HEVC – Driving Disruption in Multiscreen Converged Service Delivery Architectures

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Abstract – It has only been a handful of years since AVC/H.264 ran riot through the video delivery chain and enabled a range of cross-device and cross-network services to bloom and flourish. With the imminent publication of the HEVC/H.265 video coding standard from ITU-T VCEG and ISO/IEC MPEG enabling a similar breakthrough in relative bit-rate reduction, we are poised for potentially the fastest embraced codec ever seen. As an industry we need to be prepared to evolve our architectures to support and exploit the full promise of HEVC. This paper evaluates how the existing multiscreen video delivery architectures must evolve to embrace HEVC and the challenges that must be overcome to provide cost-effective, scalable next generation HEVC-based services to consumers. This includes not only its use in services such as 4K or UltraHD video but also addressing the implications in the area of Cloud DVR.

INTRODUCTION

Video encoding technology has come a long way in terms of compression performance, picture quality for a given bit-rate, over the last twenty years. It is hard to believe that MPEG-1 was first ratified in August 1993 heralding the start of digital video distribution with target bitrates in the 1.5Mbit/s range. In addition to being the first worldwide embraced standard for video encoding it should be noted that the same standards body delivered the MP3 audio codec specification that is prevalent today across the delivery environment for digital music.

Whilst MPEG-1 was primarily focused on the delivery of digital video on physical medium, e.g., CD-ROM, subsequent standards work in MPEG yielded the MPEG-2 Video specification first ratified in 1995, published by MPEG as ISO/IEC 13818-2 and by ITU as ITU-T Recommendation H.262. Although similar to MPEG-1, MPEG-2 Video included extensions to address a wider range of applications, in particular support for compression of interlaced analog video, which at the time was ubiquitous throughout the broadcast industry. Consequently, the primary application targeted during the MPEG-2 definition phase was the all-digital transmission of broadcast television quality video coded at bitrates between 4 and 9 Mbit/s. However, the MPEG-2 Video syntax has been found to be efficient for other applications such as those at higher bitrates and sample rates such as HDTV. Initial HDTV broadcast channels using MPEG-2 Video along with associated captions and audio were delivered multiplexed in MPEG-2 Transport, according to the 19.4 Mbit/s limit specified by ATSC A/53. However, MPEG-2 Video encoding technology progressed significantly through time resulting in bit-rate reductions to increase channel count – a necessity given the limited spectrum availability.

In response to the rise of HDTV content, H.264/MPEG-4 Part 10, commonly known as AVC (Advanced Video Coding) was developed and first released as a standard in 2003. The motivation for its adoption in the broadcast industry was to once again make better use of the limited spectrum by reducing the bitrate for the bandwidth consuming MPEG-2 HDTV by a factor of two. The introduction of AVC hit a sweet spot in the marketplace that enabled a range of new high quality video services across a range of consumer devices. DSL providers were now able to offer HDTV services over their lower bandwidth lines and extend reach to subscribers farther out, and some satellite operators (notably DirecTV in the US) switched their entire HDTV channel lineup to utilize AVC (requiring the mass upgrade of installed receivers to AVC-capable ones) in order to support a larger channel line-up of HDTV programming.

A range of new devices, in addition to existing PCs, leveraging the H.264/MPEG standard have subsequently come to market including Blu-ray (2006), XBOX 360 (2005), Playstation 3 (2006), AVCHD for digital camcorders (2006), iPod/iPod Touch/iPhone (2007) and start of tablet devices with the iPad in 2010.

With the combined increase in broadband penetration and access bandwidth, a large number of OTT (Over The Top) broadband video services have leveraged this installed base and the use of AVC for video distribution including iTunes (2005) and Netflix (2007). In the case of Netflix, and many other OTT providers, content is delivered using adaptive bitrate schemes that segment the stream into fixed chunks and the client requests content from a preset number of bit-rate profiles based on a combination of current network bandwidth availability and client performance.

At the time of writing, MPEG-2 and AVC are the predominant video compression formats used in the delivery of broadcast HDTV with AVC being predominant in the delivery of broadband video content.
High Efficiency Video Coding (HEVC)

To date there has been very limited embracement on extending the predominant HDTV picture format from 1280x720p at 60 Hz and 1920x1080i at 60 Hz to 1920x1080p at 60Hz for broadcast delivery. This is due to its high bandwidth requirements as a result of at least doubling the samples per second, and that a 50% bit-rate reduction was seen as pre-requisite if that or any higher format was to be embraced.

In 2004, the ITU-T VCEG (Video Coding Experts Group) began investigations into advances that could enable the creation of a new video compression standard or, alternatively, offer substantial enhancements to the H.264/MPEG-4 AVC standard.

The ISO/IEC Moving Picture Experts Group (MPEG) began a similar project in 2007, initially named High Performance Video Coding with a target of reducing the bit-rate by 50% over H.264/MPEG-4 AVC High Profile. By mid-2009 efforts in this group had shown an average bit-rate reduction of around 20% and a decision was made to initiate its standardization effort in collaboration with VCEG.

In January 2010 a formal joint Call for Proposals (CfP) on video compression technology was issued by VCEG and MPEG. A total of 27 full proposals were submitted and evaluated at the first meeting of the MPEG and VCEG Joint Collaborative Team on Video Coding (JCT-VC), which took place in April 2010. Evaluations showed that some of the proposals could reach the same subjective image quality as H.264/MPEG-4 AVC at half the bit-rate at a cost of 2x to 10x increase in computational complexity. At this meeting, the name High Efficiency Video Coding (HEVC) was adopted for the joint project. Moving forward the JCT-VC integrated elements of some of the best proposals into a single software codebase and performed further experiments to evaluate a range of proposed features.

The first working draft specification of HEVC was produced in October 2010 at the third JCT-VC meeting. Subsequently many changes have been made to the specification and the committee draft specification was released in February 2012. At the time of writing the specification freeze is anticipated at the January 2013 meeting with final publication of the HEVC standard in the May to June 2013 timeframe under the specification titles ISO/IEC 23008-2 MPEG-H Part 2 and ITU-T Rec. H.265.

Table 1 illustrates the primary encoding features of AVC and the relative improvements offered by HEVC.

<table>
<thead>
<tr>
<th>Coding Tools</th>
<th>AVC</th>
<th>HEVC</th>
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<tr>
<td>Picture Grid</td>
<td>Macroblock (MB) 16x16</td>
<td>64x64, 32x32, 16x16 Coding Tree Units (CTUs)</td>
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<tr>
<td>Coding Mode Granularity</td>
<td>Largest = Smallest (MB)</td>
<td>Finer, size adaptable: 64x64 to 8x8 Coding Units (CUs) via recursive Quadtree decomposition of CTU</td>
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Table 1 Comparison of Coding Tools for HEVC and AVC

Coding Performance

With the coding tools available today in HEVC it has been demonstrated that for the same subjective image quality the bit-rate can be reduced by 50% versus AVC. As was seen with the introduction of prior compression standards, we can expect improvements as more optimizations are carried out through the vendor encoding community. This reduction in bit-rate can be utilized in two ways; reducing the bit-rate for existing services (including the delivery of services over constrained bandwidth links) or enabling higher quality services such as 4K.

It is important to acknowledge the impact on encode and decode complexity associated with HEVC.

Encode Complexity

The encode complexity has increased over AVC with a projected factor that ranges between 10x and 12x.

The continued technology progression of GPU and multicore processors in general computing devices found previously only in powerful workstations have begun a migration to both general purpose servers and CE devices, such as tablets and handheld devices, mainly as a result of smaller silicon geometries that consume considerably less power. Multi-core processors with respective hardware acceleration units for media processing are finding wide use in CE devices as a result of a the counterpart progression of the software application development tools that provision acceleration capabilities of these architectures, such as multi-threading of numerical intensive computation in media processing operations. Consequently, these devices now extend parallel processing capabilities and just in time for HEVC to exploit such parallel media processing capabilities. HEVC was specifically designed with two parallel processing tools, Wavefront Parallel Processing and
Tiles, both amenable for implementation in these parallel-processing architectures.

Moreover, the CABAC design in HEVC for the entropy coding of the quantized coefficients of larger transform units (e.g., greater than 4x4 TUs) has been simplified, and deblocking can be parallelized as well.

In ABR applications, multi-core processing and GPUs are projected to find employment in both encode and decode implementations of HEVC. Coupled with faster DDR3 memories that are physically smaller and feature higher storage capacity, HEVC’s adoption appears inevitable.

One important point to note is that the current HEVC work does not have special coding tools for interlaced video. Instead, fields are expected to be coded sequentially. It is anticipated that this will be addressed in future updates to the specification.

**Decode Complexity**

Decode Complexity - The decode complexity has several key parameters that must be evaluated in concert; raw decode processing complexity, memory utilization and memory bus bandwidth requirements. All three of these have a major impact on the requirements for device manufacturers (and component suppliers) implementing HEVC decoders.

To understand the variances in decode complexity it is best to evaluate the application of HEVC Main Profile against two use cases; broadcast and streaming as illustrated in Table 2.

<table>
<thead>
<tr>
<th>Decoder Requirements</th>
<th>Broadcast HEVC Main Profile vs. AVC Baseline Profile</th>
<th>Streaming HEVC Main Profile vs. AVC Baseline Profile</th>
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<tr>
<td>Compute / processing</td>
<td>~ 1.4x</td>
<td>~ 2x</td>
</tr>
<tr>
<td>Memory Bandwidth</td>
<td>~ 1.25x</td>
<td>~ 1.5x</td>
</tr>
<tr>
<td>Memory</td>
<td>~ 1.25x</td>
<td>~ 2x</td>
</tr>
</tbody>
</table>

**APPLICATION OF HEVC IN MULTISCREEN SYSTEMS**

With an understanding of HEVC in hand it is now possible to evaluate the impact of HEVC across the end-end video distribution chain. The following sections focus on the following key areas:

- In-Home Multiple Device Support
- Device Interconnect

**Broadcast Encoding**

Given the rise in complexity for HEVC over AVC it is anticipated that real-time encoders will still have a predominantly hardware/DSP design focus, especially for 4K content. However, the continued performance improvements in multi-core processing and GPUs found in general purpose servers are projected to find employment in the encode implementations of HEVC. Work is underway across the vendor community to bring dedicated HEVC encoders to the market during 2014.

**ABR Transcoding**

ABR transcoders will be required to support generating HEVC profiles in addition to the existing MPEG-2 and AVC profiles supported today. Encapsulation into HLS, Smooth, or more likely DASH over time, can occur at this juncture or an intermediate format can be utilized and final encapsulation occur as part of a virtual origin server function before the content is handed off to the content delivery network. In ABR applications, multi-core processing and GPUs are projected to find employment in the encode implementations of HEVC and the traditional reliance on hardware/DSP implementations for real-time transcoding may be numbered.

**Content Management Workflow and Delivery**

From a content management system’s perspective HEVC-based content is just another asset with an associated workflow and attribute metadata. One of the key questions for a Service Provider will be how much duplicate content they deliver (and optionally store) in HEVC and AVC. This will only exacerbate an existing challenge for the Broadcaster and Service Provider targeting a broad device ecosystem, namely ensuring that we are properly identifying devices and capabilities in order to facilitate the content resolution services.

In the near-term the decision about content formats will be very much tied to the type of services that are being introduced utilizing HEVC and are discussed in the use case section of this paper.

Similarly, content delivery networks will be transparent to the fact that HEVC-encoded content is being transported versus existing AVC or MPEG-2 content.

**Advertising**

Linear ad insertion will likely be one of the last, or nearly last to move to HEVC. This is due to the legacy stream base which worldwide is still predominantly MPEG-2 based with
a movement towards AVC. For playlist-based on-demand content advertising HEVC can be embraced sooner giving the deterministic nature of the streams to be played out.

Content Security

From a content security perspective the use of HEVC is transparent to the security scheme employed, as this will typically encrypt the content payloads within the appropriate encapsulation scheme. This is true whether the content is protected via a traditional broadcast Conditional Access System (CAS) or a Digital Rights Management (DRM) system.

One other use case of interest is Multi-Room DVR, which is deployed today through many Service Providers. In this model Service Provider managed client set-tops can receive content from either a “master-DVR/gateway” or one another (in the case of multiple DVRs within the home). If a Service Provider deploys HEVC-capable managed set-tops/DVR/gateways into the home then it is possible to stream recorded HEVC content between them. To date content protection for this delivery within the home has been addressed mainly through DTCP/IP as supported by the content providers. With the move to 4K content delivered over a managed in home network to managed clients the use of DTCP/IP must be revalidated.

Endpoint Devices

At the time of writing we are at a very nascent stage for HEVC with the majority of endpoint devices utilizing CPU-based software decode of HEVC in their prototypes. For example, an iPad 2 is able to software decode HEVC today but the use of the main CPU, versus dedicated hardware subsystems, greatly limits battery life.

Many of the traditional silicon providers are actively sampling new chip-sets designed to natively support the decoding of HEVC for consumer products. With the relentless reduction in silicon geometries the additional circuitry to support the added decode complexity is not an issue for these new designs. However, the incremental memory and memory bandwidth requirements outlined in (insert earlier reference) potentially drive design changes such as additional memory bus interfaces based on the concurrent decode (and potentially encode) needs of the target device.

It is expected that the constrained bandwidths of mobile networks will drive early adoption of hardware-based designs into mobile platforms, phones and tablets, first with 4K televisions and set-tops as fast followers.

In-Home Multiple Device Support

It is important to note that the consumer in-home environment (along with consumer expectations) for premium video consumption has evolved dramatically over the last few years. Consumers are expecting to have access to their content on the devices they care about not just the ones provided by their Service Provider (i.e. set-top box) whether that be through their games console, PC, tablet, mobile or connected TV. Service Providers are in the process of introducing new gateway devices into the home that terminate their existing broadcast content and redistribute it over IP within the home. Many of the existing service providers are using MPEG-2 encoded content and the gateway device includes the ability to transcode it to H.264 to be compatible with a wide range of consumers’ devices.

During the initial introduction of HEVC by broadcasters they will face the opposite challenge. By definition, only HEVC-capable devices purchased by the consumer, or more likely provided by a Service Provider in the form or a set-top box, will be able to receive the content. To solve this problem, Service Provider gateways could transcode the HEVC service to AVC for delivery to AVC-capable devices in the home. In many cases in-home transcodes will also reformat the content to a resolution applicable for the device. This will be even more important in the case of 4K HEVC content given the constraints of existing AVC-capable devices.

One constraint, until recently, of transcode solutions was the relatively high expense. However, through silicon geometry reductions and others optimizations it is currently possible to support two active transcodes cost-effectively and soon up to four. It should be noted that most designs rely on a full decode followed by a full encode. An initial limiting factor will be the number of concurrent HEVC decodes on a given chipset, in turn limiting the number of HEVC to AVC transcodes.

Device Interconnect

HEVC itself does not imply any changes to physical device interconnect, e.g., between set-top box, game console and television display. However, HEVC-based services that drive higher output resolutions can require specific versions of interfaces to be supported both by the transmitting device and the receiving display.

The HDMI 1.4 specification that was released in 2009 anticipated higher maximum resolutions and supports 3840 x 2160p at 24Hz/25Hz/30Hz and 4096 x 2160 at 24Hz (as used in digital theaters).

At the time of writing the HDMI Forum is working future enhancements to the specification with an anticipated release in the first half of 2013. These would include many additions but notably, related to HEVC, support for 4K resolutions at 60Hz.
Similarly, HEVC does not drive any modifications for content delivered wirelessly within the home and in fact in many cases is helpful as for a given resolution it may reduce the bandwidth by a factor of two. Wireless technology continues to see rapid advances and with the evolution from 802.11n to 802.11ac it can be expected that wireless bandwidth in the home to reach at least 500Mbit/s, more than adequate for multiple HEVC 4K streams within the home. In addition other enhancements such as 802.11aa improve the robustness of video streaming.

**CONSUMER USE CASES**

The following use cases provide four examples of how HEVC content will be provided to consumers as it is introduced into the delivery environment:

- **Premium 4K Content**
- **Hybrid Gateway**
- **TV Everywhere**
- **Multiscreen Cloud DVR**

**Premium 4K Content**

One of the primary allures of HEVC is to build on the success of HDTV and deliver 4K services to consumers. At the time of writing multiple test broadcasts of HEVC-based 4K services are likely during 2013 with commercial services anticipated in 2014. The other piece of the equation is the availability of 4K-capable televisions. At CES 2013 more than 10 vendors announced over 20 models of 4K televisions that would be available before end of year 2013. In addition, the costs for broadcasters to create a 4K channel must be taken into account which, factoring in upgrades to existing equipment and infrastructure could be $10M to $15M (versus $2M for an HD channel). Given this it can be expected that a limited number of 4K channels will be launched early on in much the same way as was seen with the introduction of HDTV. Typical content drivers would be movies and sports (especially live events).

With the passage of time more 4K channels will appear along with more 4K decode capable devices in the form of next generation games consoles, etc.

It should also be noted that alternative delivery schemes to broadcast exist for 4K either over broadband or switched infrastructure. These delivery mechanisms can be used to either stream 4K content or pre-position it on 4K capable decode devices with their own storage, e.g. DVRs.

Given this, a very likely configuration will be for a Service Provider to introduce a “hybrid” HEVC set-top device that can receive 4K, in addition to legacy content, over the broadcast infrastructure as well as connect via broadband connection to offer a more complete 4K content experience to the consumer.

In addition, the Blu-ray Disc Association announced in 2012 that it had formed the format extension study task force to evaluate new technologies such as 4K, high frame rate, color enhancements, etc. It is anticipated that eight-layer Blu-ray with its 200GB capacity will be relied on for packaged media delivery. However, it is clear that there is a long-term trend towards network delivered content over physical media.

**Hybrid Gateway**

Given that many Service Providers have a large installed base of legacy AVC/MPEG-2 devices it can be expected that HEVC will be introduced as a tiered service. For 4K services, as described above, they will need to be delivered to 4K-capable devices. In other cases HEVC may be used to reduce bandwidth utilization over the broadcast or broadband network. If that content is required to be displayed on pre-existing AVC unmanaged devices in the home then it must be transcoded in a local gateway within the home. This transcoding process will increase the bandwidth back to AVC levels but that is already acceptable within in-home distribution systems today.

**TV Everywhere**

Many Broadcasters and Service Providers have already invested in a TV Everywhere infrastructure enabling them to deliver to unmanaged devices within the home (and in the case of many broadcasters, outside the home too) such as mobile phones, game consoles, PCs, tablets and connected TVs. These infrastructures, in the case of Service Providers, operate in parallel to their existing managed video delivery platform are predominantly AVC using ABR leveraging HLS or Smooth Streaming and traditional DRMs.

Again, HEVC can be utilized in this environment to provide Premium 4K services as described in (reference) over appropriate broadband connections. In addition, HEVC could be utilized to deliver regular services to HEVC-capable unmanaged devices thereby reducing the bandwidth requirements for the stream and potentially improving the end-user experience, this is particularly important in the mobility arena.

In this last scenario, the asset will need to be kept in both AVC and HEVC formats (and their associated bit-rate profiles). Given that HEVC is on average ½ the bandwidth of the equivalent AVC stream this results in an overall 50% increase in storage to keep both copies. Alternative approaches may become viable with the passage of time based on the evolving economics of general compute platforms as transcoders but this may be measured in multiple years. In this scenario, each piece of content is kept in HEVC using the original AVC bit-rate. HEVC-capable devices utilize this stream; AVC-capable devices request the
stream and it is dynamically transcoded to AVC (at a higher bit-rate). This would keep the storage requirements identical and would align the delivery architecture in the direction of HEVC, which would become the prevalent delivery scheme over time with the cost incurred by the AVC transcode requirements reducing over time.

**Multiscreen Cloud DVR**

The natural extension of TV Everywhere systems is to provide Multiscreen Cloud DVR services which comprise of, but are not limited to:

- **Catch-up TV**: Watch TV programs after they air by browsing through a video on demand catalog Hybrid Gateway
- **Restart TV**: Tune in to selected content in the middle of the broadcast and restart the program from the beginning
- **Reverse Electronic Program Guide (EPG)**: Navigate backwards on the EPG to discover and watch content, for example, selecting a program that aired earlier in the week
- **Pause Live TV**:Pause, rewind and fast-forward a currently airing program, without a hardware-based DVR

These configurations will deliver on customer desires to receive their content whenever they want, wherever they want based on the content agreements in place for delivery within and outside of the home.

HEVC content will be part of the lineup through the earlier mentioned premium 4K services and over an extended period of time it may be possible to encode all the content in HEVC as compatible playback devices become mass of the install base. Interim implementations may require duplicating content assets in both AVC and HEVC or utilizing the real-time transcoding approaches described earlier.

It should be noted that duplicating assets in multiple formats brings additional cost (in terms of storage and workflow) but may be seen as advantageous in that it allows the reduced bit-rate content to be delivered over lower bandwidth connections that otherwise previously addressable.

**Summary**

It is clear that HEVC is going to be a technology disruption in enabling new higher quality video services to be delivered to consumers. However, it is equally clear that it will not become the ubiquitous form of content encoding for end-end delivery any time soon. Rather it will be selectively introduced and used both in primary distribution and consumer distribution as the business cases allow.

There are clear long-term benefits to the adoption of HEVC by Broadcasters and Service Providers alike in the areas of higher quality content such as 4K and reduced bandwidth and storage requirements for other mature services such as HDTV. It is anticipated that HEVC will play a part in enabling some new distribution environments such as lower-speed DSL and IP Video over Cable.

Challenges to the wide adoption do however exist. The existing installed base of MPEG-2/AVC devices will not disappear overnight but, as has been shown with the introduction of AVC, steps can be taken to evolve the infrastructure and device base over time. In addition it is important to note that the rise of unmanaged devices as consumption devices presents a real dynamic change. The replacement cycles for these consumer-purchased devices are much shorter than Service Provider equipment and we can expect HEVC-capable devices starting in 2014 with the mobile space leading the charge followed by tablets, game consoles and connected 4K TVs.

Even with these challenges the authors believe that HEVC will become one of the, if not the, fastest embraced video codec seen in the video delivery marketplace driven through the combination of fast-paced consumer device evolution and the leverage of Internet-style delivery mechanisms. Its complete adoption will likely rely on the embracement of a unified platform by Service Providers to address both their managed and unmanaged devices.

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