Overview of the KLCS/KJLA Channel Sharing Pilot

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A Technical Report

Authors:
Alan Popkin, Director of Television Engineering & Technical Operations, KLCS-TV, Los Angeles
Roger Knipp, Broadcast Engineer, KLCS-TV, Los Angeles
Eddie Hernandez, Director of Operations & Engineering, KJLA-TV

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I. EXECUTIVE SUMMARY

Over the past several months, KLCS and KJLA have endeavored to test the feasibility of having two non-affiliated broadcast television stations sharing a single 6 MHz radiofrequency channel. This testing was performed solely to explore the technical details of channel sharing, and did not examine all the legal and practical issues associated with such sharing. Neither KLCS nor KJLA are advocating for or against channel sharing, but seek to inform the broadcast community, the FCC and the public of their findings in this real-world trial. Neither broadcast entity is committed to participate in the Incentive Auction, but both realized that without testing the concept and gathering empirical data it would be impossible to evaluate the potential consequences of such an arrangement.

While the tests are of a technical nature, the results have framed real-world implications for the hybrid business model that would be necessary for a successful channel sharing agreement to be reached. This report will reveal the issues that have been successfully overcome on the technical side, as well as the limitations. It will present some of the questions that stations need to answer for themselves in conjunction with their potential partner(s) if they choose to participate in the auction through channel sharing. Due to limitations of both time and equipment it was not possible to review every scenario sharing could entail. Each station will need to investigate for itself the impact of channel sharing on its business model and technical infrastructure. This report reflects the findings of the two participant stations, and to the extent that similar combinations arise elsewhere, may serve as a baseline assessment of sharing.

The empirical data suggests the following key findings:

- Channel sharing on both a physical and virtual level (PSIP)[1] can be done.

- On the virtual level, we found that all the TVs and tuners tested were able to receive and correctly parse all the required information. This included virtual channel, both major and minor, ratings, audio configuration, codecs, program titles and descriptions. The test results also suggest that careful thought must be put into the transition, whether for repacking or sharing, by the FCC and broadcasters to find a solution that will ensure a positive viewer experience.

- On a physical level, testing demonstrated that it is technically feasible for two 720p high definition ("HD") streams to be combined into a single Advanced Television System Committee ("ATSC") channel.[2] Results clarify that stations wishing to channel share must consider: (1) whether to utilize fixed or dynamically allocated bitstreams between the parties; (2) the relative "digital complexity" of the video content to be transmitted by two parties; (3) how to govern the division of the bitstream based on those requirements; and (4) how to monitor and manage any agreement reached on sharing of the bitstream itself.

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1 We have provided a glossary of all technical terms used in this report at Appendix F.

2 ATSC is the standards body that has developed the digital television standard used in the United States for over-the-air television broadcasting. *See* http://www.atsc.org/cms/ (last visited March 5, 2014).

- Testing demonstrated that it is technically feasible for the 2 HD (720p) streams to be combined with several variations of additional SD program streams. We observed that up to two additional SD streams are possible without major impact to the quality of experience of the overall material. While more SD streams are possible, multiplexing additional SD streams will likely require limiting the bitrate of the SD streams to avoid impacting the Quality of Experience ("QoE") of the HD programs. Stations need to test any increased program count carefully and fully optimize the statmux parameters for this to work.

- Three HD streams were also combined onto a single ATSC channel. Testing found that this combination may be technically feasible and of value for broadcasters, but each entity needs to examine the digital complexity of their material and decide if this combination is acceptable for their viewers.

- One HD stream is possible with a variety of SD programs. We tested 1 HD and up to 7 SD streams in a single ATSC channel with good results. The complexity of the content will determine the final program count.

- Bandwidth management (allocating the bitstream among a variety of services, metadata, video and audio) must be determined upfront for channel sharing to work properly. Our testing demonstrated that new encoders not only are more efficient in bit utilization but dramatically improved the QoE as well.

- Finally, additional areas of future study would include: (1) H.264 decoding and (2) ATSC 3.0 implications. We found that some consumer televisions decoded H.264 off-air. While this data is anecdotal, if the majority of future television sets can utilize H.264, greater bandwidth efficiency and/or quality of experience may be possible. H.264 offered a 10-15 percent greater efficiency in bitrate utilization.

II. OVERVIEW OF TESTING PARTICIPANTS

The testing host was KLCS-TV, a noncommercial educational television station and member of the Public Broadcasting Service, operating on digital channel 41. Its city of license is Los Angeles, California and its Designated Market Area ("DMA") is Los Angeles. KLCS-TV is a multimedia educational channel that inspires learners of all ages to higher levels of achievement and personal and professional growth through the use of programs and services that educate, inform, and enlighten. Broadcasting from Mt. Wilson, the KLCS coverage area extends from Ventura to near San Diego, reaching a potential viewing audience of over five million households in Los Angeles, Orange, San Bernardino, Riverside, Ventura, and San Diego Counties. Alan Popkin, Director of Engineering/Technical Operations, was the key participant for KLCS.

The testing sharer was KJLA, a multilingual, multicultural television station operating on digital channel 49. Its city of license is Ventura, California and its DMA is Los Angeles. KJLA is the flagship station for the LATV Network, a national entertainment network serving U.S. born Latinos, which is distributed via digital multicast services. Sharer's multicast signals presently carry up to nine additional programs of multilingual content. KJLA is carried in Los

Angeles and surrounding counties on approximately 2.8 million cable homes and 2 million DBS satellite homes, in addition to operating over the air. Eddie Hernandez, Director of Operations and Engineering, was the key participant for KJLA.

III. TESTING OVERVIEW

Testing Phases. The testing completed by KLCS and KJLA explored the feasibility and practicality of over-the-air channel sharing. The testing had a series of phases as follows:

- In the early phases, KLCS and KJLA conducted technical feasibility testing for multiplexing of signals on a single closed circuit bitstream. The testing involved a variety of content combinations (for example, multiple HD streams as well as HD and SD streams). The testing also included multiplexing standard MPEG-2 formatted content with an HD H.264 video channel.

- As described in detail below, the two stations developed reliable methodologies for modifying the Program and System Information Protocol ("PSIP") information to limit consumer disruption and ensure reliable data during over-the-air testing.

- In the next phase, the stations engaged in on-air channel sharing using a variety of configurations with replication of up to four (4) KJLA services during off-peak hours.

- Finally, the stations conducted full-time channel sharing. KJLA remained on-air, while KLCS transmitted a shared bitstream with content from both stations signaling different virtual channels.

Overview of Testing Approach. Since the implementation of the ATSC standard, television stations have been broadcasting multiple program streams in one 19.39 megabits per second ("Mbps") data stream over-the-air to viewers. The transport mechanism is a 6 MHz radiofrequency ("RF") DTV channel which is the carrier for the data. Because the Spectrum Act envisions that broadcast licensees may consider sharing their individual RF channel, questions have been raised about the viability of two broadcast entities sharing a single 19.39 Mbps data stream. If such channel sharing is technically feasible, then two broadcast licensees would be able to share a single RF channel while potentially allowing the other RF channel to be freed up and made available in the proposed incentive auction program that the FCC is considering.

In order to determine the most likely scenarios to test, we reviewed the publically available information of the program stream count of full power and Class A television stations that are present in the top 30 markets of the United States. We found, on average, television stations have a single HD stream and two SD streams. The range of configurations included two HD's with two SD streams, and no HD with as many as twelve SD streams. Approximately a quarter of stations in the top 30 markets have no HD streams, and instead rely upon multiple SD streams for their programming.[3]

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[3] This data is based on a review of FCC TV Query Search, Rabbitears at http://www.rabbitears.info/, SNL Kagan, Warren Communications Television and Cable Factbook.

The parties approached the question of channel sharing as a problem in bandwidth management as it was believed this would be the simplest and most informative methodology. A single station utilizes a data rate of 19.39 Mbps. The question sought to be answered through this testing was how potential partners could choose to divide up that bandwidth and signal it to home TV receivers. Due to the nature of the ATSC standard, there is both a physical and virtual layer to be considered, as discussed in detail below.

A. Background on Video Encoding

In the physical layer, to best utilize the limited data stream, stations must first decide what each partner is delivering. Every broadcast entity chooses its format: HD, SD, Mobile Handheld (M/H), and data. They also choose the content, as well as make choices with respect to QoE. For the purposes of this test, we limited the choice to HD and SD channels. For other users, it will be fairly easy to extrapolate the bandwidth necessary for M/H and data and adjust the HD/SD channel count downward accordingly.

Once the desired content specifications have been decided, broadcasters typically use MPEG-2 (video) and AC-3 (audio) as the compression method. This is mandated by an FCC requirement for at least one program stream in this format by every broadcaster. Consumer TVs are all required to decode these codecs.[4]

These receiver limitations and other factors will lead to a program stream model that needs to be delivered by a very sophisticated encoding pool. The technology and algorithms that are used to compress the media are the gatekeepers of bitrate efficiency. It is obvious to the technical community that encoding has made significant strides since the first-generation HD encoder. The encoder pool represents a substantial capital investment for the broadcaster. The useful life of this hardware can be as long as ten years. While all broadcasters seek efficiency in the use of their bandwidth, that efficiency is dependent on the compression scheme(s) utilized in the equipment. The reader is reminded that these tests were conducted using the latest encoder hardware and software.

We expected to find, and did find, a more efficient use of MPEG-2 with the latest generation of encoders. Additionally, since the newer models of encoders can encode H.264 we also chose to explore the use of that codec in an over-the-air environment. While not practical today, it may give some guidance as to what the near-future may hold.

Encoders use very sophisticated chips, and Moore's Law implies these chips will get faster, have more computational ability, and be less expensive in fairly short time frames. Additionally, the designers who are writing the algorithms that drive these chips have gained a far better understanding of compression and developed new tools to encode multiple streams of video. This in turn provides better choices and efficiencies in bit utilization. In any encoding system there is always a balance between bitrates, quality and picture complexity. There are a variety of settings including program-stream priority, division of the statmux pool, audio content bitrates, video format and others that determine the amount of bandwidth each program will use. There are also many parameters that are *not* user defined in the encoders and statmux. These are

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[4] A codec is a device or computer program capable of encoding or decoding a digital data stream or signal. The word codec is a shortening of "coder-decoder" or "compressor-decompressor."

hard coded by the manufacturer as well as the nature of the algorithm that decides how many bits to allocate to each encoder to achieve a "quality picture." These parameters will vary for each encoder manufacturer. There are also user defined parameters that affect the encoding efficiency for various streams combined into the single multiplexed stream. The reader is, therefore, cautioned that the results will vary between available encoder equipment, complexity of material, and user settings (assigned bitrates, weighting, *etc*).

B. Background on Video Quality Measurement

The last part of the analysis is the QoE of any given picture. Quality of experience is subjective, essentially "beauty is in the eye of the beholder." If we display the same picture to a group of people on the same monitor, different viewers will rate the picture quality differently. If we change the monitor, and only the monitor, they may rate it differently. Until recently, the method to gather these scores was to use large numbers in focus groups and ask them to rate the picture on a scale of 0 through 4 with 0 being the best score (*i.e.*, the viewer was "very satisfied" with the picture). This is referred to as the Mean Opinion Score ("MOS").

The University of Texas developed an algorithm to approximate and predict the scores people would report if they saw two pictures side by side. This Multi-Scale Structural Similarity ("MS-SSIM") algorithm, as it is called, attempts to provide an objective means of predicting a subjective score. This evolved into what is now called the Differential Mean Opinion Score ("DMOS"). To quantify an ultimately subjective measurement (video quality), it was necessary to correlate the perceptions of picture faults to a reasonably reliable and repeatable scale. After evaluating the several scales used to measure QoE, we decided to utilize the DMOS score using the VideoClarity test equipment[5] which typically uses a scale of zero to ten (0 to 10), zero being best. If there is no detectable difference between the original data stream and the encoded stream, the score would be zero, a perfect score. When there is a difference between what is presented to the encoder and what is subsequently decoded from the encoder in luminance or color, there is a measurable differential causing the DMOS score to rise. The scale we utilized is derived from the MOS score of human perception and JND (Just Noticeable Differences) translated to a 0 to 10 scale as follows:

Description	0 to 10 Scale DMOS	0 to 4 Scale DMOS	JND 0 to 13 Scale
No Defects	0	0	0
Production Quality	0.01 - 1.00	0.01 - 0.40	0.01 - 2.00
Broadcast Quality	1.00 - 7.50	0.40 - 3.00	2.00 - 7.00
Annoying	7.50 - 8.50	3.00 - 3.50	7.00 - 10.0
Unwatchable	8.50 - 10.0	3.50 - 4.00	10.0 - 13.0
Probably not aligned (error)	10.0+	4.00+	13.0+

Table 1: Comparison of DMOS/JND Value Scores

Therefore, we utilized the zero-to-ten DMOS scores for comparison of all data streams combined in the statmux to objectively compare the many varieties of combinations broadcasters

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[5] From the VideoClarity website there is a detailed description of quality measurement scales, "Understanding MOS, JND and PSNR. http://videoclarity.com/WPUnderstandingJNDDMOSPSNR/.

would wish to investigate. Each DMOS reading obtained in the tests were checked with a high-quality HD broadcast monitor to be certain that our engineers subjectively agreed with the objective results. We found that our engineers, knowing what to look for and prompted by the spikes found by the VideoClarity, were able to see some faults when the DMOS score exceeded 6.0. However, these faults were only discovered with the aid of a seamless split or side-by-side comparison. Without the comparison, the picture appeared to be nearly perfect at 6.0 because the picture area where the faults were observed were generally soft or blurred in the original. In every other respect, the pictures measuring up to 7.5 on the DMOS (zero-to-ten scale) were subjectively "broadcast quality" for the general viewing public, consistent with the VideoClarity table description.

In evaluating QoE, engineers also look for picture artifacts that do not raise DMOS scores noticeably but might cause viewers to consider the picture annoying. DMOS typically does not have a temporal component. It compares the reference frame to the encoded frame one at a time. If there is a flickering effect introduced by the encoder into the picture, the DMOS score may not rise but the overall effect may be perceptible visually. In some cases, we observed artifacts that raise the DMOS score but are virtually imperceptible to the viewer. An example of this is helicopter rotor blurs. The encoded frame may not exactly match the reference, raising the DMOS score, but since this scene will cause visual confusion in any case the difference becomes almost imperceptible.[6]

While the DMOS scores are imperfect, they can be used as an alternative or supplement to the method currently used by large numbers of TV stations. That method, in our experience, has been for the engineering staff and management to simply view the encoded material back through a decoder on a broadcast evaluation monitor and determine whether they think it is a good picture. Some stations have used focus group subjective numbers as well. Few stations have a DMOS analyzer because they are expensive and time consuming to use. The labs in major broadcast organizations will have these devices as well as the encoder manufacturers. To that end it is probable that few broadcasters know what their DMOS scores are.

For the purposes of this test, we established the DMOS scores for KLCS and KJLA as a baseline for comparison for the test. Frankly, before this test engineers from both stations had no idea what their DMOS scores were. We relied on the decode/evaluate method and viewers comments. Neither station had experienced consistent complaints about their picture quality from viewers. KLCS is watched by nearly 1 million viewers a week, and has had very few quality complaints, even though the current encoder pool is over ten (10) years old and DMOS scores were revealed to have a range of 7 to 8.5 and a peak as high as nine (9). KJLA, with six year old encoders had scores in the 6 to 7 range. When testing over-the-air with the latest generation of encoders we saw these scores improve significantly. KLCS now scored a 1.5 and KJLA ranged from a 0.69 to a high of 1.56 on the DMOS scale. We obtained these results and improvement in scores while broadcasting a higher channel count than the normal KLCS

[6] An important fact to take into account is that there are several DMOS scales available to the evaluator. Additionally, this scale can lead to comparisons that can be confusing. If one set of encoders produce a score of 1 and a second set produce a score of 3, the average person would consider this a 300% improvement. This would be true if these were absolute numbers. When interpreting DMOS it must be kept in mind it is a scale and one cannot necessarily impute a linear conclusion.

program stream (adding 1 HD and 3 SDs). It was obvious to us that the new encoders not only are more efficient in bit utilization but dramatically improve the QoE as well.

Stations considering channel sharing are encouraged to develop their own baseline DMOS score to be able to evaluate the impact that more aggressive compression (possible in the latest generation of encoding equipment) and channel sharing may have on their viewers. The reader is strongly cautioned that reliance strictly on DMOS scores can be misleading and that a combination of the scores with direct observation of the encoded material should be used for final evaluations.

C. Testing Setup/Schematics

The equipment used in the testing included a statmux pool with 8 encoders, a standalone PSIP generator, a broadcast quality decoder, broadcast evaluation monitors of a variety of sizes, a QoE analyzer, stream analyzers and recorders, as well as a large number of consumer TV sets and set top boxes. The encoders were fed by video servers, satellite receivers and fiber feeds from the sharing station. In order to feed the analyzer and the encoders the same signals, a variety of distribution amplifiers and routers were deployed as well.[7]

IV. TESTING RESULTS AND IMPLICATIONS

A. PSIP Testing

PSIP Description. The Program System Information Protocol ("PSIP") generator provides the metadata that enables consumer TVs to tune the program streams, provide the major and minor channel numbers, program title, program description, ratings, language choices and the codecs for the program stream. The PSIP information directs the receiver where to find and how to display the content in the physical stream. It is integral to the ATSC system. The PSIP allows the physical channel (where the TV programming is in the radiofrequency spectrum) to be "mapped" to a virtual channel. In effect, this allows television broadcasters to redirect television and direct-to-home receivers to the virtual channel.[8] This greatly enhances the experience for viewers as they can comfortably tune to the television channel they have grown accustomed to, while the television broadcaster can (behind the scenes) make changes to the RF (physical) channel if needed.

Overview of PSIP Testing Goals. One of the critical portions of this test was to find out if the PSIP generator could successfully carry the virtual information for two otherwise unrelated channels correctly. Additionally, the test attempted to determine how home receivers and direct-to-home providers reacted to this configuration. Without proper configuration and implementation of the PSIP generator, channel sharing would fail.

Prior to commencing any tests of bandwidth efficiencies, on- and off-air, we had to determine if the device that generates the PSIP could perform several specific tasks. This

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[7] See Appendix A for a schematic of equipment used for the channel sharing pilot.

[8] As a concrete example of this activity, NBC 4 in the Washington, DC market is actually transmitted on UHF TV Channel 48. Through use of the PSIP (and other mechanisms in the ATSC standard), television set top boxes and receivers map UHF TV channel 48 to the virtual channel 4.

essentially defines the virtual layer of the ATSC system. A good part of this information comes directly from the traffic system which will vary by broadcaster. Would the PSIP generator be able to signal two major channel numbers and several minor channels for each major; and parse the needed program information correctly from two disparate traffic systems? Further, we needed to determine how various models of TV sets and outboard tuners (ATSC converter boxes) still in use would react to this environment.

Working closely with the equipment vendor, we deployed a new version of the PSIP generator to test its ability to provide the necessary tables. Following bench confirmation, we then put this system on-air to determine how televisions reacted. For clarification, KLCS has its physical RF channel on TV Channel 41 and its virtual channel at TV Channel 58. KJLA has its physical RF channel on TV Channel 49 and its virtual channel at TV Channel 57. The testing of the PSIP generator was designed to determine how televisions would react to physical 41 signaling both virtual 58 and 57.

PSIP Testing Results. The testing found that there was a wide range of responses to changes in the PSIP information:

- Some sets found all the information when tuned to Channel 58.1 with no prompting;
- Some sets needed to be tuned to Channel 41.1 to get the information;
- Some sets needed to rescan to find the new channel information.

Importantly, all of the TVs and tuners we tested were able to receive and correctly parse all of the required information. This included virtual channel, both major and minor, ratings, audio configuration, codecs, program titles and descriptions. Obviously, we did not have the availability of every TV/tuner in the market place to test. Since all of these devices are built on an ATSC protocol, there is a strong belief that they should also be able to handle shared channel configurations in the PSIP.

We also tested what would happen with additional changes to the PSIP information. When we went back to the original station PSIP information and did not signal the additional channels for the test, most sets remembered the tuning information that we had provided on a temporary basis. This is significant. It essentially means that many if not most consumers will have to rescan with every change of each station’s physical frequency whether due to channel sharing or repacking.

Findings. The information generated in this test indicates that channel sharing on the virtual level (PSIP) can be done successfully. However, the test results also suggest that careful thought must be put into the RF transition, whether for repacking or sharing, by the FCC and broadcasters to find a solution that will minimize viewer complaints. The Commission should seek to limit the number of times that PSIP information must be modified (and/or changes to the physical channel) to ensure that viewers will not repeatedly be forced to rescan in order to continue to receive over-the-air broadcast television.

B. Bandwidth Management

A critical issue for all broadcasters wishing to engage in channel sharing is reaching a determination on how the bandwidth shared between the parties should be allocated. As part of our testing process, our first step was to develop allocation alternatives for a variety of services, metadata, video and audio.

PSIP Bitrate. One service that is universally needed is the PSIP information. This can vary in bitrate which is user defined. If the rate is set too high- unused bits are lost, set it too low and televisions can have trouble either tuning or updating the guide information or Event Information Table ("EIT"). We chose 40 kilobits per second ("kbps") per program stream in consultation with the manufacturer. If a traffic system provides verbose program descriptions, this number may need to rise. Another dependency is the number of days forward scheduled in the EIT. An EIT providing 12 hours of information consumes fewer bits than one loading 72 hours or more of information. The total PSIP bits are determined by the program stream count. The PSIP allocation needs to be adjusted up or down accordingly. Sharing stations must use the least number of bits to achieve the greatest efficiency. We have not had any problems with the TV sets we tested at this rate, though it may be possible to use a lower bitrate successfully. On the other hand, a higher number may be required, depending on the length of the program information that is delivered by each traffic system.

Audio and Video Bitrates. The remaining available bits in the pool can be allocated for audio and video. This is where the number of audio services needs to be totaled. Historically, broadcast engineers have set the bitrate for a stereo pair at 192 kbps for main, SAP and DVI and between 384 and 512 kbps for surround sound. We questioned why these were the chosen bitrates. After talking to a number of station engineers and the encoding vendor, no one could tell us why these were the selections other than historically this was the way they were set. After researching the AC-3 system and discussion with Dolby Labs, some interesting data developed.[9]

We asked Dolby Labs, how many kbps per channel was actually necessary without any perceptible audio degradation. Dolby's answer was 64 kbps per channel. This response seemed too low based on common practice, so we confirmed this several times with Dolby Labs. The question was also posed to Dolby regarding the encoding of a dual mono pair as one commonly finds in Secondary Audio Program ("SAP") and/or Descriptive Video Information ("DVI"). The answer here was 64 kbps as the two channels were redundant. They stated that the decoder would reproduce it in dual mono because that is the way it is coded to start and that since the two channels were essentially repeated, additional bits were not needed. In a 5.1 audio configuration, 384 kbps was the specified number. We tested these settings and could hear no difference between 128 kbps for a stereo pair and 192 kbps on our test television receivers. It certainly is possible that there are sets of ears and Hi-Fi sound systems that one could perceive a difference. Since the AC-3 system is proprietary to Dolby, there is no one else to ask about this. Dolby states in the referenced paper: "Single channel services may have a bit-rate as low as 32 kb/s.

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9 The reader is encouraged to review: http://www.dolby.com/uploadedFiles/English_(US)/Professional/Technical_Library/Technologies/Dolby_Digital_(AC-3)/37_ac3-flex.pdf to understand the basis of some of these findings.

The overall data stream is defined for bit rates ranging from 32 kb/s up to 640 kb/s. The higher rates are intended to allow the basic audio quality to exceed audiophile expectations."[10]

Why is this significant? It now becomes a business decision "to exceed audiophile expectations." We decided for the purposes of this test to meet those expectations, not exceed them. The reader will have to make their own decision as to the rates they choose. Broadcasters, whose material is primarily cinematic in nature, may choose a higher bitrate. This choice will affect the program channel count that is possible in a shared environment.

Settings Used For Testing. In order to pack as many channels as possible in a limited space, every bit counts. For example, when testing 10 stereo pairs in the total payload encoded at 128 kbps as opposed to 192 kbps, we saved 64 kbps per channel, the result is 640 kbps of reclaimed bits with little or no diminishment in viewer experience. If one adds in potential additional savings for the dual mono SAP/DVI in the channel count, we can potentially save 1 Mbps over the proposed channel count that can be devoted to video.

For the purposes of this test we chose 128 kbps per stereo pair, 64 kbps for dual mono and 384 kbps for 5.1 surround for the bit budget for audio per program stream, staying with the Dolby recommendation of 64 kbps per audio channel. Our assumption was that only HD channels required surround sound, all SD channels were configured for a stereo pair as the main. We chose 64 kbps for SAP and DVI for all channels as these tend to be delivered in mono or dual mono. Many broadcasters do not provide SAP and/or DVI audio channels. Additional bit savings are possible with this configuration.

C. HD Bit Considerations

There are two competing HD formats in use in the United States, 1080i and 720p. There are many arguments as to why one should use one over the other. Early users of HD chose 1080i primarily because it was the only equipment available. When 720p equipment became available, it ignited a debate about which format was "best" that continues today. Each format has its advantages and disadvantages and advocates exist for both formats. The major networks in the United States are divided in this as well. CBS and NBC have chosen 1080i, while ABC and Fox use 720p. PBS distributes in 1080i and their members use both 1080i and 720p for broadcast to the home.

Adding to the confusion is what happens at home. All screens have a native resolution whether it is 1080i, 720p or even 1080p which varies by manufacturer and model. No matter which format the broadcaster chooses, the receiver converts the signal to the screen's native resolution using a scaler device. Cable and satellite distribution further complicate the issue. Cable set top boxes can convert the signal, as well, to either 720p or 1080i, while satellite providers re-encode the signal to H.264 for delivery and their set-top box will convert it yet again. Most engineers are aware that they have little control over how their signals are displayed at home.

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[10] See http://www.dolby.com/uploadedFiles/English_(US)/Professional/Technical_Library/Technologies/Dolby_Digital_(AC-3)/37_ac3-flex.pdf to understand the basis of some of these findings.

How does this affect channel sharing? Most broadcast encoder manufacturers are of the opinion that 720p can be encoded at lower bitrates, for a comparable QoE, than 1080i. Since broadcasters have no control over the final display format at home, it makes sense to use the most efficient encoding structure for final distribution over the air. To test that theory, we compared a PBS program, NewsHour, in both formats. In 720p, we found a surprisingly better DMOS score at approximately 50% of the bitrate of 1080i. Based on this result (and manufacturer's advice), we chose 720p for the HD format in this test. The table below presents a summary of the NewsHour in 1080i and 720p formats[11]:

Source	Bitrate (Mbps)	DMOS Luma Avg	DMOS Chroma Avg
NewsHour OTA 1080i	11	3.71	2.01
NewsHour 720p	2.5-7	2.07	1.12

Table 2: DMOS Comparison for News Hour in 1080i v. 720p

This does not necessarily mean there is a need to change acquisition and contribution infrastructure at a station as the cross conversion can be accomplished just prior to final encoding. While a standalone cross converter can be used, many of today's server systems do it automatically based on Active Format Descriptor ("AFD") codes and sets of business rules.

D. Test Results for Various Scenarios

For purposes of this testing, we improvised a number of scenarios to determine the technical feasibility of sharing between broadcast stations. Initially, we set a baseline for video quality (based on the settings described above) by encoding a single HD signal to get a benchmark for comparison prior to adding more video streams. The results of these tests are provided below. Since we only had 8 encoders available to us for this test the results are limited to 8 streams of various combinations.

1. Single HD stream

To establish a baseline measurement, we encoded two different HD programs in 720p at a constant bitrate of 18 Mbps. We chose the most difficult material available to us. The first content utilized was a Las Vegas compilation ("Vegas" or "Vegas Material"). It consists of shots that include helicopters, planes, fast moving water, lights, flashing lights, fountains and more. It is a 12 minute reel that ranges from moderate to difficult in encoding complexity.

Using the newest generation of encoding equipment, the average we achieved with this material was a DMOS score of 2.16. Considering any score 7.5 or lower is considered a good "broadcast quality" picture, this was very good. To the eye, through a broadcast monitor, it was an excellent picture.

The second HD source was "National Parks, America's Best Idea" ("National Parks"), a PBS documentary produced by Ken Burns.[12] This is widely thought of in the PBS community as the most difficult content available to encode into ATSC. Suffice to say, for those not familiar

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11 See Appendix B, 1080i v. 720p.

12 See http://www.pbs.org/nationalparks/parks.

with it, it has scope, grandeur and beauty. It is subtle in its shading and nuance and to add to the difficulty it was shot in Super 16, complete with film grain and 3/2 pull down. We achieved an average DMOS score of 2.31 with this source.[13]

File Name	DMOS Luma Avg	DMOS Chroma Avg
Vegas	2.16	3.70
National Parks	2.31	2.29

Table 3: HD 18 Mbps CBR Test Results

It is important to understand these are average scores. There are areas that are significantly above and below the average. This is due to the difficulty of the material presented to the encoder at any instant. Even using the entire ATSC stream, there were scenes that rose to as high as 9.29.[14] Since we are converting an uncompressed 1.5 gigabit per second ("Gbps") HD program to under 20 Mbps (a compression ratio of over 75:1), these DMOS scores are not unexpected.

With this information we now had a baseline to compare the scores in the different configurations.

2. Two HD streams

Next, we divided the pool into two independent 9 Mbps pools and encoded each HD stream into one half of an ATSC channel. We then compared this result to the same material encoded at 18 Mbps. The scores, as we expected, rose slightly. At 9 Mbps, Vegas scored a 3.86 and National Parks rose to a 3.03. We began to notice a pattern between the four scores. The major differences in the DMOS scores apparently resulted from the way the average was affected by the handling of the most difficult transitions and scenes.

File Name	DMOS Luma Avg	DMOS Chroma Avg
Vegas	3.86	4.50
National Parks	3.03	2.99

Table 4: HD 9 Mbps CBR Test Results

We then put both programs into a single statmux pool of 18 Mbps, instead of splitting the two HD signals into two separate 9 Mbps channels. Statistical multiplexing is well understood by broadcast engineers. By letting the encoders decide how best to encode, they could now use greater than 9 Mbps when necessary. We set the lower limits at 2.5 Mbps per channel with a max of 11 Mbps.

As expected, we achieved better DMOS scores with the Vegas Material now scoring a 3.07 and National Parks remained at 3.03. It appeared that the collective results were due to a better handling of the peak difficulty scenes by sharing the bit pool. In the constant bit rate 9

13 All of the tables contained in the narrative are sections of the test tables that are available in Appendices B-E. The tables also contain the methodology for determining the statmux pool.

14 See Appendix C, One through Multiple HDs, with some SD. In reviewing Tables 3-11, please refer to Appendix C.

Mbps pools, the encoders had little trouble with a majority of the scenes as only the excursions were running out of bits. The new encoder's bit rate efficiency is noteworthy, but testing demonstrated that they can still become bit starved if not optimally configured.

File Name	Bitrate (Mbps)	DMOS Luma Avg	DMOS Chroma Avg
Vegas	11-2.5	3.07	4.25
National Parks	11-2.5	3.03	2.93

Table 5: 2 HD 18.29 Mbps VBR Test Results

We now have empiric proof of the viability of two 720p programs in one ATSC channel with good QoE scores. Observing the encoded material in a split screen with the original source, we were unable to determine the original from the encoded. A blind sample of a number of station personnel confirmed this. While it is possible that certain programs can exceed the difficulty of the test material, we did not have access to them. Broadcasters are cautioned to evaluate their own material in contemplation of sharing with a partner. Moreover, this testing result suggests that statistically multiplexing the 18 Mbps bit stream may be more effective than simply splitting the bit stream into two 9 Mbps pools. However, such a combined pooling will require careful negotiations between broadcasters, especially if the encoding "difficulty" of the material is dissimilar between the two stations.

3. Three HD streams

With the success of encoding two moderate to difficult HD programs in an ATSC channel we moved on to three HD streams. We chose for the third HD source a reel of underwater material ("Underwater"). This reel contains numerous scenes of various types and amounts of fish from the perspective of a diver. We believe this material to be in the moderate range of difficulty to encode. We set the encoders to range from a maximum of 11 Mbps to a low of 2.5 Mbps. They were all weighted equally.

We noted acceptable scores for the Vegas material in the luma information. The chroma portion had excursions that pulled the chroma average upward, although these occurred in scenes that would be difficult for the eye to detect. The National Parks material showed an increase in the luma and chroma DMOS, and the Underwater material was good in both. There were no obvious artifacts (such as macroblocking, etc.) in the content, and these scores remained well within the "broadcast quality" range. Reliance on just the score without a visual check of the material can be misleading as mentioned before. In summary, this combination may be of value, but each broadcaster needs to examine their material and decide if this combination is acceptable for their viewers.

File Name	Bitrate (Mbps)	DMOS Luma Avg	DMOS Chroma Avg
Vegas	11-2.5	3.42	4.69
National Parks	11-2.5	4.11	3.82
Underwater	11-2.5	3.60	2.47

Table 6: 3 HD 17.37 Mbps VBR Test Results

4. Two HD and One SD stream

We next attempted to add an SD stream to the two HD streams. A large number of broadcasters have one HD and one or more SD streams currently. We chose APT's "Create" channel for the first SD stream. This channel is a combination of cooking, gardening and how to material. We rated it as a moderate to easy channel to encode. We set the upper limit to 3 Mbps with a low of 850 kbps and added it to the pool.

We weighted the HD programs at 95 in the vendors' target quality scale and the SD at 75, believing the HDs would be "more important" to the broadcaster.[15] In tests of just SD channels, we were able to achieve excellent DMOS scores with bit rates as low as 1 Mbps. We felt that giving the HD material priority would produce better results overall. Test results showed that the QoE for the SD material did not rise as rapidly as the HD with fewer bits available.

File Name	Bitrate (Mbps)	DMOS Luma Avg	DMOS Chroma Avg
Vegas	11-2.5	2.96	4.36
National Parks	11-2.5	3.35	3.27
Create	3.5-0.85	1.48	1.23

Table 7: 2 HD/1 SD 18 Mbps pool VBR Test Results

We achieved a DMOS score of 1.48 for Create. The Vegas material now was at 2.96, while National Parks rose to 3.35. Essentially, the Vegas material was unchanged. We had expected both scores to rise. We theorize this has to do with the level of simultaneity of the material and that the difficulty of all the material combined with the weighting system in the encoders. Both HD pictures still looked excellent when displayed on a number of broadcast monitors and random viewers still could not distinguish between the original and the encoded. The SD channel was virtually indistinguishable from the original. We therefore concluded that it was possible to combine two HD streams with a single SD stream, under the test conditions described above.

5. Two HD and Two SD streams

Having achieved a good QoE for 2 HD and 1 SD streams, we added another SD stream to the pool. In this case, we chose one of KJLA's channels, LATV, which is targeted to the young Hispanic market. We kept all the settings the same as before and observed the results.

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15 It may be beneficial to the reader to discuss the nature of the "target quality scale." Essentially this is one of the key user settings in the statmux we tested. The Target Quality configuration does not set the average bitrate, it only biases the bit rate towards a direction. For example, a lower target quality will require a lower bit rate for a demanded content. It enables the user to tell the pool the relative importance of each stream. In the event of not enough bits being available for all streams, it will prioritize the bits for the one of highest weight. Many encoder vendors have a similar setting. Its effect on the outcome will vary by manufacturer. Anecdotally, we found a better result with a 95 setting for the HD than 90.

File Name	Bitrate (Mbps)	DMOS Luma Avg	DMOS Chroma Avg
Vegas	11-2.5	3.19	4.54
National Parks	11-2.5	3.42	3.99
Create	3-0.85	0.61	0.96
KJLA 1 (LATV)	3-0.85	0.91	2.74

Table 8: 2 HD/2 SD 17.7 Mbps pool VBR Test Results

Vegas material now rose to a 3.19 DMOS score and National Parks rose to 3.42. Both HDs still achieved what most viewers would consider a "very good" picture quality. Interestingly, the Create stream actually improved to a 0.61 DMOS score and LATV scored a 0.91. We attribute the improvement in Create due to the fact that the material was 16x9 embedded in a 4x3 frame, creating a black letter box in the material (as was LATV material). In the previous test Create was a full 4x3 picture.

It is clear that 2 HD and 2 SD program streams of this complexity can be multiplexed into a single ATSC channel with excellent quality.

6. Two HD and Three SD streams

We then added another SD stream to the encoding pool. Here we observed the QoE of National Parks begin to rise to a 4.27 DMOS score. The Vegas score continued to be an excellent score of 3.52. National Parks scores were still within the "broadcast quality" range. The SD content continued at perfectly acceptable levels.

File Name	Bitrate (Mbps)	DMOS Luma Avg	DMOS Chroma Avg
Vegas	11-2.5	3.52	4.79
National Parks	11-2.5	4.27	4.05
Create	3-0.85	1.22	1.13
KJLA 1	3-0.85	1.33	2.14
KJLA 2	3-0.85	2.88	1.60

Table 9: 2 HD/3 SD 17.4 Mbps pool VBR Test Results

Our experience with the QoE of the SD material led us to another experiment. We were curious to discover if the total content would be affected by lowering the maximum bit rate for the SD content from 3 Mbps to 2 Mbps. We theorized that the SD QoE would be minimally impacted while the HD QoE would correspondingly improve. The results were as predicted. Under these modified settings, the Vegas DMOS fell to a 3.45 and National Parks to a 4.01. The SD content scores did rise to a 2.13 for Create, but the other two channels actually received a better score.

File Name	Bitrate (Mbps)	DMOS Luma Avg	DMOS Chroma Avg
Vegas	11-2.5	3.45	4.64
National Parks	11-2.5	4.01	3.83
Create	2-0.85	2.13	1.13
KJLA 1	2-0.85	0.83	3.11
KJLA 2	2-0.85	1.73	2.57

Table 10: 2 HD/3 SD 17.4 Mbps pool VBR Test Results

It was hard to pinpoint the actual visual impact on National Parks on an evaluation monitor even by experienced engineers examining the picture only a few inches away. While we could find specific scenes that were impacted when we compared still frames of the worse scoring areas, in full motion most observers saw no difference. At the average viewing distance we conclude that the public will not perceive any encoder induced errors.

Again, it is the complexity of the program streams that will lead to variations in QoE. This combination of 2 HD and 3 SD may be suitable for stations based on their content.

7. Two HD and Four SD Streams

Based on experience with the 2 HD and 3 SD test, we believed that the best way to make this combination work was to lower the maximum bitrate for the SD material to 1.5 Mbps, essentially redistributing the previous combination of the three SD's bits to the four SD programs. The Vegas material scored a 3.47 and National Parks a 4.20.

File Name	Bitrate (Mbps)	DMOS Luma Avg	DMOS Chroma Avg
Vegas	11-2.5	3.47	4.67
National Parks	11-2.5	4.20	4.08
Create	1.5-0.85	1.23	1.50
KXLA	1.5-0.85	2.29	2.62
KVMD	1.5-0.85	1.65	2.61
Nightly Business Report SD	1.5-0.85	1.31	2.05

Table 11: 2 HD/4 SD 17.4 Mbps pool VBR Test Results

The HD and SD material held well within the target DMOS values and there were no major artifacts that were easily observable. With the channel count information for the top 30 markets we have gathered, this combination could accommodate a majority of TV stations with HD that may consider sharing. While additional SD services may be possible we leave this to entities who are interested in sharing to explore.

8. One HD and Four SD streams

We started with a relatively low SD program count to furnish a basis for comparison as the SD count increased. As expected, there were no problems with this combination. We weighted the HD at 95 with the SDs set at 75. The table below represents the results.[16]

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[16] See Appendix D, 1 HD, Multiple SD. In reviewing Tables 12-15, please refer to Appendix D.

File Name	Bitrate (Mbps)	DMOS Luma Avg	DMOS Chroma Avg
Vegas	11-2.5	3.41	4.61
PBS Kids	3-0.85	1.05	1.71
Create	3-0.85	0.84	0.95
MHz	3-0.85	1.17	0.85
KJLA 1	3-0.85	1.22	1.45

Table 12: 1 HD/4 SD 17.65 Mbps pool Test Results

9. One HD and Five SD streams

In this test, we performed several variations of the test to see the effect of different HD material with the combination of 5 SD programs. Due to the decreasing amount of bits available for video and the increase in audio and metadata, we lowered the SD weighting to 70 at this point to give the HD the best chance of success. All of the SD streams performed very well with this setting. We also thought it would be informative to see the range of scores possible varying the difficulty of the HD material. We tested Vegas, National Parks, PBS NewsHour and PBS Kids as alternative HD sources one-at-a-time. NewsHour is a moderately difficult program to encode and PBS Kids, being cartoons, is considered easy to encode.

File Name	Bitrate (Mbps)	DMOS Luma Avg	DMOS Chroma Avg
Vegas	11-2.5	3.81	4.95
National Parks	11-2.5	4.19	3.84
NewsHour	11-2.5	2.55	1.19
PBS Kids HD	11-2.5	1.74	2.49
KLCS 2	3-0.85	1.67	1.39
Create	3-0.85	1.16	1.21
MHz	3-0.85	1.31	1.33
KJLA 1	3-0.85	1.85	1.43
KJLA 2	3-0.85	0.80	2.71

Table 13: 1 HD/5 SD 17.36 Mbps pool Test Results

While the most difficult HD material DMOS score was slightly elevated from the previous test, we could see little evidence of this on a broadcast monitor. In simultaneous playback of the original and encoded HD material in a split screen and seamless playback, no station personnel could discern the difference. In fact, several of them chose the encoded material as their preference. This emphasizes the difficulty in assigning a QoE to any material that does not contain obvious artifacts. It appears to us that combining 1 HD and 5 SD programs in a single transport stream is feasible depending on the choice of content.

10. One HD and Six SD streams

As the numbers of streams begin to climb, due to the added audio and metadata information, the available bit pool for video continues to shrink. To counter this we chose to lower the maximum bitrate for the SD material to 2.5 Mbps, as well as set the weighting at 70. The HD encoder settings remained unchanged. Once again, we tested a variety of HD material with different difficulty with the same encoder set up. We did not test PBS Kids HD feeling the results were predictable based on the other tests.

File Name	Bitrate (Mbps)	DMOS Luma Avg	DMOS Chroma Avg
Vegas	11-2.5	4.53	5.34
NewsHour	11-2.5	2.89	1.18
KLCS 2	2.5-0.85	1.42	2.11
Create	2.5-0.85	0.71	0.98
MHz	2.5-0.85	0.77	1.31
KJLA 1	2.5-0.85	1.49	2.00
KJLA 2	2.5-0.85	1.84	1.64
KJLA 3	2.5-0.85	0.63	3.46

Table 14: 1 HD/6 SD 17.06 Mbps pool Test Results

The data suggests a decision point with this compliment of programs. If the encoded HD content approximates the difficulty of Vegas, the testing performed demonstrates that the DMOS numbers remain in the "broadcast quality" range. However, visual perception is the true test. Upon close inspection of the Vegas HD material we began to detect small artifacts in the evaluation monitor in a side by side comparison. At a normal viewer distance from the monitor (5 times screen height) we did not perceive the differences. This configuration may not work for extremely complex content based on direct observation. The NewsHour footage certainly had no problem. It remains for each station to determine what its target QoE and desired visual quality must be.

11. One HD and Seven SD streams

This test is a simple extension of the previous one. What is most interesting is that the HD program DMOS does not change greatly from having one additional SD program. This is counterintuitive, so we ran this test twice with the same result. Our only theory is the level of simultaneity of the material, the bit demands of the SD material, and the weighting of the encoder pool keeps the HD material in a close range. The statmux's algorithm is efficient enough to accommodate the extra stream and maintain the overall quality. There were no obvious artifacts in the SD programs and the scores were certainly within the target range.

File Name	Bitrate (Mbps)	DMOS Luma Avg	DMOS Chroma Avg
Vegas HD	11-2.5	4.55	5.14
NewsHour HD	11-2.5	2.81	1.28
KLCS 2	2.5-0.85	1.33	2.11
Create	2.5-0.85	1.36	1.25
MHz	2.5-0.85	1.12	1.04
KJLA 1	2.5-0.85	2.96	1.21
KJLA 2	2.5-0.85	3.16	2.17
KJLA 3	2.5-0.85	0.59	3.26
KJLA 4	2.5-0.85	1.48	2.75

Table 15: 1 HD/7 SD 16.77 Mbps pool Test Results

All the caveats in the previous test apply here as well. This configuration should not be taken as a limit. We stopped here for two reasons: (1) time limitations and (2) lack of additional encoders needed to test additional sharing. If a broadcaster utilizes HD material of less complexity adding more SD streams may be possible. Each broadcaster will need to decide for themselves the ultimate workable channel load.

V. ADDITIONAL TECHNICAL AREAS FOR FUTURE EXPLORATION

A. H.264 encoding

One area we thought might be of interest is the use of H.264 in an over-the-air environment. With the explosive growth of online video delivery, the use of this codec has mushroomed. It is more efficient than MPEG-2 and could provide broadcasters with greater opportunities than MPEG-2.

There were two phases to this test; the first was to measure the effect on bitrate and DMOS scores of H.264. The results are in the table below:[17]

Program	Bitrate (Mbps)	DMOS Luma Avg	DMOS Chroma Avg	Format
NewsHour HD	11-2.5 MPEG-2	2.07	1.12	720p
	7-2.5 H.264	1.30	0.76	720p

Table 16: MPEG-2 vs H.264 Test Results

Clearly we could achieve a better QoE at a lower bitrate utilizing H.264. The next phase involved actually broadcasting the channel.

We configured the encoding pool to replicate the current configuration of KLCS and added one additional H.264 HD channel to it. The PSIP generator must be configured correctly to signal this format to the television or it will not decode it at all. When we put this on-air we found mixed results. Most, but not all, of the "smart" TVs could decode and display this codec off-air. We conjecture this is due to the engineering architecture of the set. Some manufacturers may not port the off-air stream to the H.264 decoder and use either a different chip or signal path for the ATSC and the web streams. A great number of older models could not decode the format at all.

We enlisted the aid of a major TV manufacturer to test a range of their models dating back a few years. The results here are encouraging, at least with this vendor. A vast majority of their sets (whether "smart" or ordinary) successfully decoded an H.264 signal with no issues.

H.264 is not a magic bullet. Our tests show that it offers a 10 to 15% greater efficiency than MPEG-2. It also does not produce the same artifacts when bit starved, rather than macro blocking, it "softens" the picture. This is, in our opinion, a better result for the viewer, but is much harder to detect for the engineer on a casual basis. The largest concern is what portion of the over-the-air audience can decode it. There will be a tipping point at which the majority of TVs in service will be able to use this format off-air, but when that will occur would be conjecture on our part. Broadcasters will need to work with TV manufacturers to gather this data.

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[17] See Appendix E, H.264.

If we consider that ATSC 3.0 could be implemented by then (discussed below) with HEVC as the codec, H.264 for over-the-air may not be of interest to broadcasters.

B. Implications of ATSC 3.0

ATSC 3.0 presents interesting possibilities. The initial reports on this standard indicate a change to an OFDM modulation scheme from 8VSB. It offers a greater bit rate than the current modulation scheme, approximately 28 Mbps in a six megahertz channel. Such an increase in available bitrate would give channel sharing partners close to the original ATSC (8VSB) bitstream for each entity. Essentially broadcasters would be at the same point they are today with an 8VSB channel. This sounds like wonderful news except for one rather large problem. We do not believe that many current TV sets in the United States can tune OFDM. There may be some models that are capable, but we know of none that advertise this feature.

One viable solution to this would be an outboard tuner similar to the ones used in the DTV transition. If the FCC, broadcasters and equipment manufacturers can work together to offer a converter that would not only tune ATSC 3.0, but would also offer internet connectivity as well, then the transition to ATSC 3.0 may be accelerated.

With ATSC 3.0, the use of the HEVC codec is envisioned. Best estimates for this codec indicate today's HD may fit into as little as 2 -3 Mbps. What is not known today is the bitrates that 4K and its big brother 8K will require in the future. Additionally, it is not known if 4K and 8K will be a viable business opportunity for a broadcaster or will be delivered through alternate paths.

It is far beyond the scope of this report to answer these questions, we are only pointing out that larger capacity transport streams may be in the offing for broadcasters in the future.

VI. CONCLUSION

From the data we have gathered, it is clear that channel sharing is possible. The technology exists that makes it viable for two compatible broadcasters to do so. Whether two entities can successfully combine their required program streams and business models can only be answered by the stations interested in sharing.

The best results in stream count and QoE are accomplished by using dynamic bit allocation (statistical multiplexing). This in turn leads to a more complicated business and engineering agreement. Alternatively, those interested in channel sharing can simply divide the stream in half. If the program load allows for equal division of available bits, it simplifies an agreement. Attention must be used in evaluating this type of agreement, as a dynamic allocation appears to permit superior results in picture quality.

ATSC 3.0, if implemented, will give each broadcaster in a shared environment approximately 14 Mbps. This is equivalent to what broadcasters have today, especially with advancements in encoder efficiency. Whether this would be enough for future services such as 4K or 8K signals is unknown, as are the precise nature of future services. How to craft an agreement that has enough flexibility to allow for future changes in transport streams is more of a legal question than a technical one. Certainly sharing partners should make provision for this possibility of both future encoding improvements and more demanding content.

This test has revealed to the participants that a substantial program count, with a good QoE that is visually acceptable, is possible with the latest generation of encoders. It remains for broadcasters to determine for themselves whether or not channel sharing is of interest.

VII. ACKNOWLEDGEMENTS

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- Alan Popkin, Director of Television Engineering and Technical Operations
- Roger Knipp, Broadcast Engineer
- Richard Reyes, Producer
- Anthony Bankston, Broadcast System Operator (Master Control)

B. KJLA personnel involved in the testing

- Walter Ulloa, Principal
- Francis Wilkinson, General Manager
- James Downey, Advisor
- Eddie Hernandez, Director of Operations/Engineering

C. CTIA-The Wireless Association

- Scott Bergmann, Vice President, Regulatory Affairs
- Krista Witanowski, Assistant Vice President, Regulatory Affairs
- Amy Story, Assistant Vice President, Public Affairs
- Charles Ellis, CTIA Consultant, Ellis Engineering

D. PBS (loan of equipment)

- Tom Crowe, Senior Director, Engineering Interconnection
- Chris Homer, Vice President, Operations & Engineering
- Steve Scheel, Sr. Director, Media Operations

E. Association of Public Television Stations (“APTS”)

- Lonna Thompson, Executive Vice President, Chief Operating Officer and General Counsel

VIII. TECHNICAL APPENDICES

A. APPENDIX A: Schematic of Equipment

B. APPENDIX B: 1080i v. 720p

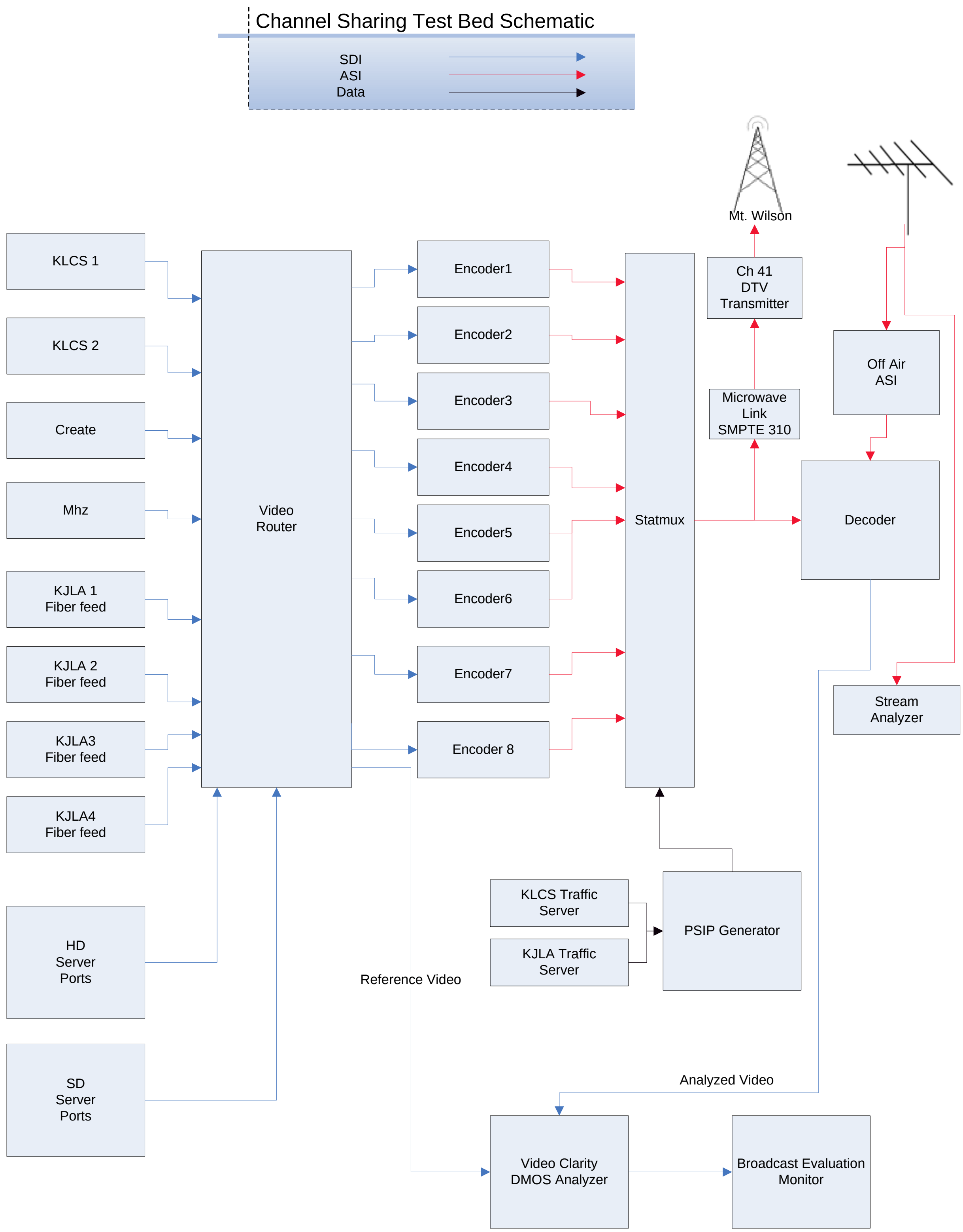
C. APPENDIX C: 1-Multiple HDs with Some SD

D. APPENDIX D: 1 HD, Multiple SD

E. APPENDIX E: H.264

F. APPENDIX F: Glossary

APPENDIX A: EQUIPMENT SCHEMATIC



APPENDIX B- HD- 1080i vs. 720p

CONTENT	FILE NAME	BIT RATE	SOURCE	DECODE	LUMA DMOS AVG	LUMA DMOS HIGH	LUMA DMOS LOW	CHROMA DMOS AVG	FORMAT
NewsHour 1080i	kocenewshor2	11	satellite	off air	3.71	9.29	0.01	2.01	1080i
NewsHour 720p	nwshr3142hd2sd	7-2.5 (Avg. 6.7)	nwshr3142hd2sdserver	nwshr3142hd2sddecode	2.07	8.61	0.00	1.12	720p

APPENDIX C: Up to 3 HDs, with SD

TEST NAME	FILE NAME	BIT RATE	SOURCE	DECODE	LUMA DMOS AVG	LUMA DMOS HIGH	LUMA DMOS LOW	CHROMA DMOS AVG	NOTES	AUDIO BIT ALLOWANCE	PSIP BIT ALLOWANCE
HD 18.29 Mbs CBR	vegas18mbscbr	18	vegas18mbscbrserver	vegas18mbscbrdecode	2.16	9.29	0.00	3.70		512	40
	np18mbs	18	np18mbsserver	np19mbsdecoder	2.31	5.34	0.31	2.29			
HD 9 Mbs CBR	vcbr9mbs	9	1hdcbr9mbsserver5	1hdcbr9mbsdecode	3.86	4.5	0.00	4.50		512	40
	np1hd9mbcbr	9	hdnpcbr9mbsserver	hdnpcbr9mbsdecode5	3.03	7.18	0.51	2.99			
2 HD 18.29 Mbs VBR	v2hd18mbvbr	11-2.5	2hdvegas18mbspoolserver	2hdvegas18mbspooldecode	3.07	9.75	0.00	4.25	wt 75 ea	1024	80
	np2hd18mbvbr	11-2.5	2hd18mbspoolnp.dopmc	2hd18mbspoolnpdecode	3.03	6.92	0.15	2.93			
2 HD 1 SD 18 Mbs VBR	v2hd1sd18mbvbr	11-2.5	2hd1sdvegas18mbspoolsvr	2hd1sdv18mbenc	2.96	9.81	0.00	4.36	wt hd95/sd75	1280	120
	2hd1sd18mbspoolnp	11-2.5	2hd1sdnp18mbspoolserver	2hd1sdnp18mbspoolserver	3.35	7.63	0.51	3.27			
	2hd1sd18mbspoolcreate	3.5-0.85	2hd1sd18mbspoolcreateserver	2hd1sd18mbspoolcreatedecode	1.48	4.41	0.17	1.23			
2 HD 2 SD 17.7 Mbs VBR	2hd2sd18mbspoolvegas	11-2.5	2hd2sd18mbspoolvegasserver	2hd2sd18mbspoolvegasdecode	3.19	9.94	0.00	4.54	wt hd95/sd75	1536	160
	2hd2sd18mbspoolnp	11-2.5	2hd2sd18mbspoolnpserver	2hd2sd18mbspoolnpdecode	3.42	6.93	0.77	3.99			
	2hd2sd18mbspoolcreate	3-0.85	2hd2sd18mbspoolcreateserver	2hd2sd18mbspoolcreatedecoder	0.61	1.62	0.21	0.96			
	2hd2sd18mbspoolkjla	3-0.85	kjlaserver	kjladecode	0.91	2.69	0.46	2.74			
2 HD 3 SD 17.4 Mbs VBR	2hd3sdvegas	11-2.5	2hd3sdvegasserver	2hd3sdvegasdecoder	3.52	9.88	0.00	4.79	wt hd95/sd75	1792	200
	2hd3sdnp	11-2.5	2hd3sdnpserver	2hd3sdnpdecoder	4.27	9.73	0.95	4.05			
	2hd3sdcreate	3-0.85	2hd3sdcreateserver	2hd3sdcreatedecode	1.22	3.30	0.11	1.13			
	2hd3sdkjla1	3-0.85	2hd3sdkjla1server	2hd3sdkjla1deocde	1.33	5.49	0.22	2.14			
	2hd3sdkjla2	3-0.85	2hd3sdkjla2server	2hd3sdkjla2decode	2.88	7.77	0.48	1.60			
2 HD 3 SD 17.4 Mbs VBR	2hd3sdvegassd2m	11-2.5	2hd3sdvegassd2mserver	2hd3sdvegassd2mdecode	3.45	9.94	0.00	4.64	wt hd95/sd75	1792	200
	2hd3sdnpsd2m	11-2.5	2hd3sdnpsd2mserver	2hd3sdnpsd2mdecoder	4.01	9.73	0.94	3.83			
	2hd3sdcreatesd2m	2-0.85	2hd3sdcreatesd2mserver	2hd3sdcreatesd2mdecode	2.13	4.01	0.96	1.13			
	2hd3sdkjla1sd2m2	2-0.85	2hd3sdkjla1sd2mserver2	2hd3sdkjla1sd2mdecode2	0.83	2.07	0.30	3.11			
	2hd3sdkjla2sd2m	2-0.85	2hd3sdkjla2sd2mdecode	2hd3sdkjla2sd2mdecode	1.73	6.06	0.41	2.57			
2 HD 4 SD 17.1 Mbs VBR	2hd4sdvegas	11-2.5	2hd4sdvegas1server	2hd4sdvegas1decode	3.47	9.88	0.00	4.67	wt hd95/sd75	2048	240
	2hd4sdnp	11-2.5	2hd4sdnpserver	2hd4sdnpdecode	4.20	9.62	0.65	4.08			
	2hd4sdcreate	1.5-0.85	2hd4sdcreateserver	2hd4sdcreatedecode	1.23	3.54	0.44	1.50			
	2hd4sdkxla	1.5-0.85	2hd4sdkxlaserver	2hd4sdkxladecode	2.29	6.24	0.41	2.62			
	2hd4sdkvmd	1.5-0.85	2hd4sdkvmdserver	2hd4sdkvmddecode	1.65	4.85	0.34	2.61			
	2hd4sdnbr	1.5-0.85	2hd4sdnbrserver	2hd4sdnbrserver	1.31	6.20	0.38	2.05			
3 HD 17..37	3hdvegas	11-2.5	3hdvegasserver	3hdvegasdecode	3.42	9.97	0.00	4.69	wt 95 ea.	1536	120
	3hdnp	11-2.5	3hdnpserver	3hdnpdecode	4.11	9.46	0.67	3.82			
	3hdfish	11-2.5	3hdfishserver	3hdfishdecode	3.60	7.81	0.51	2.47			

APPENDIX D: 1 HD Multiple SD

TEST NAME	FILE NAME	BIT RATE	SOURCE	DECODE	LUMA DMOS AVG	LUMA DMOS HIGH	LUMA DMOS LOW	CHROMA DMOS AVG	NOTES	AUDIO BIT ALLOWANCE	PSIP BIT ALLOWANCE
1HD 4 SD 17.65MI	1hd4sdvegas	11-2.5	1hd4sdvegasserver	1hd4sdvegasdecode	3.41	9.95	0.00	4.61	wt hd95/sd 75	1536	200
	1hd4sdklcs2	0.85-3	1hd4sdklcs2sserver	1hd4sdkjcs2decode	1.05	4.81	0.15	1.71			
	1hd4sdcreate	0.85-3	1hd4sdcreateserver	1hd4sdcreatedecode	0.84	2.78	0.28	0.95			
	1hd4sdmegahertz	0.85-3	1hd4sdmegahertzserver	1hd4sdmegahertzdecode	1.17	4.68	0.25	0.85			
	1hd4sdkjla1	0.85-3	1hd4sdkjla1server	1hd4sdkjla1decode	1.22	3.44	0.29	1.45			
1HD 5 SD 17.36 M	1hd5sdvegas	11-2.5	1hd5sdvegasserver	1hd5sdvegasdecode	3.81	9.97	0.00	4.95	wt hd95/sd 70	1792	240
	1hd5sdpbskids	11-2.5	1hd5sdpbskidsserver	1hd5sdpbskidsdecode	1.74	5.51	0.00	2.49			
	1hd5sdNH	11-2.5	1hd5sdNHserver	1hd5sdNHdecode	2.55	9.08	0.00	1.19			
	1hd5sdNP	11-2.5	1hd5sdNPserver	1hd5sdNPdecode	4.19	9.4	0.76	3.84			
	1hd5sdklcs2	0.85-3	1hd5sdklcs2server	1hd5sdklcs2decode	1.67	7.43	0.73	1.39			
	1hd5sdcreate	0.85-3	1hd5sdcreateserver	1hd5sdklcs2decode	1.16	3.72	0.15	1.21			
	1hd5sdmegahertz	0.85-3	1hd5sdmegahertzserver	1hd5sdmegahertzdecode	1.31	7.47	0.14	1.33			
	1hd5sdkjla1	0.85-3	1hd5sdkjla1server	1hd5sdkjla1decode	1.85	4.10	0.54	1.43			
	1hd5sdkjla2	0.85-3	1hd5sdkjla2server	1hd5sdkjla2decode	0.80	4.20	0.29	2.71			
1HD 6 SD 17.06 M	1hd6sdvegas	11-2.5	1hd6sdvegasserver	1hd6sdvegasdecode	4.53	9.98	0.00	5.34	wt hd95/sd 70	2048	280
	1hd6sdNH	11-2.5	1hd6sdNHserver	1hd6sdNHdecode	2.89	8.56	0.00	1.18			
	1hd6sdklcs2	0.85-2.5	1hd6sdklcs2server	1hd6sdklcs2decode	1.42	5.36	0.21	2.11			
	1hd6sdcreate	0.85-2.5	1hd6sdcreateserver	1hd6sdklcs2decode	0.71	2.33	0.20	0.98			
	1hd6sdmegahertz	0.85-2.5	1hd6sdmegahertzserver	1hd6sdmegahertzdecode	0.77	2.26	0.13	1.31			
	1hd6sdkjla1	0.85-2.5	1hd6sdkjla1server	1hd6sdkjla1decode	1.49	3.11	0.26	2.00			
	1hd6sdkjla2	0.85-2.5	1hd6sdkjla2server	1hd6sdkjla2decode	1.84	4.58	0.59	1.64			
	1hd6sdkjla3	0.85-2.5	1hd6sdkjla3server	1hd6sdkjla3decode	0.63	2.09	0.15	3.46			
1HD 7 SD 16.77 M	1hd7sdvegas	11-2.5	1hd7sdvegasserver	1hd7sdvegasdecode	4.55	9.98	0.00	5.14	wt hd95/sd 70	2304	320
	1hd7sdNH	11-2.5	1hd7sdNHserver	1hd7sdNHdecode	2.81	8.58	0.00	1.28			
	1hd7sdklcs2	0.85-2.5	1hd7sdklcs2server	1hd7sdklcs2decode	1.33	5.47	0.32	2.11			
	1hd7sdcreate	0.85-2.5	1hd7sdcreateserver	1hd7sdklcs2decode	1.36	3.57	0.40	1.25			
	1hd7sdmegahertz	0.85-2.5	1hd7sdmegahertzserver	1hd7sdmegahertzdecode	1.12	5.68	0.30	1.04			
	1hd7sdkjla1	0.85-2.5	1hd7sdkjla1server	1hd7sdkjla1decode	2.96	5.66	1.14	1.21			
	1hd7sdkjla2	0.85-2.5	1hd7sdkjla2server	1hd7sdkjla2decode	3.16	8.64	0.73	2.17			
	1hd7sdkjla3	0.85-2.5	1hd7sdkjla3server	1hd7sdkjla3decode	0.59	2.53	0.34	3.26			
	1hd7sdkjla4	0.85-2.5	1hd7sdkjla4server	1hd7sdkjladecode	1.48	3.47	0.16	2.75			

APPENDIX E: H.264

TEST NAME	FILE NAME	BIT RATE	SOURCE	DECODE	LUMA DMOS AVG	LUMA DMOS HIGH	LUMA DMOS LOW	CHROMA DMOS AVG	FORMAT
MPEG2 vs. H.264	nwshr3142hd2sd	11-2.5	nwshr3142hd2sdserver	nwshr3142hd2sddecode	2.07	8.61	0.00	1.12	720p
	nwshr3142hd2sdh264	7-2.5	nwshr3142hd2sdh264server	nwshr3142hd2sdh264decode	1.30	3.90	0.00	0.76	720p

APPENDIX F
GLOSSARY OF TERMS

1. 1080i – is an abbreviation referring to a combination of frame resolution and scan type, in the domains of high-definition television and high-definition video. The term assumes a widescreen aspect ratio of 16:9, a spatial resolution of 1920 pixels × 1080 lines (2.1 megapixels), and a temporal resolution of 50 or 60 interlaced fields per second.
2. 1080p – is a set of HDTV high-definition video modes characterized by 1080 horizontal lines of vertical resolution[1] and progressive scan, as opposed to interlaced, as is the case with the 1080i display standard. The term usually assumes a widescreen aspect ratio of 16:9, implying a resolution of 1920x1080 (2.1 megapixel) often marketed as Full HD.
3. 480i – is the shorthand name for a video mode, namely the US NTSC television system or digital television systems with the same characteristics. The i, which is sometimes uppercase, stands for interlaced, the 480 for a vertical frame resolution of 480 lines containing picture information. This is the common form resolution for standard definition digital broadcasting television in the United States.
4. 720p – is a progressive HDTV signal format with 720 horizontal lines and an aspect ratio of 16:9. The number 720 stands for the 720 horizontal scan lines of image display resolution (also known as 720 pixels of vertical resolution), while the letter p stands for progressive scan (i.e. non-interlaced).
5. AC-3 (or Dolby Digital) – is the name for audio compression technologies developed by Dolby Laboratories. Except for Dolby TrueHD, the audio compression is lossy. It is used for other applications such as HDTV broadcast, DVDs, Blu-ray Discs and game consoles.
6. AFD (or Active Format Description) – is a standard set of codes that can be sent in the MPEG video stream or in the baseband video signal that carries information about their aspect ratio and active picture characteristics. It has been used by television broadcasters to enable both 4:3 and 16:9 television sets to optimally present pictures transmitted in either format. It has also been used by broadcasters to dynamically control how down-conversion equipment formats widescreen 16:9 pictures for 4:3 displays.
7. ATSC (or Advanced Television System Committee) – ATSC is the standards body that has developed the digital television standard used in the United States for over-the-air television broadcasting. See http://www.atsc.org/cms/ (last visited March 5, 2014).
8. Bitstream – is a series of bits in a computing or telecommunications system.
9. Codec – a device or program that compresses data to enable faster transmission and decompresses received data.
10. DTH (or Direct to Home) – is term used to refer to satellite transmissions directly intended for home viewers from cable television distribution services that are sometimes carried on the same satellite.

11. DVI (or Descriptive Video Information) – also referred to as a video description or more precisely called a visual description, refers to an additional narration track intended primarily for blind and visually impaired consumers of visual media (including television and film, dance, opera, and visual art). It consists of a narrator talking through the presentation, describing what is happening on the screen or stage during the natural pauses in the audio, and sometimes during dialogue if deemed necessary.
12. EIT (or Event Information Table) – is extra data that is broadcast with a television signal, much like Closed Caption Text in the VBI stream. EIT provides program data for the current show and future shows which can be then used to view on-screen program information, such as title, length, description and more. This can also be gathered to build a program guide for current and future shows on all your available channels.
13. Encoder – is a device, circuit, transducer, software program, algorithm or person that converts information from one format or code to another, for the purposes of standardization, speed, secrecy, security or compressions.
14. H.264 – is a video compression format, and is currently one of the most commonly used formats for the recording, compression, and distribution of video content. H.264 is perhaps best known as being one of the video encoding standards for Blu-ray Discs; all Blu-ray Disc players must be able to decode H.264. It is also widely used by streaming internet sources, such as videos from Vimeo, YouTube, and the iTunes Store, web software such as the Adobe Flash Player and Microsoft Silverlight, and also various HDTV broadcasts over terrestrial (ATSC, ISDB-T, DVB-T or DVB-T2), cable (DVB-C) and satellite (DVB-S and DVB-S2).
15. HD (or High Definition) – is video of higher resolution than is standard definition. While there is no specific meaning for high definition, generally any video image with more than 480 horizontal lines (North America) or 576 lines (Europe) is considered high definition. 720 scan lines is generally the minimum even though many systems greatly exceed that.
16. Mbps/kbps/bps – stands for millions of bits per second or megabits per second and is a measure of bandwidth (the total information flow over a given time) on a telecommunications medium. Depending on the medium and the transmission method, bandwidth is also sometimes measured in the bps (bits per second), kbps (thousands of bits or kilobits per second) range or the Gbps (billions of bits or gigabits per second) range.
17. Moore's Law – is the observation that, over the history of computing hardware, the number of transistors on integrated circuits doubles approximately every two years. The law is named after Intel co-founder Gordon E. Moore, who described the trend in his 1965 paper.
18. MOS/DMOS (or Mean Opinion Score or Differential Mean Opinion Score) – MOS is a test that has been used for decades in telephony networks to obtain the human user's view of the quality of the network. DMOS is the difference between

"reference" and "processed" Mean Opinion Score in a full reference test system. DMOS can be presented in a 0 – 4 scale as well as a lowest score value of 7 or 10 in a ClearView analyzer.

19. MPEG-2 – is a standard for the generic coding of moving pictures and associated audio information. It describes a combination of lossy video compression and lossy audio data compression methods, which permit storage and transmission of movies using currently available storage media and transmission bandwidth. MPEG-2 is widely used as the format of digital television signals that are broadcast by terrestrial (over-the-air), cable, and direct broadcast satellite TV systems. It also specifies the format of movies and other programs that are distributed on DVD and similar discs. TV stations, TV receivers, DVD players, and other equipment are often designed to this standard.

20. MPEG-4 – is a method of defining compression of audio and visual (AV) digital data. It was introduced in late 1998 and designated a standard for a group of audio and video coding formats and related technology agreed upon by the ISO/IEC Moving Picture Experts Group (MPEG) (ISO/IEC JTC1/SC29/WG11) under the formal standard ISO/IEC 14496 – Coding of audio-visual objects. Uses of MPEG-4 include compression of AV data for web (streaming media) and CD distribution, voice (telephone, videophone) and broadcast television applications.

21. MS-SSIM (or Multi-Scale Structural Similarity) – Structural SIMilarity is based on the idea that the human visual system is highly adapted to process structural information, and the algorithm attempts to measure the change in this information between and reference and distorted image. At a high level, SSIM attempts to measure the change in luminance, contrast, and structure in an image. Luminance is modeled as average pixel intensity, contrast by the variance between the reference and distorted image, and structure by the cross-correlation between the 2 images. The resulting values are combined (using exponents referred to as alpha, beta, and gamma) and averaged to generate a final SSIM index value. Multi-Scale Structural SIMilarity is layered on SSIM. The algorithm calculates multiple SSIM values at multiple image scales (resolutions). By running the algorithm at different scales, the quality of the image is evaluated for different viewing distances. MS-SSIM also puts less emphasis on the luminance component compared to the contrast and structure components.

22. Multicasting – is a method by which multiple analog message signals or digital data streams are combined into one signal over a shared medium.

23. Orthogonal Frequency-Division Multiplexing (or OFDM) – is a method of encoding digital data on multiple carrier frequencies. OFDM has developed into a popular scheme for wideband digital communication, whether wireless or over copper wires, used in applications such as digital television and audio broadcasting, DSL Internet access, wireless networks, powerline networks, and 4G mobile communications. The primary advantage of OFDM over single-carrier schemes is its ability to cope with severe channel conditions (for example, attenuation of high frequencies in a long copper wire, narrowband interference and frequency-selective fading due to multipath) without complex equalization

filters.

24. Physical Channel – the radiofrequency on which the broadcast transmissions actually occur.

25. PSIP (or the Program and System Information Protocol) – is the protocol (1) originally defined by General Instrument for the DigiCipher 2 system and later extended for the ATSC digital television system for carrying metadata about each channel in the broadcast MPEG transport stream of a television station and (2) for publishing information about television programs so that viewers can select what to watch by title and description. PSIP defines virtual channels and content ratings, as well as electronic program guides with titles and (optionally) descriptions to be decoded and displayed by the ATSC tuner.

26. QoE (or Quality of Experience) – is a subjective measure of a customer's experiences with a service (web browsing, phone call, TV broadcast, call to a Call Center). Quality of Experience systems will try to measure metrics that customer will directly perceive as a quality parameter (in example: time for a new channel to be played when changing channel on TV).

27. SAP (or Secondary Audio Programming) – is an auxiliary audio channel for television that can be broadcast or transmitted both over-the-air and by cable television. SAP is often used to provide audio tracks in languages other than the native language included in the program.

28. SD (or Standard Definition) – is a television system that uses a resolution that is not considered to be either high definition television (HDTV 720p, 1080i, and 1080p) or enhanced-definition television (EDTV 480p). The common SDTV signal type in North America is 480i based on the American National Television System Committee NTSC system.

29. Statmux (or statistical multiplexing) – is a type of communication link sharing. In statistical multiplexing, a communication channel is divided into an arbitrary number of variable bit-rate digital channels or data streams. The link sharing is adapted to the instantaneous traffic demands of the data streams that are transferred over each channel. When performed correctly, statistical multiplexing can provide a link utilization improvement, called the statistical multiplexing gain.

30. Virtual Channel – the channel that broadcast content is mapped to for convenience for viewers rather than the actual physical channel.