SCTE Tech Expo 2007 Technical Paper

Category: How to Best Accommodate High Definition

Title:

3:1 HDTV Using MPEG-2 - Techniques for Delivering a Highly Competitive Customer Experience

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Introduction

One of the competitive challenges facing cable operators today is to offer the consumer a high definition experience with an increasing number of HD channels while maintaining the highest possible HD picture quality. Dozens of new HD channels will be available in the next few years, and consumers will be demanding their favorites. Each new HD channel needs bandwidth, which often just isn't available in cable plants today. Cable system operators are required to choose between making substantial investments to upgrade their plant, introducing first iterations of MPEG-4 or switched video solutions, or reducing the bit-rate – and potentially the quality – of all HD channels.

The expense and timeframe for deploying more advanced encoding technologies compel the industry to adopt a more immediate solution for offering a competitive lineup of HD content by optimizing its existing network architecture. As this paper will discuss, additional enhancements to MPEG-2 systems and practices can allow cable system operators to meet or exceed the outcomes of first generation MPEG-4 encoding technologies.

In addition to accommodating consumer demand for more HD content, we can expect consumers will become more demanding for greater quality as they experience HD via other devices, such as games and HD DVDs.

This will be a significant change from the current marketplace, where most consumers are genuinely confused by HD technology. According to a recent Leichtman Research Group survey, only half of the 24 million HD households have the equipment necessary to receive any HD programming; and, even more compelling, half of those don't even know they are not receiving HDTV. That means 6 million families spent an average of $1,000 on an HDTV set and don't even know they are still watching standard definition TV.

This reality is slowly changing, and the availability of new HD-based consumer electronics (CE) devices should accelerate the change. High-definition disks, video game consoles and even camcorders are starting to establish higher expectations for HD picture quality in the consumer's mind. Today, one need only visit the AVS Forum web site to understand the importance of video quality among an ever-growing class of educated consumers.

The Comcast Media Center's experiences in evaluating a number of current HD CE products is consistent with industry research that found the picture quality for many of these devices can and does surpass cable or DBS-sourced channels.[i] Our own testing has shown consumers can differentiate between subtle differences in picture quality and have clear preferences when comparing cable with DBS. With this in mind, cable operators will need to pay greater attention to picture quality while adding more channels.

Display Technology

One of the primary drivers for maintaining picture quality is the availability of larger and higher quality HDTV sets at a lower cost. There were 13.6 million new HDTV sets sold last year, according to the Consumer Electronics Association.

This downward price trend for HDTV is allowing consumers to afford ever-larger sets. Set makers are increasing manufacturing capacity and yield rates for the large glass panels required to make even larger TVs at even lower prices. New technology like DLP and LCOS are reducing electronics cost and improving picture quality. Plasma and LCDs are optimizing their technology and breaking through longstanding price/performance barriers.

Fifty and 60-inch displays are now common and well within the reach of many consumers. This size makes it easy for a non-technical consumer to notice problems with video quality, particularly when they are viewing from a distance that is closer than 4.5 to 5 screen heights back.

One of the CE industry initiatives that will increase consumer sophistication concerning HD is the promotion of “True1080”. This serves to separate the new class of 1080i/p displays from older 700-800 line displays. However, it is important to note that there are still millions of these older 720p based displays in U.S. television households today.[ii]

One of the hot new features in HDTV is support for the 1080p video format. These sets offer full 1080x1920 resolution and the same fast-motion clarity of 720p. 1080p is now a common feature on HDTV sets costing less than $2,000. Although not currently supported by broadcasters, this format is supported by both HD disk standards and newer gaming platforms.

Sources

Along with ever improving display technology, there are a number of other new HD content sources available to the consumer. These will all influence the standard for picture quality.

Although delayed, the launch of Blu-ray and HD-DVD formats and the recent availability of dual-format players, show HD disks may finally experience some

traction in the marketplace. Momentum is building with over 500 titles now available and more coming each week, according to industry sources.

Regardless of the HD disk format, the quality of the end consumer product (disks) is heavily dependent on the source quality of the mastering. For example, film grain and high contrast are effective production techniques for the big screen in a movie theater, but they do not translate well to video. As a result, some HD disk titles are spectacular while others are only marginally better than standard definition DVDs.

In addition, low-cost 1080p HD camcorders are now available allowing consumers to shoot home movies and edit them on their home-PC. This will become more and more popular as camera prices continue to decline. The recovered video quality from these cameras is excellent when compared to multichannel distribution. This is because the original video content delivered to the HD display from the camera didn't experience any MPEG-2/MPEG-4 compression impairments, statistical multiplexing or up-conversion.

Consumers are also experiencing higher HD quality via the latest game consoles. Both Sony's Play Station 3 and Microsoft's X-Box console offer HD output for video game players. Subscribers to Microsoft's xBox 360 Live service can even download movie and TV content to their xBox. Microsoft isn't the only one; MovieLink and CinemaNow offer HD movies for download in a rental model. Apple recently launched its HD-capable AppleTV product. Although HDTV or movie titles aren't currently available via the iTunes service, it can be assumed they will become available in response to market demand.

Competitive HD

Both DBS providers have announced aggressive plans to add HD content to their lineups. While primarily focused on launching HD broadcast channels into local markets, both providers are planning to launch up to 100 national channels.

AT&T, Verizon and many other large telcos are also expanding their HDTV service offerings. AT&T is planning to spend over six billion dollars for their deep-fiber based Project Lightspeed and U-Verse service, and Verizon has committed to spend over $10 billion for fiber-to-the-home for FIOS. Today, Verizon claims more than 117,000 subscribers across nine states.

The switched nature of the IPTV architecture will allow the telcos to offer a larger number of channels than a traditional broadcast network. Much of the added capacity will be used for HD programming, as indicated by press reports.[iii]

Solutions

As the vast majority of cable TV Households in America today watch television that relies on legacy MPEG-2 set-top box technology, it is difficult to envision abandoning this platform in the immediate future. The capital costs and potential operational impacts associated with a complete replacement of the legacy MPEG- 2 infrastructure can be measured in multiples of billions of dollars. In addition, the integration complexity involved in any transition to MPEG-4 or Switched Digital Video cannot be underestimated as it will likely require additional plant bandwidth, at least short-term, to simulcast with the existing platform. Truck rolls, in-home wiring, technician training, customer messaging and infant mortality of the equipment or systems all are potentially significant issues that need to be considered here as well.

Yet emerging competitive threats based on newer, more flexible approaches, to video transport technology are placing pressure on operators to evaluate upgrades or enhancements to their existing plant. These upgrades will be required to conform to the constraints associated with MPEG-2 transport technology, as well as legacy set-top box capabilities or significant disruption can occur.

In short, the following assumptions can be considered:

1. HDTV adoption by consumers will drive more source content creation and distribution opportunities, requiring more plant bandwidth or more efficient solutions to accommodate.
2. Manufacturers and vendors are driving newer, more innovative approaches to video transport that do not rely on MPEG-2.
3. Competitors can leverage a certain amount of “greenfield” opportunities in their infrastructure to deploy advanced technologies and service offerings

In general, there are two approaches to consider in order for a cable operator to remain competitive. The first is to continue to drive efficiency from the existing MPEG-2 transport delivery facilities. The second is to begin evaluating the use of second pass encoding downstream from the existing compression system.

3:1 HD

One area of particular focus is improving transport efficiency by delivering three HD channels in each QAM rather than just two. After extensive research into pre-processing and noise reduction, and with the support of a number of vendors, the Comcast Media Center has achieved competitive picture quality while yielding a 50% increase in HD capacity per QAM. Unfortunately, this is not as easy as simply multiplexing an additional channel into each QAM. Instead, significant engineering is required to ensure the resulting video quality remains competitive with the 2:1 configuration. The primary lessons learned in this project were the importance of selecting the best compliment of channels for a 3:1 multiplex, new high-frequency noise reduction techniques, and source and plant network quality.

Channel Selection

There are three criteria for selecting channels for a 3:1 QAM:

1. Typical Picture Complexity (TPC),

2. Market penetration/demand
3. Ad insertion requirements

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The process began by classifying each available and proposed HD channel into groups based on TPC. High-action sports channels were classified as “Most Difficult.” Channels with some high-action, but primarily average TPC were classified as “Difficult”. Channels with little high-action programming and mainly film content were classified as “Easy” (due to the efficiency in MPEG-2 processing associated with the 3/2 pull-down). These classifications were validated by logging the average bit-rate in a statistical multiplex group over a multi-day period.

	Most Difficult	Difficult	Normal	Easy
Typical Bit-rate	14 Mb/s	13 Mb/s	11 Mb/s	10 Mb/s
Sports and other high-action content	Nearly all	Some	Little	Very little
Film Content	Very Little	Some	Most	Most

All of the “Most-Difficult” channels were excluded from 3:1 use. They simply require too much bandwidth and cause “starvation” for the other two channels in the multiplex group. Based upon the CMC’s experiences, the optimum 3:1 QAM has one channel from each remaining category, Difficult, Normal, and Easy.

The multiplexer configuration is straightforward, and only required trusting the efficiency of the statistical multiplexing algorithm. A typical configuration would weight each channel equally (even though the channels have different TPC values) and allow a wide dynamic range of bit rates. A typical range would be from a minimum of 4 Mb/s to a maximum of 18 Mb/s for each channel in the multiplex. Higher complexity channels can be given higher maximums or weighted more heavily; however testing showed a y negative effect when all three channels were evaluated for quality.

The market penetration of each channel also influenced its placement into a 3:1 multiplex. The most widely distributed HD channels rank among the most desirable for inclusion.

The final criterion influencing the creation of 3:1 multiplex is the necessity for ad insertion using Digital Program Insertion (DPI). To minimize the amount of ad insertion equipment required at the head-end, it is desirable to group ad-inserted channels into the same multiplex. An optimal configuration would involve having all three channels in a 3:1 multiplex employ DPI. This would maximize the utility of DPI splicing equipment in the head-end. This is not always possible, but a minimum of two optimized channels per multiplex should be used.

Another impact of the shift to 3:1 grouping was the need to review the bit-rate used to encode digitally inserted ad spots. The rate of 11.5 Mb/s was chosen as the maximum bit rate for ads, since the recovered video quality at this rate is consistent with most HD programming.

Noise Reduction

The next area of focus when engineering the solution was the requirement to reduce the amount of high-frequency (HF) noise in the source content. The amount of HF noise (both visible and invisible) has a direct and significant impact on the bit rate required to encode a signal. Using a combination of techniques, we have developed a system to reduce the HD noise without significantly softening the picture, which can result from overly aggressive HF noise reduction strategies. These techniques can be used for processing VOD assets as well.

Source and Plant Network Quality

The final step in our approach was a comprehensive evaluation of each piece of equipment in the broadcast chain capable of impacting video quality. Receivers, cabling, connectors, patch-panels, splitters, and encoders were all reviewed and their impact on video quality characterized.

One area of particular focus is the format of the transport from receiver to encoder. This is a critical link as the programming is about to be re-encoded and any quality reduction is immediately seen.

Our choice is the use of High Definition Serial Digital Interface (HD-SDI or SMPTE 292M) for connecting receivers to encoders. This preserves the maximum quality when connecting these devices. Using Analog baseband interfaces introduced additional high-frequency noise, even with the best cabling. The amount of pre-processing required to remove this noise causes undesirable softening of the picture.

The output of the source receiver is the best picture quality possible; it can only be degraded from there. Every effort must be made to preserve this quality throughout the broadcast chain.

Results

With all this in mind, it is now possible to create mux groups with three HD channels and do so at a level of picture quality that is competitive with current 2:1 groupings.

Validation

To validate the work completed, a neutral third party conducted consumer focus group testing using over 300 randomly selected, screened participants. Testing was conducted using a variety of content types including action movie, movie, documentary, sports and news content shown on matched 50" displays. The survey tested the consumer's perception of recovered picture quality, which they graded for a variety of elements, including color saturation, digital impairments and image resolution. The results show that consumers can reliably differentiate picture quality between the major service providers, (cable, DBS and broadcast).

Second Pass Encoding

Since the initial consumer testing, an emerging area of opportunity being developed is the ability to insert a second pass encode system downstream from the primary MPEG-2 system. The challenge is to support a real-time methodology as non-linear processing is neither viable nor cost-effective. This methodology needs to be cost-effective to implement, provide a level of service availability equal to the existing plant and not materially impact the existing day-to-day operational environment.

The approach should include the ability to analyze the incoming video signal, evaluate potential corrective actions to minimize further impairments and determine how to mitigate existing impairments created upstream. The goal is two-fold: improve the recovered video quality perceived at the output of the set-top box while also maintaining MPEG-2 operational requirements and potentially freeing up bandwidth for the deployment of additional HD channels of service in the plant.

Conclusion

Balancing the demand for adding new HD channels with the need to maintain HD picture quality will always be a challenge. However, by optimizing the HD compression and distribution system, and carefully selecting channels, a cable system operator can achieve greater HD density on an MPEG-2 plant, while continuing to provide a competitive recovered picture quality.

[i] *"Switched On! Video,"* Consumer Electronics Association, 2007
[ii] *"Home Theater Video,"* Consumer Electronics Association, 2006
[iii] "ATT U-verse IPTV Offers One Year Free HDTV," tvover.net, April 3, 2007