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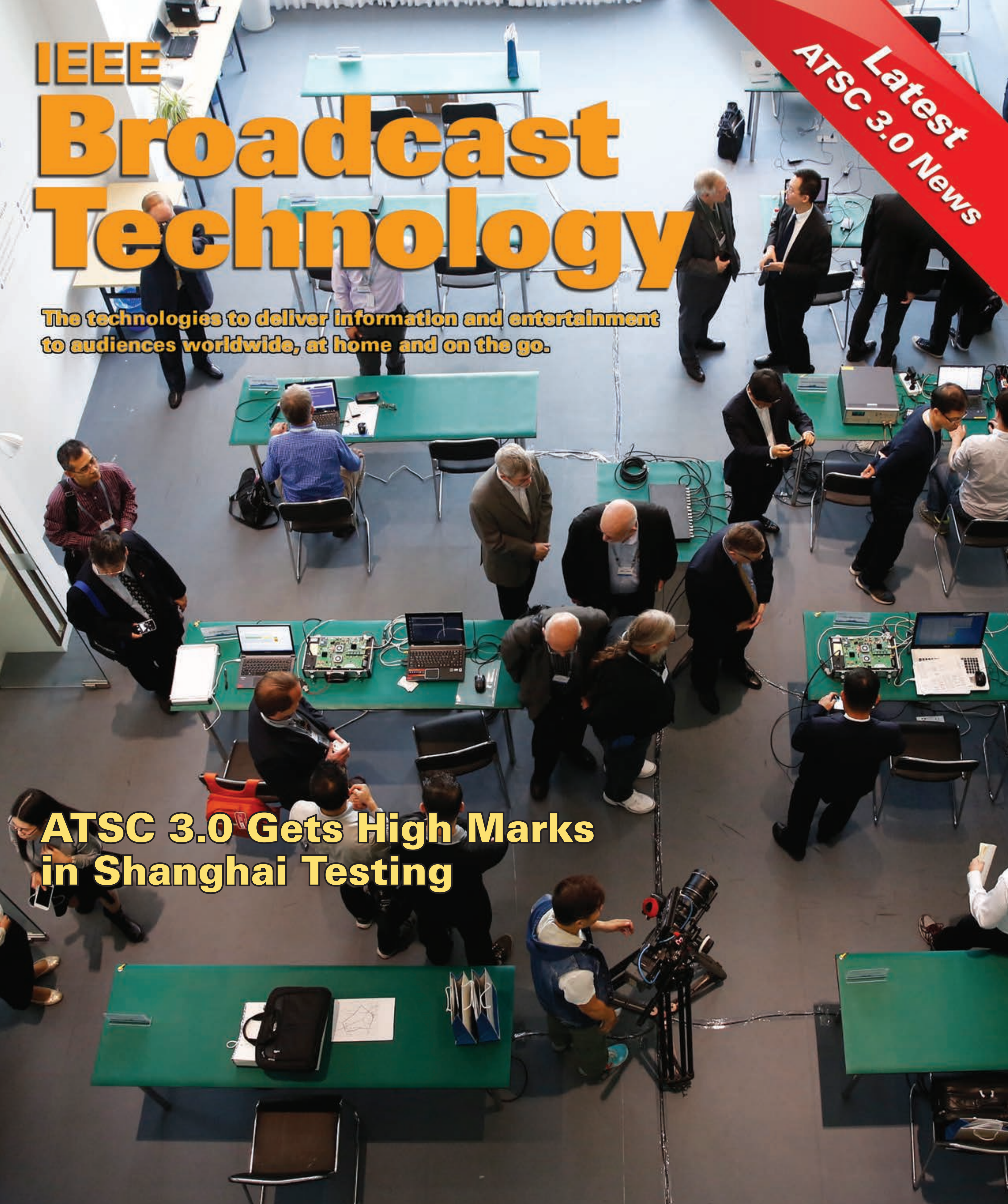

ATSC 3.0 Gets High Marks in Shanghai Testing

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First Field Testing of Proposed ATSC 3.0 Physical Layer Technologies

By Tim Laud and Wayne Luplow, Zenith Electronics LLC; Sung-ryong Hong, LG Electronics and Joe Seccia, Gates Air

Abstract: As is well known, work is progressing under the auspices of the ATSC (Advanced Television System Committee) to develop a standard for next-generation broadcast television. Because the eventual, so-called 3.0 standard is likely to contain an amalgamation of technologies from many different organizations, no hardware currently exists to enable even preliminary lab or field tests. However, the companies represented by the authors have proposed a complete next-generation transmission system (known as the physical layer in ATSC parlance), simulated its performance, developed hardware and tested that hardware using full-power over-the-air transmitters in Madison, Wisc. and Cleveland, Ohio. These results are expected to be indicative of capabilities and performance achieved by the final ATSC 3.0 broadcast television system.

FutureCast, the Universal Terrestrial Broadcasting System, has been developed as a full Physical Layer system. The partners: LG Electronics, Zenith Electronics, and GatesAir ("LZG") have each contributed in their areas of expertise to develop a hardware platform allowing actual lab and field test of the design elements. This paper will present a brief high-level overview of FutureCast, its unique features, and most importantly, the progress that has been made in refining the proposed system to enable real-world performance urgently requested by the broadcast community, namely simultaneous delivery of UHDTV (4K), reliable indoor reception and superior handheld/mobile device reception, all within a single six MHz channel.

Results of extensive field testing in the two different metropolitan areas will be shown and compared with field tests of Mobile DTV (ATSC A/153) and fixed ACTS 8-VSB transmission from the same towers. These results will represent a benchmark for testing against future embodiment of the Candidate Standard version of the ATSC 3.0 physical layer.

Introduction

FutureCast has been developed as a full system embodiment of the requirements for the Physical Layer of the ATSC 3.0 Next-Generation Broadcast Television (NGBT) system. The partners: LG, Zenith Electronics, and GatesAir ("LZG") developed a hardware platform allowing actual lab and field test of the design elements. This has been done in parallel with the development of the ATSC 3.0 Candidate Standard in order to get early experience with the technologies involved and their implementation, so that paper proposals can be guided by real-world experience. This paper presents a brief high-level overview of FutureCast, its unique features, and most importantly, the progress that has been made in refining the proposed system to one ready for acceptance and use, based on real-world field tests of working hardware.

System Overview

LZG has applied expertise in all aspects of digital video broadcast to the end-to-end design of FutureCast. Of particular interest, and the main coverage of this paper, is the Physical Layer. However, other aspects have been given close attention as well to provide a system that is both state-of-the-art and expandable/extensible, i.e., "future-proof."

System highlights include:

- OFDM Modulation
- Multiple Data Pipes
- LDPC coding
- 36 percent capacity increase over ATSC 1.0 (A/53)
- HEVC coding for video

Orthogonal Frequency Division Multiplexing (OFDM) modulation provides a flexible emission format for carrying different services with different degrees of robustness and efficiency in the same RF channel. These multiple choices, or "data pipes," are easily configurable for any desired type of service. Multiple data pipes are carried simultaneously in a single RF channel, enabling multiple simultaneous services ranging from rugged reception with mobile/handheld devices to UHDTV (4K) for stationary large-screen entertainment receivers.

Low Density Parity Check (LDPC) coding approaches the theoretical limit of data rate and robustness more closely than any other known forward error correction (FEC) coding, a 36 percent increase in data throughput rate compared to ATSC 1.0 (A/53) at the same signal-to-noise ratio (SNR). A large range of selectable coding parameters provides for tradeoffs between capacity and SNR for difficult mobile and indoor reception scenarios. (See Figure 1.)

LDPC coding brings the threshold SNR and data capacity very close to the Shannon limit, as shown in Figure 1.

High Efficiency Video Coding (HEVC) for all types of video reduces the bit rate needed and provides for both higher quality video services (e.g., 4K UHDTV) and multiple services per channel.

Physical Layer

This section describes the physical layer of FutureCast and its similarity to details adopted as part of the ATSC 3.0 candidate standard(s), to illustrate the utility of this early parallel development of hardware. The physical layer of FutureCast is based on OFDM modulation in the frequency domain, as

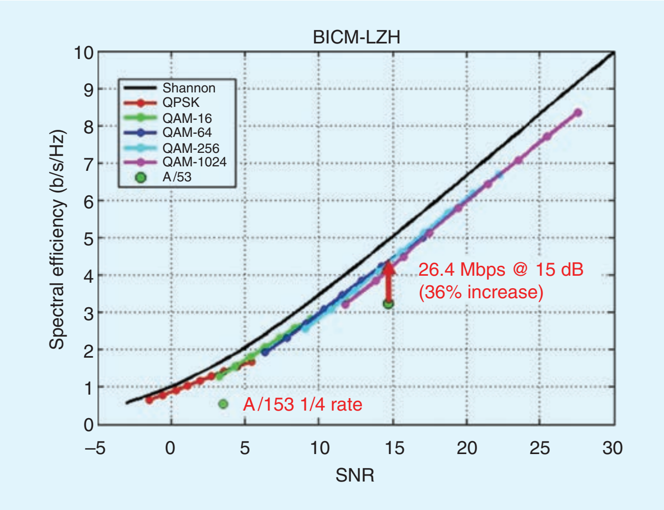

Figure 1. Performance of FutureCast available code rates with 32k fast Fourier transform (FFT), compared to ATSC 1.0 (A/53) and the theoretical Shannon limit.

is ATSC 3.0. Furthermore, the emission is organized in the time domain into Data Frames that both define the current capabilities and provide for future-proof modification. Data Frames are organized into a higher level repetitive structure, Frame Repetition Units (FRUs) and SuperFrames, as shown in Figure 2. The repetitive structure provides greater robustness for the receiver to coast through signal dropouts, since each program is carried in a known time slot. This type of hierarchical structure was adapted in ATSC 3.0 as Frames and Sub-Frames.

A Data Frame begins with a simple preamble. The preamble announces that the signal is FutureCast or ATSC 3.0, but has system identification bits that can be set to announce any future system with completely different transmission configuration (which might replace ATSC 3.0 many years in the future). ATSC 3.0 has adopted a similar system-identifying construct known as a "bootstrap" signal as the first part of a Data Frame, followed by the remaining preamble content (system signaling).

Elements of Figure 2:

- FRU – Frame Repetition Unit
- Preamble – identifies system as FutureCast (or ATSC 3.0, or in the far distant future, some presently unspecified system).
- FFT: (Fast Fourier Transform size), GI: Guard Interval (basic transmission parameters)
- PLS1, PLS2 – Physical Layer signaling
- EAC – dedicated Emergency Alert Channel
- FIC – Fast Information Channel
- DP – Data Pipe – payload data with specific choices of modulation/coding parameters for a particular use-case/reception environment
- ModCod – parameters of modulation (constellation;, e.g., QPSK, 64-QAM) and coding (forward error correction, FEC)

When the preamble indicates the current FutureCast transmission configuration, it also signals basic parameters of the Frame, such as FFT size and Guard Interval (GI), and is followed by secondary header information (PLS1, PLS2) that indicates a Data Frame structure and parameters including the multiple Data Pipes (DPs), each of which can have different trade-offs of parameters ("Mod/Cod") for robustness/data-rate. Thus, a single RF channel might simultaneously carry 4K UHDTV, 720p HDTV mobile TV, and super-robust SDTV for handheld and high-speed mobile reception—which is what was done in the field tests described below.

The data Frames with the current FutureCast structure may also be interspersed with Future Extension Frames (FEFs) as another form of future-proofing. The FEFs may have an entirely different structure and modulation from current FutureCast, thus providing a means to phase in a completely new system or to inject a new or alternative (e.g., LTE) signal in time-shared fashion with an ATSC 3.0 signal.

Madison Tests

In the fall of 2014, two field tests were conducted in Madison, Wisc., with the help of Quincy Broadcast's WKOW-TV, RF Ch. 26.

Testing in Madison was done in the middle of the night when WKOW-TV's normal programming was suspended. However, the inclusion of ATSC Mobile/Handheld (M/H; A/153) in the normal daytime programming of WKOW-TV enabled comparison between FutureCast, A/153, and A/53 reception.

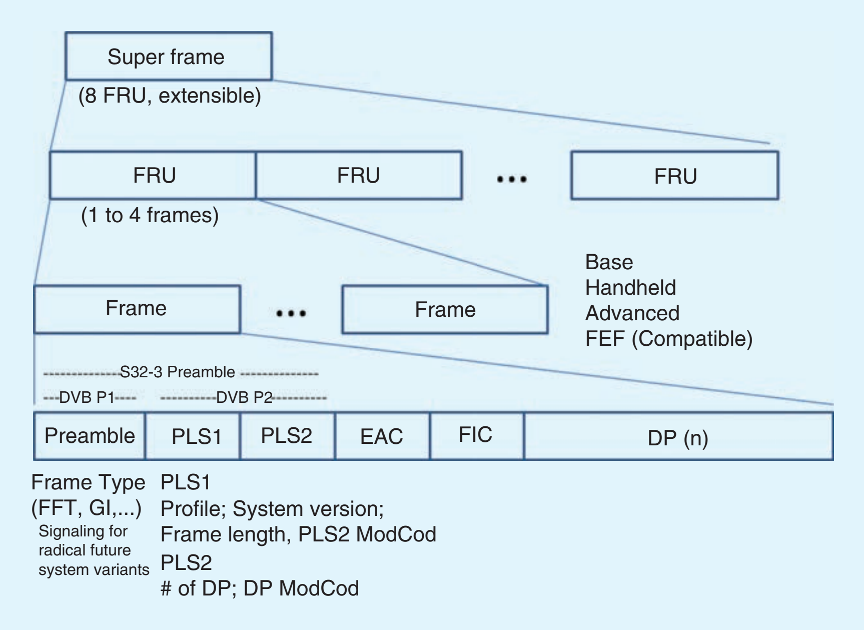

Figure 2. FutureCast Physical Layer frame structure.

Figure 3. Field test hardware in operation inside the University of Wisconsin's Kohl Center arena.

Figure 5. Mobile test van interior.

In August 2014, an unannounced initial system shakedown was undertaken. This was important not only for testing the system, but also to establish the error-logging techniques and software. Tests were designed to cover a wide range of reception conditions and program material:

- Fixed reception – 4K UHDTV
- Indoor reception – 720p HDTV on portable devices
- Mobile reception – SDTV on rapidly moving devices; deep indoor reception at low SNR

Over 50,000 data points were logged, but it was discovered that the data logs sometimes recorded duplicate errors, which required debugging before subsequent tests. Nevertheless, things were learned about detailed performance of the receiver and system, such as performance of the preamble, in real world conditions.

In October 2014, a second round of tests was made with slightly modified hardware and debugged data logging, duplicating the original routes and locations. Broadcasters and press were invited to witness demonstrations of the results. Figures 3, 4 and 5 show views of some of the October test and demo venues.

Three data pipes (designated as DP0, DP1, DP2), each with different parameters, were used:

- DP0 High Data Rate Mode
  - 30 percent higher capacity than VSB
  - 15.7 Mbps payload
- DP1 Similar Threshold to ATSC Mobile/Handheld, operating in the 1/4-rate mode
  - 2 .5 times the data capacity of M/H
  - 1.25 Mbps payload

Figure 4. Indoor reception demonstration.

- DP2 Very Robust, Deep Building Penetration
  - 590 kbps payload

VSB (ATSC 1.0) and FutureCast DP0 both had good outdoor reception; as expected, indoor reception faded quickly when moving away from the signal ingress location. Indoor tests were made with a portable antenna tethered to the prototype receiver in the test van. Comparable M/H and DP1 reception was obtained indoors as far as cable lengths allowed. DP2 showed significant margin over M/H.

Mobile reception was tested over three routes, mapped in Figure 6:

- 53 miles southwest from the transmitter
- 40 miles northwest (past a ridge)
- Downtown

Over 16,500 data points were taken for each mode.

- Mobile performance of DP0 was poor (as expected), but DP0 carried 4K UHDTV intended for fixed receivers, simultaneously with mobile HD and SD services in DP1 and DP2, something for which ATSC 1.0 was not designed.
- DP1 performance was similar to ATSC M/H, but with the capability to carry 1280 x 720p HDTV instead of 416 x 240p resolution images.

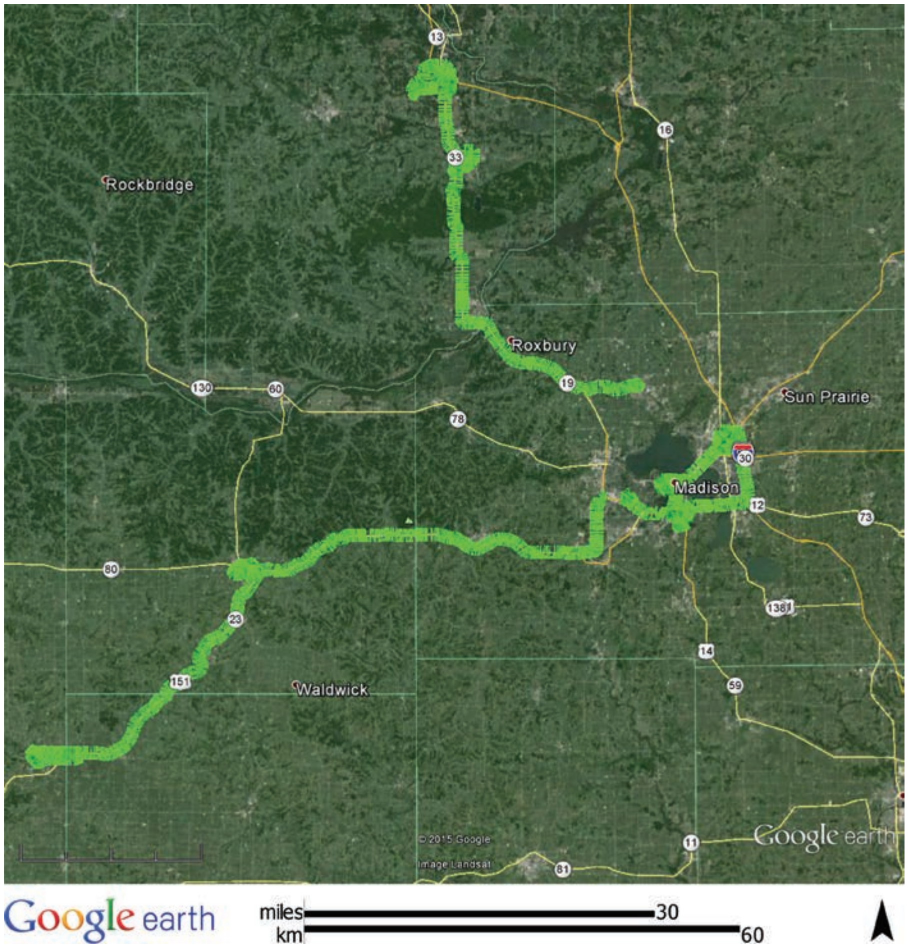

Figure 6. Field test routes, WKOW-TV, Madison, Wisc.

Madison Demonstrations

During the middle of the night of Oct. 21, expert viewers, including approximately three dozen engineers from around the country, many attending the annual Wisconsin Broadcasters Association Clinic, witnessed successful FutureCast reception at a number of difficult reception sites.

Implementation Issues From Initial Tests

While the hardware tests in Madison were encouraging, and the lab tests showed the white noise performance was close to theoretical, these initial field tests showed some shortfall that seemed to be related to signal reacquisition after signal loss. Subsequent tests of the hardware revealed some acquisition problems, but also erroneous high error counts due to a bug in the recording software. Work to address these issues was done in two stages, between the two trials in Madison and then prior to the mid-2015 trials in Cleveland.

System Improvements As A Result of The First Testing Of FutureCast

As a result of the analysis of the field data from the Madison tests, a few areas were identified for improvement.

- The preamble was improved to give more robust coding and improved time diversity.
- The robust data was improved with a hybrid time interleaver (later adopted as part of the ATSC 3.0 Candidate Standard) to afford a longer interleave time.
- Receiver software was fine-tuned to improve the reacquisition time after loss of signal.
- Error reporting was improved to more accurately reflect the one-second time interval of the logging software.

Updating Of Ch. 31 Transmission Facilities In Cleveland

For the Cleveland FutureCast field testing, a three-tube IOT transmitter was used for Ch. 31. The transmitter was decommissioned, but not dismantled, with the analog turn-off in 2009. It had operated at 625 kW ERP, with a transmitter power output of 40.2 kW. The transmission line remained pressurized and the cooling system remained filled. Assessing the transmitter for powering-up again involved many things. The transmission line and antenna were checked for good VSWR. The coolant was chemically analyzed and found to be good. Some coolant leaks were fixed, and two cavity blowers were

Figure 7. Cleveland test routes.

used to enable equal radiated power for the testing program. The ERP for testing was adjusted to 420 kW to insure emission within the limits of the FCC RF mask.

Cleveland Mobile Tests

In the Cleveland tests, over 75,000 mobile data points were recorded. The transmitter, on Ch. 31, was dedicated to this field test on a 24/7 basis. This provided time to obtain data for comparison to ATSC 1.0 from matching route segments:

- FutureCast was transmitted/received for one direction of each mobile route
- ATSC DTV and ATSC Mobile DTV were transmitted/received for the opposite direction

A map of the test routes used is shown in Figure 7.

The first set of tests in the Cleveland area showed good performance. They confirmed that the COFDM modes matching the AWGN thresholds of known ATSC 1.0 modes provided similar performance. However, it was difficult to quantify the robust mode differences between FutureCast and A/153 because a large amount of the data came from locations with good reception. This caused the robust modes to show 90 percent or better reception. In order to get a better comparison, data was selected from some of the more challenging routes, resulting in the "qualified" (difficult areas) bar chart shown as Figure 8.

To obtain a clear robust mode comparison, it was decided to collect more data over a very challenging route. This route is the east-west route on the lower portion of the Figure 7 map. During that time frame, the transmitter was running at a reduced power output,[1] so the route was closer to the transmitter than would normally be the case for challenging reception.

The results from this challenging reception route are shown in bar graph form in Figure 9. Here it can be readily seen that the ATSC 1.0 M/H mode and the FutureCast mode of the same threshold (DP1) performed almost identically. This is quite noteworthy because DP1 carried more than twice the bits per Hertz of ATSC 1.0 M/H.

DP2, with an AWGN threshold of about 4 dB lower than DP1, showed impressive results compared to DP1. This confirmed the substantially improved performance, which had been masked when the data was taken mostly at relatively easy reception points.

rebuilt. High voltage components were a little more involved. Thyratron assemblies were tested to ensure they would protect the IOT's before high voltage was applied. A rectifier assembly in the beam supply was burned and was replaced, along with two bias supply assemblies, and beam supply breakers that had been tripping. Moreover, two of the three IOT's needed to be replaced as they were arc-prone. The system was slowly raised to power while pre-correction was applied to bring the transmitter in compliance with FCC mask specifications for tests. Both the 8-VSB exciter and the FutureCast exciter were

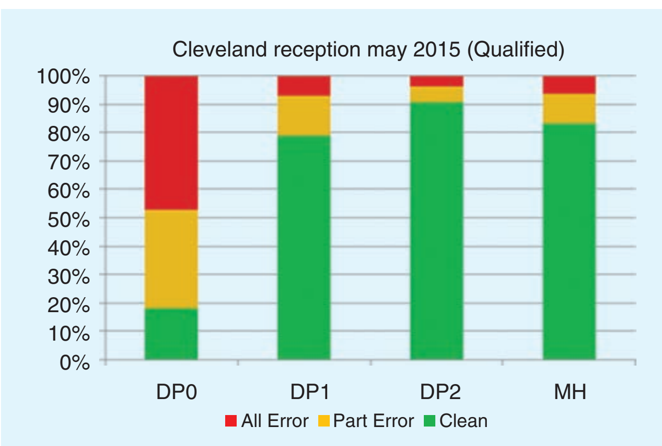

Figure 8. Mobile reception in "qualified" (difficult) portions of test routes.

[1] Occasionally, during the testing in Cleveland, one of the three tubes used in the power-amplifier became non-functional.

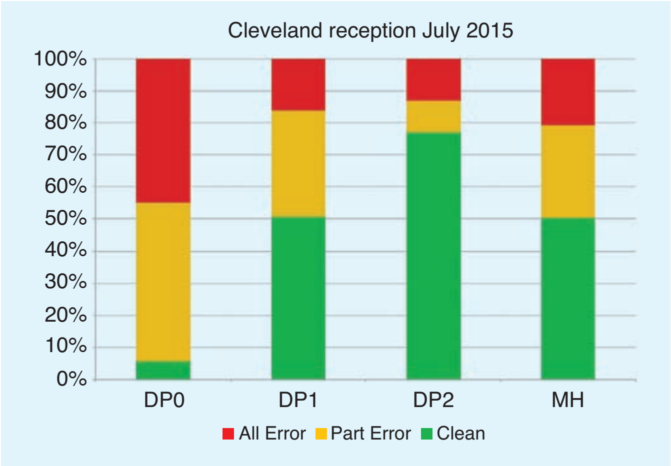

Figure 9. AWGN thresholds under difficult channel conditions for ATSC A/53(VSB), ATSC A/153 (MH), and FutureCast data pipes (DP0, DP1, DP2)

Figure 11. Mobile reception at highway speeds and in the concrete canyon.

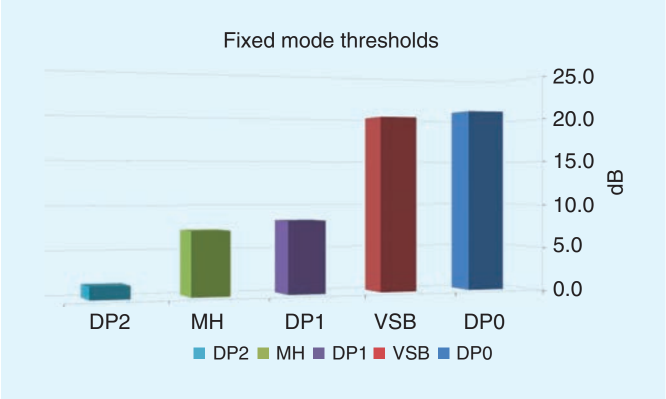

Figure 10. Mobile reception at highway speeds and in the concrete canyon.

Figure 12. Basement reception downtown using a short vertical antenna.

Test Results At Indoor/Fixed Locations In The Cleveland Area

Approximately 20 stationary tests were performed outside of homes and inside restaurants and office buildings. The results showed that modes with similar White Noise Threshold (WNT) had similar performance. One interesting point to note here is that the noise enhancement (caused by channel impairments such as reflections) was nearly identical for both VSB and COFDM systems. Another interesting point is that the noise enhancement is dependent on the WNT. Lower WNT measured less channel noise enhancement than the modes with higher WNT.

The comparison of SNR thresholds in fixed reception at challenging sites for ATSC 1.0 (VSB and M/H) to FutureCast (DP0, DP1, and DP2) is shown in Figure 10.

Demonstrations

The FutureCast system was demonstrated at various locations in Cleveland. Expert viewer participants included some 40 members of the technical broadcast industry as well as a few members of the trade press. During the bus ride between locations, the robust mode was received and displayed on the bus AV system. Highway speeds along Lake Erie and weaving through the concrete canyon downtown had no detrimental effect on reception.

Indoor reception was achieved by using a short vertical antenna in the basement of one of the downtown office buildings. On a spectrum analyzer, the signal was indistinguishable from the noise floor as the television showed clean reception of FutureCast's most robust mode. No ATSC 1.0 reception was possible.

Conclusion

FutureCast has undergone rapid and intense development, after simulation to discover the optimum theoretical overall system choices, through prototype hardware and real-world field trials to verify capabilities and agreement with theory and simulations. Initial success has been followed by continued refinement to produce system elements providing the performance and reliability needed for ATSC 3.0. Indeed, performance achieved during these field tests in two markets should be a good indication of what is likely to be achieved with the technology to be deployed in the Physical Layer of the future ATSC 3.0 next-generation broadcast television standard.

Acknowledgments

Zenith, LG and GatesAir greatly appreciate the extraordinary cooperation received from the broadcast organizations, their stations and their talented personnel to make their full-power broadcast facilities available for these tests; specifically: in Madison, WKOW-TV, an ABC Affiliate, owned and operated by Quincy Broadcast; and in Cleveland, WJW-TV, a Fox affiliate, owned and operated by Tribune Broadcasting. The staff from WKOW literally had to work around the clock to enable transmitter support in the middle of the night. In Cleveland, the WJW-TV staff was joined by other talented professionals to bring back to life their dormant Ch. 31 facilities. The cooperation of other organizations that opened their facilities for in-building and in-home testing and demonstrations is also much appreciated.

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Mobile broadband applications are getting more popular and mobile broadband interests are clamoring for more spectrum to meet the demands of their services. This doesn't just impact broadcasters, but many other areas such as radiolocation services [and] radar operators."

DiLapi described the work of the International Telecommunication Union, along with radio regulation work within that organization, with emphasis on the treatment of spectrum issues that have arisen worldwide due to the ever-increasing popularity of mobile broadband services. She noted in particular the difficult nature of securing an agreement by all parties on the best way to resolve spectrum sharing issues.

"At the study group level, there was a lack of consensus, so [these issues] will be taken to the Radio Communication Assembly that meets a week before [the] WARC to see if there could be approval there," she said.

In summarizing the difficulties in securing an agreement that was acceptable to all parties, she noted that it was difficult "to come up with one set of values in terms of geographic separation and frequency separation" that was satisfactory to both broadcasters and mobile service providers and noted that a modification would probably be necessary to some of the existing ITU agreements covering these frequency bands.

"I would urge broadcasting interests to stay on top of these issues," she said. "As the years go on this is just going to get more topical and critical. A lot of different stakeholders want to use frequency spectrum these days and there's a lot of pressure on the spectrum."

Antenna Design Tools

Eric Wandel concluded the program with a presentation on the place of currently available modeling tools in antenna pattern design, noting that this area of technology was could be useful in helping to ameliorate some radio interference issues.

"The antenna patterns play into the geographic separation [of transmitters]," said Wandel. "And in the U.S., directional patterns provide protection from interference.

"One example that has come up recently in the U.S. is [the impact of] LTE services on high power broadcast transmit sites—FM stations, for instance—while they meet the current FCC regulations, can still produce [interference] with the LTE services trying to come on line. You can use some of these design tools to try and minimize coupling between services on the tower."

He noted too that the use of such tools could help broadcasters maximize desired placement of their signals at lower costs, and could also help in making more efficient use of spectrum. Wandel discussed antenna modeling techniques and stated they could help engineers better understand antenna radiation patterns and performance.

He said that although the FCC required the use of a physical model to determine directional characteristics of an FM antenna, but a computer model could be very useful in getting "to the first step" before the real world modeling is attempted.

Wandel also discussed the place of modeling tools in helping to allay concerns about the effects of the large turbines installed in wind farms on exiting broadcasting services, and also in assisting with the design of single frequency networks and other contemporary over-the-air broadcasting technologies.