ATSC 3.0 NEXT GENERATION DIGITAL TV STANDARD

– An Overview and Preview of the Issue

Rich Chernock, David Gomez Barquero, Jerry Whitaker, Sung-Ik Park, and Yiyan Wu

The Advanced Television Committee (ATSC) has been working on the next generation broadcast television system, known as ATSC 3.0, to replace the first-generation (ATSC 1.0) A/53 standard, the basic component technologies of which have been in use for 20 years.

The goals of ATSC 3.0 are to improve the television viewing experience with higher audio and video quality, improved and more flexible reception on both fixed and mobile devices, and more accessibility, personalization and interactivity. The ATSC is also addressing changing consumer behavior and preferences, providing TV content on a wide variety of devices. Furthermore, the ATSC is working to add value to the broadcasting service platform, extending its reach and adding new business models – all without the restriction of backward compatibility with the legacy system. The ATSC 3.0 standard enables system options for the broadcast industry (not just system parameter options), and provides toolboxes for the broadcasters and specifies how the tools are used. The selection of which tools are utilized and how depends upon the broadcasters' needs and business models.

Work on ATSC 3.0 has been divided into functional layers: physical layer, transport layer, and the application and presentation layer.

The physical layer for ATSC 3.0 starts every physical layer frame with a bootstrap signal that provides synchronization and signals basic information about the technology used in the physical layer itself (major and minor version, which enables graceful evolution of the physical layer itself in the future) as well as an Emergency Alert Service wake up flags, system bandwidth, time to the next frame of a similar service, and the sampling rate of the current frame. This bootstrap is extremely robust, able to be received in very challenging radio frequency conditions. The bootstrap is followed by a preamble, which carries the information needed to define the payload framing, including the information needed for the receiver to acquire the data frame. The remainder of the physical layer structure is the data payload itself.

By taking advantage of recent advances in modulation, coding, error correction, constellations, and multiplexing, the ATSC 3.0 physical layer offers a wide range of operating performance points in the BICM (bit interleaver, coding, and modulation) chain that is very close to the Shannon Limit (the theoretical limit for the amount of information that can be carried in a noisy channel). The ATSC 3.0 physical layer offers broadcasters the capability to operate in a robust/lower bitrate fashion for mobile and deep indoor services and/or a less robust/higher bitrate fashion for services to large screens in the home. If desired, the broadcaster can also operate with a simultaneous mixture of types of services using either Time Division Multiplexing (TDM) or Layer Division Multiplexing (LDM), or both. This allows broadcasters construct their broadcast emission to support a variety of different business models and to experiment with new ones.

The ATSC 3.0 transport layer uses IP (Internet Protocol) encapsulation for both streaming and file delivery, rather than the MPEG-2 Transport Stream (TS) encapsulation as is currently used in today's systems. When the ATSC A/53 standard was developed, the Internet was in its infancy, but now it is used for a large portion of entertainment content delivered to homes. Rather than remaining an independent silo, ATSC 3.0 allows broadcasting to become part of the Internet. This allows the creation of new services and business models for broadcasters and enables evolution nearer the pace of how the Internet evolves. The use of IP transport also enables incorporation of hybrid services, where components of services can be delivered by broadcast and broadband in a way that they can be synchronized and combined as needed to create services. This gives the broadcaster a large degree of flexibility and control over the services they offer. The use of IP transport, coupled with another decision – to deliver "streaming" content as chunks of ISO Base Media File Format (ISOBMFF) files (similar to streaming delivery over the Internet) rather than continuous streams of bits – enables another business model that has been difficult to support in the past: the ability to do advertising (or content) insertion at the receiver in a personalized fashion, by simply delivering file segments along with an associated playlist.

The applications and presentation layer encompasses video and audio coding, interactive features, accessibility, and other services. With current advances in video coding technology HEVC/H.265, ATSC 3.0 offers the capability to move to more pixels, 4k Ultra-High Definition (UHD) video, and also "better" pixels, specifically: (i) High Dynamic Range (HDR) 1000-nit (or more) color grading rather than 100-nit; (ii) Wider Color Gamut (WCG) approaching Rec. ITU-BT 2020 rather than Rec. ITU-BT 709; (iii) 10 bits per pixel rather than 8; and (iv) Higher Frame Rate (HFR) up to 120 Hz. While not currently in the design, the move to 8K UHD video may be supported in the future (should it be desired). Scalable video coding (SHVC) is also included in the video toolbox, both temporal and spatial scalability features, since scalability allows additional efficiency and flexibility.

While the selection of audio technology for ATSC 3.0 is still under discussion at this writing, the new audio system will provide a number of new capabilities, such as providing the capability to personalize audio rendering where a broadcaster can choose to give the viewer control over a number of aspects of the audio, or full audio immersion which includes height information (typically 7.1+4) that adds a significant degree of immediacy to the experience. Another major departure from the past is that in the ATSC 3.0 system a common audio stream is broadcast and rendered at the receiver appropriately according to the type of receiver and the actual speaker configuration.

Interactivity will be an important feature of ATSC 3.0 and work is underway to develop a robust application runtime environment supporting HTML5 and based on hybrid broadcast broadband TV (HbbTV) 2.0. Interactivity capabilities are expected to include, among others, targeted ad insertion, on-demand content launcher, T-commerce, voting and polling, etc.

In summary, ATSC 3.0 represents a significant step forward in capabilities for a broadcast television system. It provides a set of flexible capabilities for broadcasters that enable new services and new business cases. ATSC 3.0 is being built to last, and the concepts of flexibility, extensibility and scalability are in the core of the system and will allow graceful evolution over a long period of time, being possible to signal minor and major version changes and updates to enable graceful transitions from one technology to another and avoiding disruptive technology transitions.

The first article in this Special Issue [1], "*An Overview of the ATSC 3.0 Physical Layer Specification*," is by L. Fay, L. Michael, D. Gomez-Barquero, N. Ammar, and M. W. Caldwell. The authors present an overview of the physical layer technologies of ATSC 3.0, covering the ATSC A/321 standard that describes the so-called bootstrap, which is the universal entry point to an ATSC 3.0 signal, and the ATSC A/322 standard that describes the physical layer downlink signals after the bootstrap. A summary comparison between ATSC 3.0 and DVB-T2 is also provided.

The second article [2] "*System Discovery and Signaling Transmission Using Bootstrap in ATSC 3.0*," by D. He et al., provides a thorough overview of the ATSC 3.0 bootstrap signal. The bootstrap signals the type and nature of the transmitted waveform that immediately follows the bootstrap, and facilitates receiver synchronization and signal acquisition. In order to ensure flexibility and extensibility for future technology advances, the bootstrap introduces a fundamental signaling paradigm change by signaling rudimentary digital communication parameters such as the sampling frequency and channel bandwidth.

In the third article [3], "*Bit-Interleaved Coding and Modulation (BICM) for ATSC 3.0*," by L. Michael and D. Gomez-Barquero, the authors summarize and expound upon the choices made for the BICM (Bit-Interleaved Coded Modulation) part of ATSC 3.0. The paper provides an overview of the coding, bit interleaving and modulation, which provide ATSC 3.0 with superior capacity and coverage performance compared to any existing digital terrestrial broadcasting standard. The BICM block of ATSC 3.0 provides a SNR operating range of more than 30 dB, with the most robust mode operating below -5 dB SNR, and a maximum transmission capacity of 10.4 bits per second per Hertz, with a spectral efficiency very close to the theoretical Shannon limit less than 1 dB away in AWGN and Rayleigh channels.

The fourth article [4], "*Low-Density Parity-Check Codes for ATSC 3.0*," by K,-J. Kim et al., provides a detailed overview of the LDPC codes of ATSC 3.0. The paper presents the encoding methods for the two structures adopted: irregular repeat accumulate (IRA) structure and multi-edge type (MET) structure, together with some performance results compared to LDPC codes of other standards.

In the fifth article [5], "*Non-Uniform Constellations for ATSC 3.0*," N. Loghin et al. present the one-dimensional and two-dimensional non-uniform constellations adopted for ATSC 3.0. In contrast to conventional uniform QAM constellations, such constellations provide additional shaping gain which allows reception at lower SNRs. The design considered different channel realizations, and took the combination of LDPC code and bit interleaver into account.

The sixth article [6], "*Flexible and Robust Transmission for Physical Layer Signaling of ATSC 3.0*," by H. Jeong et al., presents the methodology adopted in ATSC 3.0 to apply a proper segmentation and LDPC coding of the physical layer signaling (Layer-1 signaling), which is transmitted in preamble OFDM symbols at the beginning of each frame.

The seventh [7], eighth [8] and ninth [9] papers cover one of the main new technologies of ATSC 3.0: Layered Division Multiplexing (LDM), a form of non-orthogonal multiplexing access for simultaneously offering stationary and mobile/indoor services in the same radio frequency (RF) channel. LDM can also be used to provide local content insertion for each SFN transmitter with seamless local coverage. In "*Layered Division Multiplexing: Theory and Practice*," by L. Zhang et al., the authors describe the theory and practice of LDM, and present a system description and performance analysis with a signal cancellation technology under different channel conditions. The paper "*Low Complexity Layered Division Multiplexing System for ATSC 3.0*," by S.-I. Park et al., describes the transmitter architecture adopted as a baseline technology of ATSC 3.0 that shares time and frequency interleavers, FFT, pilot patterns, guard interval, preamble, and bootstrap among the two layers, so that the implementation of LDM receivers can be realized with a limited complexity increase. In "*LDM Core Services: Indoor and Mobile Performance in ATSC 3.0*" by C. Regueiro et al., a comprehensive analysis of the LDM mobile performance is presented for different use cases, channel models, and configurations of the transmission parameters.

The tenth paper [10], "*Physical Layer Time Interleaving for the ATSC 3.0 System*," by P. Klenner et al., presents the optimized time interleaver (TI) adopted for the ATSC 3.0 system as a physical layer tool to mitigate the effects of burst errors. The time interleaver is very flexible and can have different configurations according to the number of physical layer pipes and service type: sheer convolutional TI, twisted block TI, and hybrid TI composed of cell interleaver, twisted block interleaver, and a convolutional delay-line.

The eleventh paper [11], "*Physical Layer Framing for ATSC 3.0*," by M. Earnshaw, K. Shelby, H. Lee, Y. Oh, and M. Simon, focuses on the subframe structure of ATSC 3.0, configuration, and contents, including subframe boundary symbols. Various methods for cell multiplexing multiple Physical Layer Pipes (PLPs) within a subframe are discussed and described, including Time Division Multiplexing (TDM), Frequency Division Multiplexing (FDM), Time-Frequency Division Multiplexing (TFDM), and Layered Division Multiplexing (LDM).

The twelfth paper [12], "*Transmit Diversity Code Filter Sets (TDCFS), a MISO Antenna Frequency Pre-Distortion Scheme for ATSC 3.0*," by S. LoPresto, R. Citta, D. Vargas, and D. Gomez-Barquero, provides an overview of the TDCFS Multiple-Input Single-Output (MISO) antenna scheme adopted in ATSC 3.0, together with experimental analysis of capacity and specific worst-case conditions that illustrate the benefits of using the TDCFS approach in Single Frequency Networks.

The thirteenth paper [13], "*Predicted ATSC 3.0 Broadcast Coverage*," by J. Kutzner and D. Lung, presents broadcast coverage maps in four reference U.S. markets with different terrains and population distributions to illustrate performances of individual transmitters and several transmitters in combination forming SFNs.

The fourteenth paper [14], "*Channel Bonding for ATSC 3.0*," by L. Stadelmeier, D. Schneider, J. Zöllner, and J. J. Gimenez, explains the channel bonding concept of ATSC 3.0, which spreads data of a single PLP over two different, standard-bandwidth RF channels. The channels can be located at any frequency, not necessarily adjacent to each other. The technical details as well as possible network gains are illustrated in the paper for different use cases such as services with increased data rates, or improved statistical multiplexing and mixed VHF/UHF operation. Channel bonding receivers require two tuners, but still allow for simple and memory efficient implementations. The relation to other two tuner operation modes and the underlying common architecture are also discussed in this paper.

The fifteenth paper [15], "*MIMO for ATSC 3.0*," by D. Gomez-Barquero et al., provides an overview of the optional cross-polarized (i.e., horizontal and vertical polarization) 2×2 Multiple-Input Multiple-Output antenna scheme adopted in ATSC 3.0 to improve robustness and/or increase capacity via spatial diversity and multiplexing by sending two data streams in a single radio frequency channel. The MIMO scheme re-uses as much as possible the ATSC 3.0 single antenna baseline specification, and it introduces a very flexible MIMO precoder with different signal processing algorithms available, two MIMO pilot encoding schemes, and twelve different MIMO scattered pilot patterns. ATSC 3.0 also introduces the use of MIMO with non-uniform constellations, improving the transmission robustness compared to the use of uniform constellations.

The sixteenth paper [16], "*8K Terrestrial Transmission Field Tests Using Dual-polarized MIMO and Higher-order Modulation OFDM*," by S. Saito et al., describes the dual-polarized MIMO field trials carried out by the Japanese broadcaster NHK, which successfully demonstrated an 2×2 MIMO 8K video transmissions at 91 Mbps at a distance greater than 27 km over a single 6 MHZ RF channel in the UHF band, and 4×2 MIMO transmission with two SFN transmitters. The paper presents the analysis of the 2×2 MIMO propagation characteristics and the advanced SFN using the 4×2 MIMO, in particular the variability of the required field strength, the degradation in required SNR as estimated from the condition number, and the long-term time variation of the received signal.

The seventeenth paper [17], "*The ATSC Link-layer Protocol (ALP): Design and Efficiency Evaluation*," by W. Kwon et al., describes the novel data link layer protocol adopted in ATSC 3.0, which has been optimized to transport IP (Internet Protocol) packets, but can also carry MPEG-2 transport stream (TS) packets. The paper also presents an efficiency analysis of the signaling overhead introduced, showing its benefits over existing transport protocols.

The eighteenth paper [18] "*ROUTE/DASH IP Streaming Based System for Delivery of Broadcast, Broadband and Hybrid Services*," by G. K. Walker et al., presents the new IP-centric broadcast delivery protocol ROUTE (Real-time Object delivery over Unidirectional Transport), which is based on IETF protocols such as Layered Coding Transport (LCT) over User Datagram Protocol (UDP), and it is used with DASH (Dynamic HTTP Streaming). The paper demonstrates that the ROUTE-based approach is a lean and powerful media delivery method optimized for streaming media and also non-real time media delivery.

The nineteenth paper [19], "*Delivery of ATSC 3.0 Services with MPEG Media Transport Standard*," by K. Park and Y. Lim, introduces use of MPEG Media Transport (MMT) standards for delivery of ATSC 3.0 services, and explains the restrictions and extensions to enable an efficient delivery including packet by packet conversion into an MPEG-2 transport stream.

The twentieth paper [20] by "*Dedicated Return Channel in ATSC 3.0*," by D. He, W. Zhang, Y. Wang, L. Ding, and F. Yang, describes a solution for ATSC 3.0 to be a bi-directional broadcasting system without dependence on other network infrastructures. The proposed solution includes some new technologies for the return channel, such as single-carrier frequency division multiple access (FDMA), adaptive modulation, and hybrid automatic repeat request (HARQ).

In closing, we would like to thank all the authors who have made this Special Issue possible and hope it meets readers' expectations, for whom this Special Issue on ATSC 3.0 has been prepared. It should be pointed out that due to the standards development schedule, this special issue can only cover the Physical Layer and Transport/Protocol Layer development up to now. Other layers' technology will be dealt with in later issues.

REFERENCES

[1] L. Fay, L. Michael, D. Gomez-Barquero, N. Ammar, and M. W. Caldwell, "An Overview of the ATSC 3.0 Physical Layer Specification," *IEEE Trans. Broadcast.*, vol. 62, no. 1, 2016.

[2] D. He, *et al.*, "System Discovery and Signaling Transmission Using Bootstrap in ATSC 3.0," *IEEE Trans. Broadcast.*, vol. 62, no. 1, 2016.

[3] L. Michael and D. Gomez-Barquero, "Bit-Interleaved Coding and Modulation (BICM) for ATSC 3.0," *IEEE Trans. Broadcast.*, vol. 62, no. 1, 2016.

[4] K,-J. Kim, *et al.*, "Low-Density Parity-Check Codes for ATSC 3.0," *IEEE Trans. Broadcast*. vol. 62, no. 1, 2016.

[5] N. Loghin, *et al.*, "Non-Uniform Constellations for ATSC 3.0," *IEEE Trans. Broadcast*., vol. 62, no. 1, 2016.

[6] H. Jeong, *et al*., "Flexible and Robust Transmission for Physical Layer Signaling of ATSC 3.0," *IEEE Trans. Broadcast*., vol. 62, no. 1, 2016.

[7] L. Zhang, *et al*., "Layered Division Multiplexing: Theory and Practice," *IEEE Trans. Broadcast*., vol. 62, no. 1, 2016.

[8] S.-I. Park, *et al.*, "Low Complexity Layered Division Multiplexing System for ATSC 3.0," *IEEE Trans. Broadcast.*, vol. 62, no. 1, 2016.

[9] C. Regueiro, *et al*., "LDM Core Services: Indoor and Mobile Performance in ATSC 3.0," *IEEE Trans. Broadcast.*, vol. 62, no. 1, 2016.

[10] P. Klenner, *et al*., "Physical Layer Time Interleaving for the ATSC 3.0 System," *IEEE Trans. Broadcast.*, vol. 62, no. 1, 2016.

[11] M. Earnshaw, K. Shelby, H. Lee, Y, Oh, and M. Simon, "Physical Layer Framing for ATSC 3.0," *IEEE Trans. Broadcast.*, vol. 62, no. 1, 2016.

[12] S. LoPresto, R. Citta, D. Vargas, and D. Gomez-Barquero, "Transmit Diversity Code Filter Sets (TDCFS), a MISO Antenna Frequency Pre-Distortion Scheme for ATSC 3.0," *IEEE Trans. Broadcast.*, vol. 62, no. 1, 2016.

[13] J. Kutzner and D. Lung, "Predicted ATSC 3.0 Broadcast Coverage," *IEEE Trans. Broadcast.*, vol. 62, no. 1, 2016.

[14] L. Stadelmeier, D. Schneider, J. Zollner, and J. J. Gimenez, "Channel Bonding for ATSC 3.0," *IEEE Trans. Broadcast.*, 2016.

[15] D. Gomez-Barquero, *et al*., "MIMO for ATSC 3.0," *IEEE Trans. Broadcast*, vol. 62, no. 1, 2016.

[16] S. Saito, *et al*., "8K Terrestrial Transmission Field Tests Using Dual-polarized MIMO and Higher-order Modulation OFDM," *IEEE Trans. Broadcast.*, vol. 62, no. 1, 2016.

[17] W. Kwon, *et al*., "The ATSC Link-layer Protocol (ALP): Design and Efficiency Evaluation," *IEEE Trans. Broadcast.*, vol. 62, no. 1, 2016.

[18] G. K. Walker, *et al*., "ROUTE/DASH IP Streaming Based System for Delivery of Broadcast, Broadband and Hybrid Services," *IEEE Trans. Broadcast.*, vol. 62, no. 1, 2016.

[19] K. Park and Y. Lim, "Delivery of ATSC 3.0 Services with MPEG Media Transport Standard," *IEEE Trans. Broadcast.*, vol. 62, no. 1, 2016

[20] D. He, W. Zhang, Y. Wang, L. Ding, and F. Yang, "Dedicated Return Channel in ATSC 3.0," *IEEE Trans. Broadcast.*, vol. 62, no. 1, 2016.