolutions. Gigabit Ethernet (GbE) at 1 Gbps and 3G-SDI at 2.97 Gbps do not even support full color uncompressed 1080p60.

Since no distribution technology is being considered with bandwidths at or above 12 Gbps (with the exception of the proposed 12G-SDI broadcast standard), compression becomes the only alternative for distribution over 20-30 feet. The good news is that there are several compression options available, each with their own advantages and disadvantages.

Professional AV designers and integrators have historically leveraged uncompressed video distribution to deliver video at the lowest latency and highest quality. However, the demand for increasing resolutions is challenging available distribution technologies, and those designers and integrators will need to determine which switching, distribution, and compression technology best suits their 4K applications.

VIDEO BANDWIDTH

High Definition (HD) and Ultra-High-Definition (UHD) video content requires substantial bandwidth to transport in an uncompressed format. Several techniques can be used to reduce the required bandwidth, but these can impact the overall video quality.

The first of these is chroma subsampling, which takes advantage of the fact that human vision can better detect changes in luminance than in color. Full color sampling at 4:4:4 is uncompressed video at the highest fidelity. 4:2:2 color sampling reduces the bandwidth by

[1] Bandwidths in this paper are raw bandwidths and will differ from TMDS bandwidths. Please see Table 1 for information on how these bandwidths are calculated.

a third and is the standard for broadcast and cinema. 4:2:0 color sampling reduces bandwidth by a half and is the standard for streaming video.

The second technique is to reduce the frame rate. A video at 30 fps will use half the bandwidth of a video at 60 fps. However, certain content, such as PC graphics or digital signage, will look less smooth at the reduced frame rate.

Table 1 shows the uncompressed video bandwidth required for common HD and UHD video resolutions at different color sampling rates and frame rates. Note that most of these resolutions exceed 1 Gbps.

Table 1. Uncompressed video bandwith for common HD and UHD resolutions.

Resolution	Pixel Count	Frame Rate	Color Sampling	Bandwidth*
1080p60	1920x1080	60 fps	4:4:4	3 Gbps
1080p60	1920x1080	60 fps	4:2:2	2 Gbps
1080p60	1920x1080	60 fps	4:2:0	1.5 Gbps
1080p30	1920x1080	30 fps	4:4:4	1.5 Gbps
1080p30	1920x1080	30 fps	4:2:2	1 Gbps
2160p60	3840x2160	60 fps	4:4:4	12 Gbps
2160p60	3840x2160	60 fps	4:2:2	8 Gbps
2160p30	3840x2160	30 fps	4:2:2	4 Gbps

* These are the raw bandwidth values calculated as (vertical pixels) x (horizontal pixels) x 8 bits/pixel x 3 colors/pixel x (frame rate). These bandwidths do not include blanking intervals or 8b/10b encoding as those do not apply to the encoded data and will be lower than HDMI (TMDS) bandwidths.

VIDEO DISTRIBUTION

There are a number of video distribution and switching technologies available to integrators. These technologies have different maximum bandwidths, cable requirements, and transmission distances that can impact the overall design. The most common of these technologies are Gigabit Ethernet (GbE), 10 Gigabit Ethernet (10GbE), HDBaseT, and 3G-SDI.

Table 2 provides the advantages and disadvantages of various video distribution technologies.

Table 2. Comparison of various video distribution technologies.

Technology	Advantages	Disadvantages	Distance (typical)
Gigabit Ethernet (GbE)	• Mature • Widely deployed • Inexpensive • Works with existing installed Cat 5e • Supports PoE • Stringent standards • Large number of vendors	• Bandwidth supports uncompressed 1080p30 only • Requires higher compression ratio	• Twisted-pair cabling (Cat-5, Cat-5e): 100 meters • Twisted-pair cabling (Cat-6, Cat-7): 100 meters • Multi-mode fiber: 220 to 550 meters • Single-mode fiber: 5 km
10 Gigabit Ethernet (10GbE)	• Widely deployed • Supports uncompressed video up to 2160p30 • Stringent standards • Backwards compatibility with GbE	• Approx 10x cost per port vs GbE • Doesn't support PoE • Reduced number of vendors compared to GbE	• Twisted-pair cabling (Cat-5, Cat-5e): Not available • Twisted-pair cabling (Cat-6, Cat-7a): 100 meters • Multi-mode fiber: 300 to 400 meters • Single-mode fiber: 10 km

HDBaseT	• Supports uncompressed video up to 2160p30 at 4:4:4 (2160p60 video at 4:2:0) • Supports PoC (Power-over-Cable) • Dedicated infrastructure guarantees delivery of audio and video data • HDBaseT connectivity on source and display devices eliminates need for separate encode/decode devices • Certification program allows *certified* devices to interoperate.	• Single vendor for core chip • Cost of dedicated infrastructure	• Twisted-pair cabling (Cat-5e): 100 meters* • Twisted-pair cabling (Cat-6, Cat-7a): 100 meters
3G-SDI	• Widely deployed in broadcast applications • Standardized • SDI connectivity on source and display devices eliminates need for separate encode/decode devices • Dedicated infrastructure guarantees delivery of audio and video information	• Bandwidth supports 1080p60 4:2:2 only • Doesn't support PoE • Cost of dedicated infrastructure	• Coax: 100 meters (depending on cable quality)

* Note that some manufacturers of HDBaseT products advise against the use of Cat-5e for their intended applications and instead recommend the use of Cat-6, Cat-7a, or proprietary cable.

COMPRESSION OPTIONS FOR PROFESSIONAL-GRADE VIDEO

In order to distribute high-resolution video using the distribution and switching technologies available today, some level of compression needs to be considered. Table 3 lists the most commonly available video compression technologies along with their advantages and disadvantages. Each of these compression options can be implemented for any of the distribution technologies in Table 2.

Latency and video quality are frequent concerns when using video compression for professional applications. The proliferation of internet streaming sites that use MPEG2, MPEG4, or H.264 are responsible for most of this apprehension. These sites transmit store-and-forward content over very low-bandwidth internet connections, and they require highly compressed video to do-so. The good news is that careful selection and implementation of compression technology can result in high video quality with low latency.

Since transport latencies for each of these technologies are well below a frame time, video latency and fidelity are determined by the compression codec. JPEG2000 and Line-Based Wavelet Compression (LBWC) perform all their compression on or within a single frame, and therefore do not have added latencies associated with compression algorithms that depend on multiple frames. Furthermore, JPEG2000, used by the SVSI N2000 products, supports tiling to break frames up into smaller pieces for faster transport and greatly reduced latency. With tiling, JPEG2000 latency can be reduced from the full-frame value of 32-50 msec to 10-15 msec.

Line-Based Wavelet Compression (LBWC), used by the SVSI N1000 products, operates by compressing a single line at a time. Encoding is very fast (and end-to-end latency is low), since it operates on a single line at a time and then transmits it. The resulting image quality is also very high; however, the compression ratio is typically on the order of 4-6x.

H.264 compression achieves very high compression ratios by performing inter-frame compression that accounts for motion in the image. However, because of the dependency on multiple frames to encode the image, latencies will necessarily be higher. This dependency also creates a lower tolerance to bit errors – a single error can impact multiple frames of video. By reducing the H.264 key frame interval, lower latencies at higher video quality can be obtained but at the cost of higher bandwidths. Tiling is not compatible with H.264, and for this reason, no H.264 vendor advertises zero-frame latency products.

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Table 3. Advantages and disadvantages of different compression technologies.

Codec	Description	Advantages	Disadvantages
H.264	Inter-frame Motion-based Compression	• High compression ratio – 300x-2000x • Relatively inexpensive decoders • Software decode option • User-adjustable bandwidths (50kbps - 10Mpbs)	• Multiple-frame latency • Reduced video fidelity • Expensive encoder costs • Low bit-error tolerance • No support for 2160p60 currently
JPEG2000	Intra-frame Compression	• High video fidelity • Moderate compression ratio – 6x-25x • High bit-error tolerance • Zero-frame latency • User-adjustable bandwidths (25-800Mbps)	• Intensive processing precludes software encode or decode
LBWC	Line-based Wavelet Compression	• High video fidelity • Minimal encode and decode processing • Zero-frame latency	• Minimum compression ratio – 4-6x or less

COMPRESSION QUALITY

Users unfamiliar with Networked AV will invariably question video fidelity when hearing that the video is compressed. Today's compression codecs are very sophisticated and allow for video quality comparable to that of uncompressed video for many applications.

The two wavelet-based compression codecs – JPEG2000 and LBWC – allow zero-frame latency (using tiling) at high video fidelity compatible with professional applications. High-contrast, high-spatial-frequency computer-generated imagery presents the worst-case scenario for both of these compression algorithms. Dense spreadsheets and detailed maps are two examples of worst case imagery. Below are several screen-shots demonstrating video quality for a 2160p image of a representative worst-case spreadsheet both with and without JPEG2000 compression. The first image is the 2160p full uncompressed spreadsheet image with which subsequent images are compared. The second image is the same uncompressed image shown at 100% to provide a reference for comparison with the subsequent compressed images.

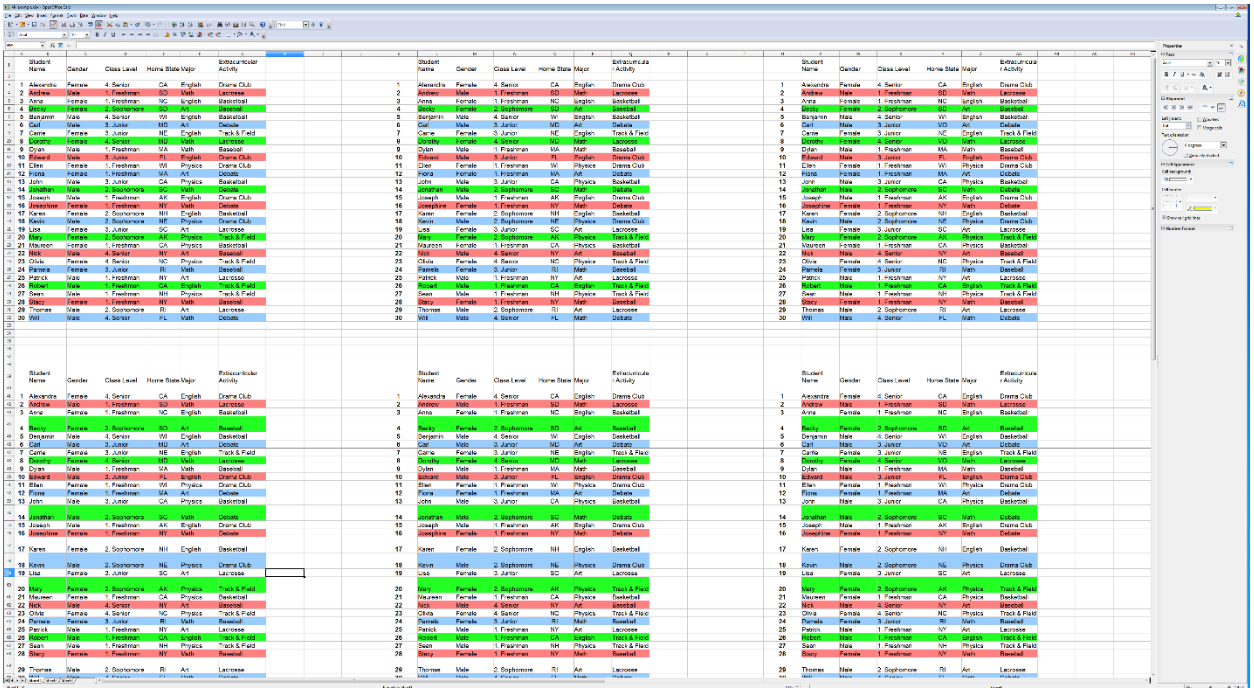


Figure 1. Uncompressed 2160p image at full-color sampling of 4:4:4

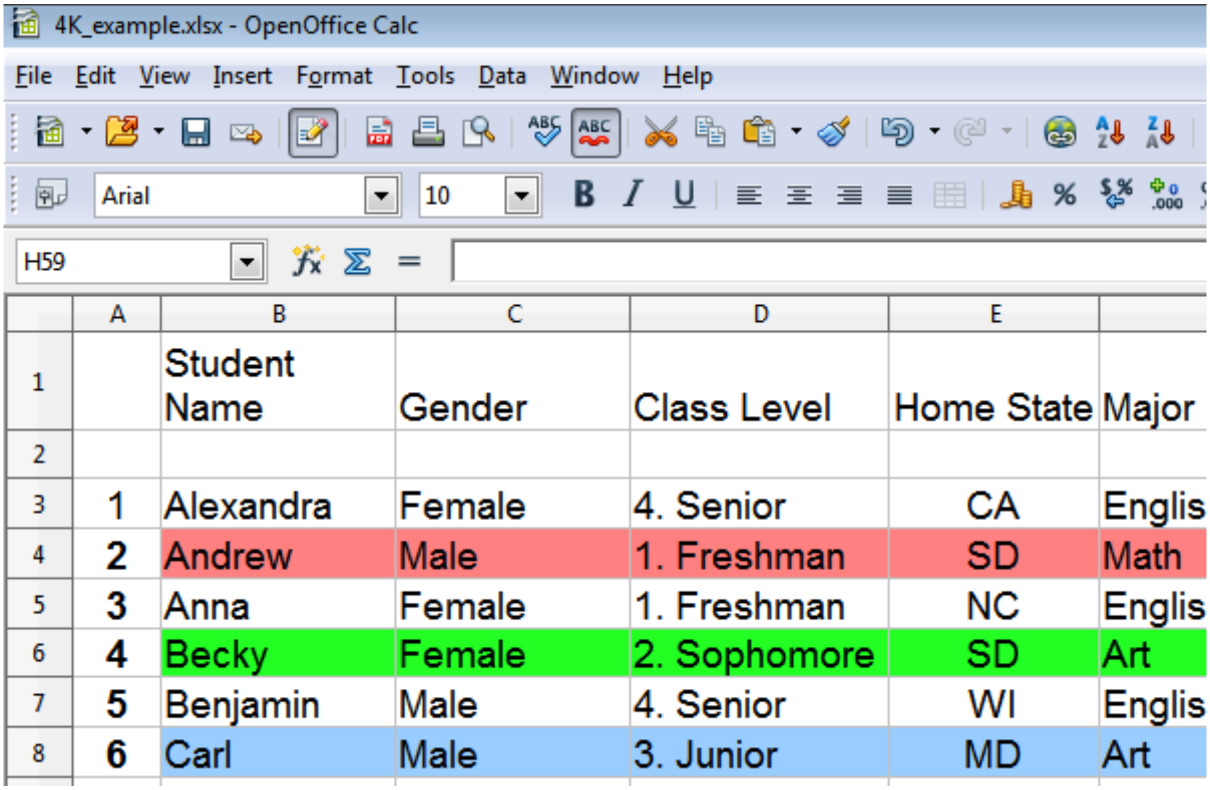
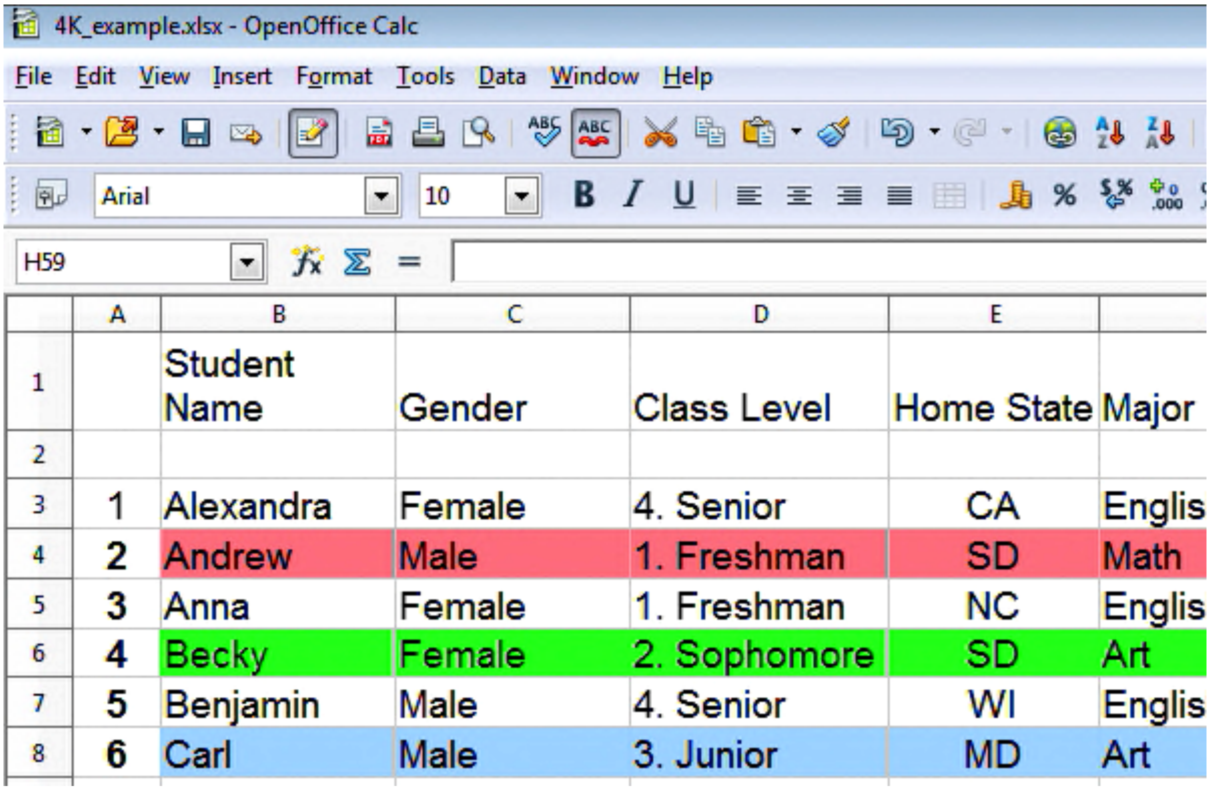
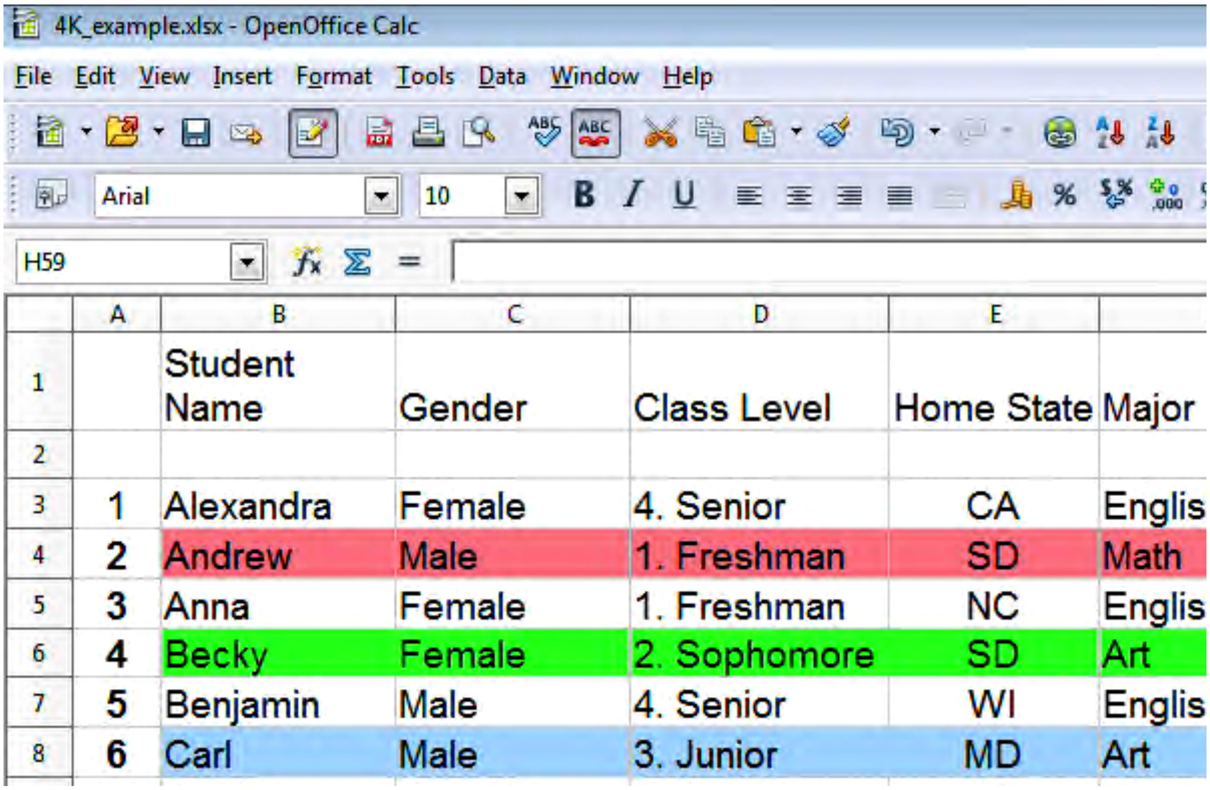


Figure 2. Top left corner of uncompressed 2160p image shown at 100% to show any details of compression artifacts in subsequent images



	A	B	C	D	E	
1		Student Name	Gender	Class Level	Home State	Major
2						
3	1	Alexandra	Female	4. Senior	CA	Englis
4	2	Andrew	Male	1. Freshman	SD	Math
5	3	Anna	Female	1. Freshman	NC	Englis
6	4	Becky	Female	2. Sophomore	SD	Art
7	5	Benjamin	Male	4. Senior	WI	Englis
8	6	Carl	Male	3. Junior	MD	Art

Figure 3. Top left corner of JPEG2000 compressed 4:2:2 2160p30 image shown at 100%. Video bandwidth of 400 Mbps (the default JPEG2000 bandwidth for the SVSI 4K N2000 encoder) is compatible with GbE networks and very few compression artifacts are visible. 2160p60 is the same quality but at 800-Mbps.



	A	B	C	D	E	
1		Student Name	Gender	Class Level	Home State	Major
2						
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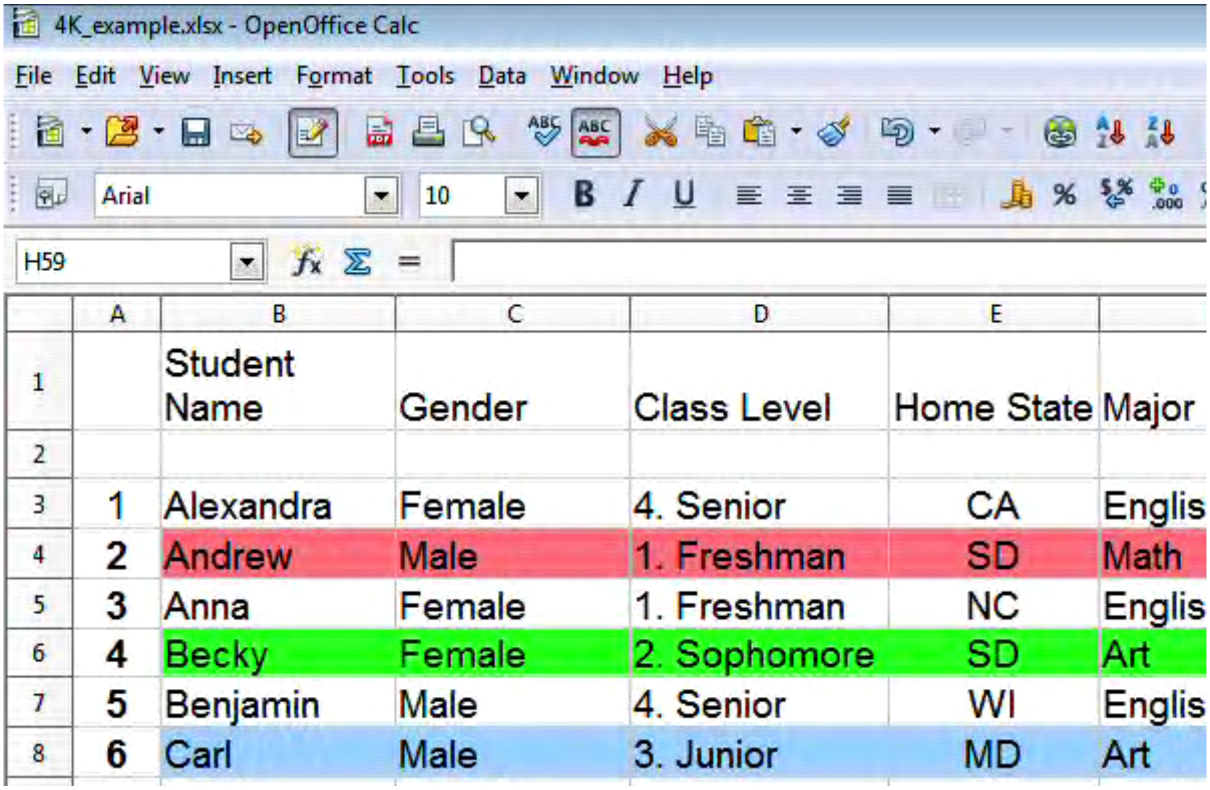
4	2	Andrew	Male	1. Freshman	SD	Math
5	3	Anna	Female	1. Freshman	NC	Englis
6	4	Becky	Female	2. Sophomore	SD	Art
7	5	Benjamin	Male	4. Senior	WI	Englis
8	6	Carl	Male	3. Junior	MD	Art

Figure 4. JPEG2000 4:2:2 compressed to a bandwidth of 200 Mbps shown at 100%. Although readable at reasonable magnification, compression artifacts are visible. GbE drops can accommodate four of these streams.



	A	B	C	D	E	
1		Student Name	Gender	Class Level	Home State	Major
2						
3	1	Alexandra	Female	4. Senior	CA	Englis
4	2	Andrew	Male	1. Freshman	SD	Math
5	3	Anna	Female	1. Freshman	NC	Englis
6	4	Becky	Female	2. Sophomore	SD	Art
7	5	Benjamin	Male	4. Senior	WI	Englis
8	6	Carl	Male	3. Junior	MD	Art

Figure 5. JPEG2000 4:2:0 compressed to a bandwidth of 400 Mbps shown at 100%. It is also readable at reasonable magnification but compression artifacts are visible.

The video quality for 4:2:2 JPEG2000 compressed images at 400-Mbps are virtually identical to the original uncompressed image. However, compression artifacts can be seen in both of the 4:2:0 sampled images and in the 4:2:2 200-Mbps images. JPEG2000 compressed 4K30 4:2:2 video at bandwidths of 400-Mbps are the default settings per stream for SVSi's N2x51 products allowing high quality 4K video over GbE networks at zero-frame latency. 4K60 4:2:2 would have the same quality but at a bandwidth of 800-Mbps making it still compatible with GbE drops.

Computer graphics can be the most challenging content to encode due to fine details and high-contrast content. Motion graphics can often be encoded at lower bitrates because the nature of the content allows for higher compression ratios. The images below are captured from Big Buck Bunny at similar bitrates to the computer content. It should be noted that while artifacts can be seen these images, when the actual graphics are in motion, it is extremely difficult for a user to see these artifacts.

Figure 6. Uncompressed 2160p image from Big Buck Bunny at full-color sampling of 4:4:4

Figure 7. Part of the uncompressed 2160p image shown at 100% to show any details of compression artifacts in subsequent images

Figure 8. Part of the JPEG2000 compressed 4:2:2 2160p30 image shown at 100%. Video bandwidth of approximately 500 Mbps is compatible with GbE networks and very few compression artifacts are visible. 2160p60 is the same quality but at 800-Mbps. The loss of color space information can be seen when comparing this image with the uncompressed image.

Figure 9. JPEG2000 4:2:2 compressed to a bandwidth of approximately 150 Mbps shown at 100%. Although usable at reasonable magnification, compression artifacts are visible. GbE drops can accommodate four to six of these streams.

Figure 10. JPEG2000 4:2:0 compressed to a bandwidth of approximately 500 Mbps shown at 100%.

CONCLUSION

Using low-latency, high-fidelity codecs, it is possible to send high quality video at bandwidths less than 1 Gbps. At those bandwidths, it becomes very practical to transport and switch video using an existing enterprise IP network, which means that users can distribute professional-quality video on an existing infrastructure, thereby reducing total system cost, simplifying installation, and allowing for easy system expansion.

JPEG2000 is the codec used by the SVSI products to deliver 4K video at bandwidths less than 1 Gbps. By using this codec and tiling the image, the video quality remains very high at codec latencies less than a frame. This paper provided sample JPEG2000 images at various bitrates, but to really appreciate the quality of this codec, consider some high-profile applications where the codec is used today:

- Digital Cinema Initiatives (DCI) uses JPEG2000 as the codec for digital encoding of motion pictures.
- The Library of Congress uses JPEG2000 to archive digital images.
- Twentieth Century Fox uses JPEG2000 as a master format for video.
- ABC uses JPEG2000 to transport live video over their IP backbone.

By combining the advantages of low-bandwidth transmission with the use of a high-quality codec, professional-quality video can be distributed throughout a campus in a cost-effective manner.

For more information on SVSI products, contact your AMX Representative or visit www.amx.com/svsi.