Implications and Optimization of Coverage and Payload for ATSC 3.0

Steven Rossiter
GATESAIR
Quincy, IL
steven.rossiter@gatesair.com

Abstract *- Broadcasters today are faced with many challenging and new technological advances, including the transition from ATSC 1.0 to ATSC 3.0. ATSC 1.0 provided a robust single modulation scheme with a fixed payload and a fixed coverage scenario, the new modulation ATSC 3.0 provides far greater flexibility in terms of configuration parameters (e.g., 12 coding rates, 6 modulation orders, 16 pilot patterns, 12 guard intervals, and 2 time interleavers). Along with the addition of power dependent Layered Division Multiplexing (LDM) and other enhancements, there are many ways to tailor the modulation to optimize payload, program quality and receiver types.*

With the tremendous number of variables available in the ATSC 3.0 transmission layer, there also comes with it a wide-ranging variation in coverage scenarios. Many broadcasters may be wondering how they can maximize coverage, payload, number of programs (SD, HD and UHD), new mobile services and other needs to suit their own business model. This paper will examine the various trade-offs between data payload, number and type of services to be carried and replication of existing coverage, when transitioning to ATSC 3.0.

ATSC 1.0

Similar to analog coverage, ATSC 1.0 was based on the following variables; the height of the antenna above average terrain, the antenna gain, the length and size of the transmission line (detriments line losses), the RF system losses, and transmitter RF power output (TPO). This variable gives us the effective radiated power (ERP), using the ERP value, the height of the antenna above average terrain and the frequency, the FCC determined the coverage for ATSC 1.0 with the addition of the signal-to-noise ratio (SNR) of 15.2dB. The signal-to-noise ratio (SNR) of 15.2dB for ATSC 1.0 is a set value, this made it easy to determine the coverage. The FCC currently bases most coverage areas on the 36dBuV/m for VHF and 41dBuV/m for UHF, this is what gives us the FCC contour.

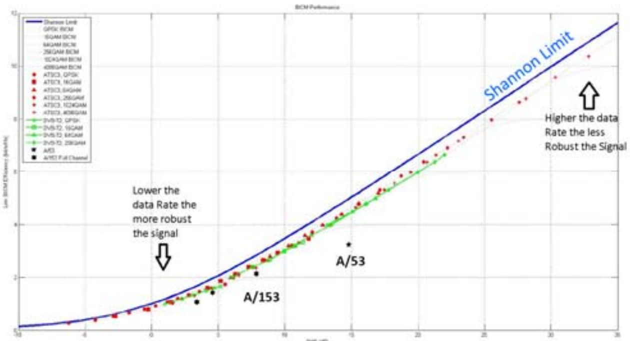
ATSC 3.0

The Advanced Television System Committee (ATSC) has created the next generation of ATSC Modulation, ATSC 3.0. Unlike ATSC 1.0 being an 8VSB modulation (8 level, vestigial side band modulation), ATSC 3.0 is an orthogonal frequency division multiplex modulation (OFDM). ATSC 3.0 is similar to ISDB-T, DVB-T and DVB-T2 modulations in that all of these standards utilize the OFDM modulation technique. The advantages of ATSC 3.0 is it has additional modulation parameters available. DVB-T2 for example has QPSK, 16QAM, 64QAM and 256QAM, ATSC 3.0 also has QPSK, 16QAM, 64QAM and 256QAM, but now includes the addition of 1024 QAM and 4096 QAM. The additional QAMs allow for much higher data rates. As with ATSC 1.0, ATSC 3.0 allows for different program resolutions to include low definition television (LDTV), Standard Definition television (SDTV), and High Definition television (HDTV).

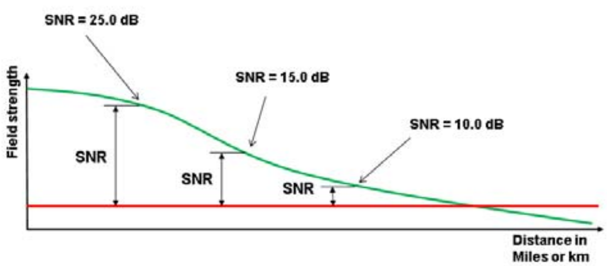
ATSC 3.0 has the additional capability to provide even higher data rates than ATSC 1.0, this allows for the expanded resolutions of 4k Ultra High Definition TV programming (4k UHDTV) and future 8k Ultra High definition television potentially (8k UHDTV) formats. With higher data rates also comes higher signal to noise ratios. ATSC 1.0 has a set signal-to-noise ratio of 15.2dB with ATSC 3.0, the signal-to-noise ratios can vary from -5.5dB to as high as 36.54dB. These signal-to-noise ratios can help coverage or inhibit coverage and have a direct relationship to the data rate.

ATSC 3.0 has other parameters that affect data rate and signal-to-noise ratios, the length and code rate of the forward error correction. The forward error correction used with ATSC 3.0 is low density parity check (LDPC), this being the inner coding and Bose, Chaudhuri, Hocquenghem (BCH) being the outer coding. The length of the low density parity check (LDPC) can be 16200 Bits or 64800 bits for QPSK, 16QAM, 64QAM and 256QAM. For the higher QAMs, 1024QAM and 4096QAM, the low density parity check (LDPC) length is limited to the 64800 bit length. The low density parity check (LDPC) code rate has 12 different settings available, 2/15, 3/15, 4/15, 5/15, 6/15, 7/15, 8/15, 9/15, 10/15, 11/15, 12/15 and 13/15. The 2/15 is a more robust code rate, but less data efficient, while the 13/15 is more data efficient but less robust. This means the length 16200 bits and code rates 2/15 are less data efficient but have a lower signal-to-noise ratio. Within ATSC 3.0 you have the capability to turn on or off the Bose, Chaudhuri, Hocquenghem (BCH), this affects the signal-to-noise ratio and data rate. Other parameters that have an effect on data rate are fast Fourier transform (FFT), the scattered pilots (time) spacing, the scattered pilots density, the frame duration, and the guard interval (GI). The guard interval also determines the maximum distance between transmitters within the single frequency network (SFN).

This means the higher the data rate the higher the signal-to-noise ratio (SNR); the lower the data rate the lower the signal-to-noise ratio (SNR). This also means the higher the signal to noise ratio (SNR) the less robust the signal, the lower the signal-to-noise ratio (SNR) the more robust the signal.



The signal-to-noise ratio (SNR) and the data rate have a direct relationship to the distance the ATSC 3.0 signal can be received. The lower the signal-to-noise ratio (SNR) the more distance the signal can travel and be received. The higher the signal-to-noise ratio the less distance the single can travel and be received.



ATSC 1.0 AND ATSC 3.0 COMPARISON

Looking closer at ATSC 3.0 we can do a comparison between ATSC 1.0 and ATSC 3.0. Using the equal antenna gain, tower height, transmission line (line losses), RF system losses, transmitter output power (TPO) and similar data rate for both ATSC 1.0 and ATSC 3.0 we can determine the difference in coverage.

The ATSC 1.0 parameters are as follows:

- Data Rate: 19.39 Mbit/s
- Signal to Noise Ratio (SNR): 15.2dB
- Gaussian Channel (AWGN)
- Receive antenna Height: 10m
- Receive antenna Gain: 10dB
- Transmit Channel: 25
- Transmit Center Frequency: 539Mhz
- Channel bandwidth: 6MHz
- Transmitter Power out:36.4kW pre-filter
- Transmit antenna gain: 13.0dBd
- Antenna type: Omni directional slot
- Antenna mount: Top Mounted
- Antenna beam tilt: -1.25°
- Antenna null fill: 20%
- Antenna Height above ground level: 1023.4ft
- Line type: 6-1/8” 50 Ohm Rigid line
- Line losses: -1.32dB
- Mask filter and RF system losses: -.30dB
- Effective radiated power: 500kW

The ATSC 3.0 parameters are as follows:

- Data Rate: 19.5 Mbit/s
- Signal to Noise Ratio (SNR): 11.5dB
- QAM: 64QAM
- Low density parity check Length:64800 bits
- Low density parity check code rate: 9/15
- Bose, Chaudhuri, Hocquenghem (BCH): On
- Fast Fourier transform (FFT): 32K
- Guard interval: 222.22 usec
- Scatter Pilots density: normal
- Scatter Pilots (time) spacing: normal
- Frame duration 200ms
- Gaussian Channel (AWGN)
- Receive antenna Height: 10m
- Receive antenna Gain: 10dB
- Transmit Channel: 25
- Transmit Center Frequency: 539Mhz
- Channel bandwidth: 6MHz
- Transmitter Power out:36.4kW pre-filter
- Transmit antenna gain: 13.0dBd
- Antenna type: Omni directional slot
- Antenna mount: Top Mounted
- Antenna beam tilt: -1.25°
- Antenna null fill: 20%
- Antenna Height above ground level: 1023.4ft
- Line type: 6-1/8” 50 Ohm Rigid line
- Line losses: -1.32dB
- Mask filter and RF system losses: -.30dB
- Effective radiated power: 500kW

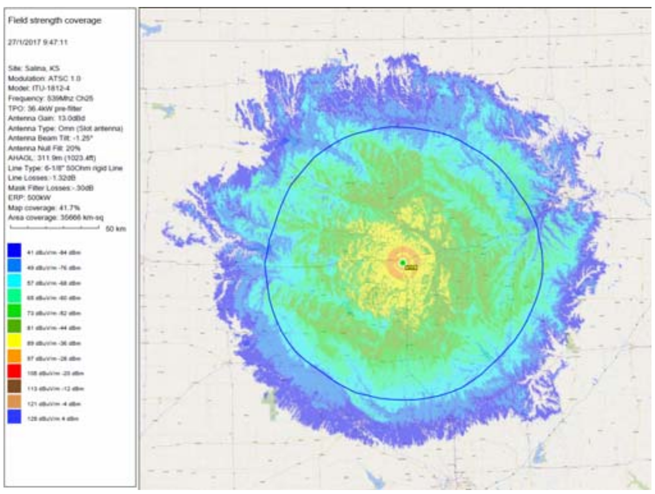
Looking at the parameters for ATSC 3.0 you can see that it does require a number of different parameters to be selected to get the desired final result.

The FCC used the Longley Rice propagation model for the ATSC 1.0 coverage analysis. While this model works well with analog and fixed location coverage, it does not work as well with digital and mobile applications. For this reason, and to keep the coverage comparison equal the use of the ITU 1812-4 model is used for both ATSC 1.0 and for ATSC 3.0. The ITU1812-4 propagation model is recommended by the ITU for DVB-T2 and other orthogonal frequency division multiplex modulations (OFDM).

To provide a point of reference the map area is set at a constant square km area. The coverage is then measured in reference to the set map area. This provides a percentage of coverage in reference to the map. Example: the total map area is 10,000 sq-km, the coverage predicted is 5000 sq-km, so the percentage of coverage is 50%.

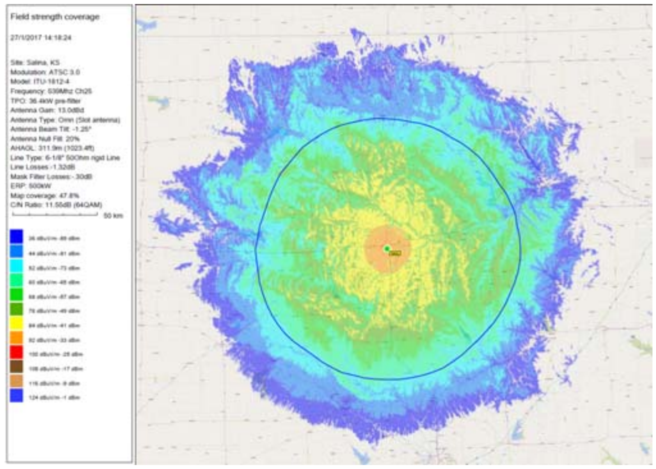
The map area chosen for this comparison is a location near Salina, KS; the reason for the location is because it is very open and flat terrain with little to no obstructions.

Using the ITU 1812-4 propagation model and the ATSC 1.0 parameters above we calculate the coverage of the ATSC 1.0 modulation to be 41.7% of the total map area.



ATSC 1.0 coverage model

The same physical parameters are utilized for the ATSC 1.0 and ATSC 3.0 coverage. Using the ITU 1812-4 propagation model and the ATSC 3.0 parameters above we calculate the coverage of the ATSC 3.0 modulation to be 47.8% of the total map area.



ATSC 3.0 coverage model

Comparing the ATSC 1.0 to the ATSC 3.0 the coverage increased by approximately 6.1%. The signal-to-noise ratio difference is 3.7dB better for ATSC 3.0 when compared to ATSC 1.0 with a difference in bit rate of .11Mbit/s. The better signal-to-noise ratio of ATSC 3.0 provides an approximate 6% increase in overall coverage.

ATSC 3.0 DATA RATE AND COVERAGE

ATSC 3.0 has advantages over ATSC 1.0. One of those advantages is it has better signal-to-noise ratios over ATSC 1.0, it also has the advantages of higher or lower data rates using the different parameters / settings within ATSC 3.0.

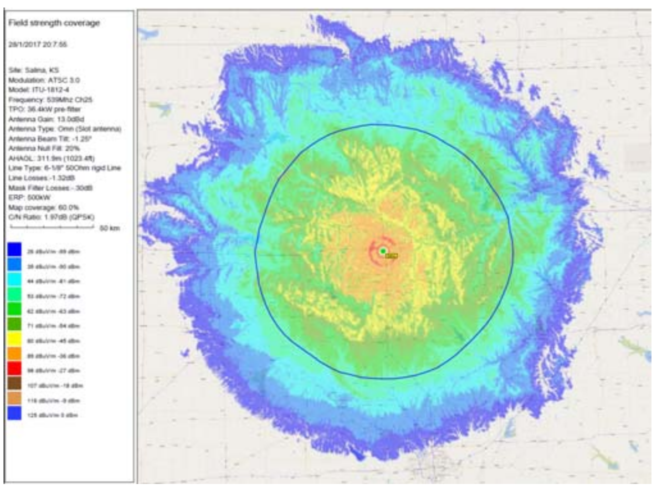
ATSC 3.0 as stated earlier can utilize different modulation parameters to increase or decrease the data rate. As we have shown the signal-to-noise ratio (SNR) value also increases and decreases with data rate.

The following looks at what happens when you utilize the different data rates and increase and decrease the signal-to-noise ratio. Using the same parameters as the ATSC 1.0 and ATSC 3.0 comparison with one exception we will adjust QAM of the ATSC 3.0, essentially changing the signal-to-noise ratio and significantly changing the data rates. The parameters are as follows:

- QPSK Data Rate: 6.5Mbit/s
- Signal-to-Noise Ratio (SNR): 1.97dB
- Signal strength: -99dBm
- Low density parity check Length:64800 bits
- Low density parity check code rate: 9/15
- Bose, Chaudhuri, Hocquenghem (BCH): On
- Fast Fourier transform (FFT): 32K
- Guard interval: 222.22 usec
- Scatter Pilots density: normal
- Scatter Pilots (time) spacing: normal

- Frame duration 200ms
- Gaussian Channel (AWGN)
- Receive antenna Height: 10m
- Receive antenna Gain: 10dB
- Transmit Channel: 25
- Transmit Center Frequency: 539Mhz
- Channel bandwidth: 6MHz
- Transmitter Power out:36.4kW pre-filter
- Transmit antenna gain: 13.0dBd
- Antenna type: Omni directional slot
- Antenna mount: Top Mounted
- Antenna beam tilt: -1.25°
- Antenna null fill: 20%
- Antenna Height above ground level: 1023.4ft
- Line type: 6-1/8” 50 Ohm Rigid line
- Line losses: -1.32dB
- Mask filter and RF system losses: -.30dB
- Effective radiated power: 500kW

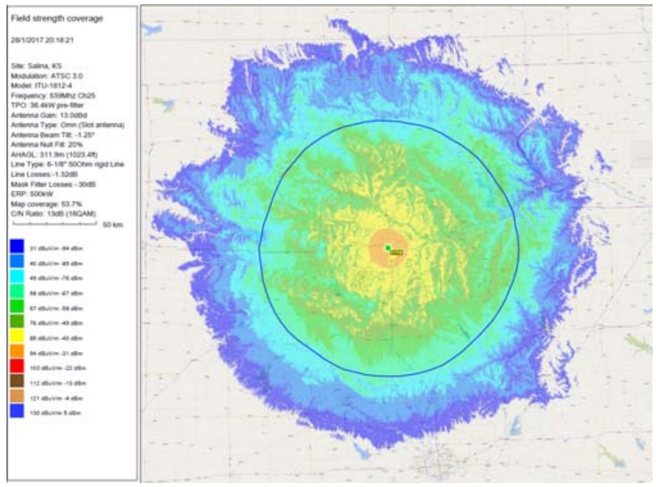
Using QPSK the coverage area is calculated to be 60% of the total map area.



ATSC 3.0 QPSK

Changing the Parameters to 16QAM
- 16QAM Data Rate: 13.0Mbit/s
- Signal-to-Noise Ratio (SNR): 7.32dB
- Signal strength: -94dBm

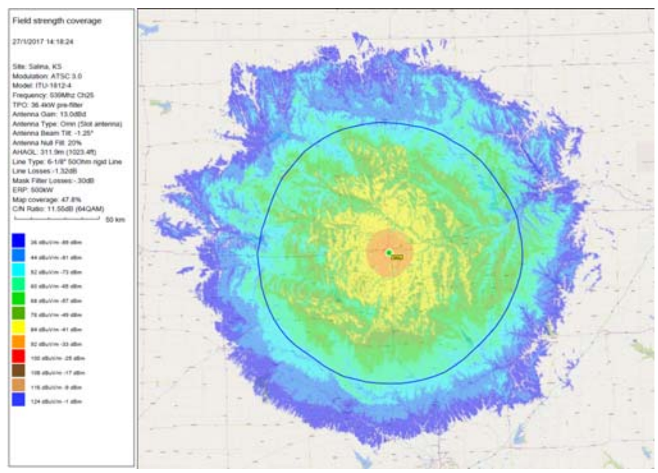
Using 16QAM the coverage area is calculated to be 53.7% of the total map area.



ATSC 3.0 16QAM

Changing the Parameters to 64QAM
- 64QAM Data Rate: 19.5Mbit/s
- Signal-to-Noise Ratio (SNR): 11.55dB
- Signal strength: -89dBm

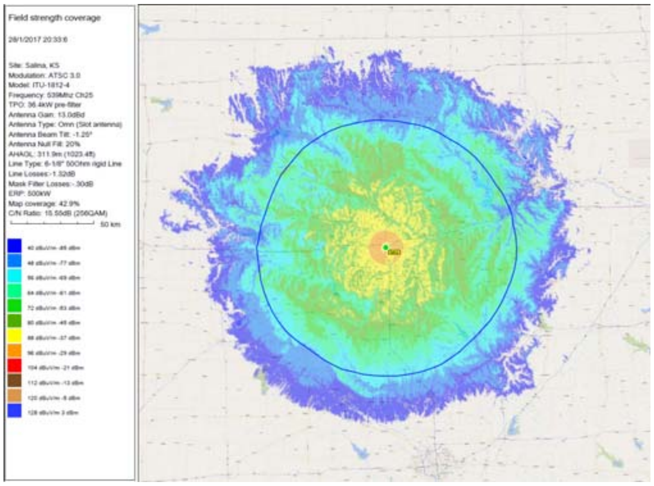
Using 64QAM the coverage area is calculated to be 47.8% of the total map area.



ATSC 3.0 64QAM

Changing the Parameters to 256QAM
- 256QAM Data Rate: 26.0Mbit/s
- Signal-to-Noise Ratio (SNR): 15.55dB
- Signal strength: -85dBm

Using 256QAM the coverage area is calculated to be 42.9% of the total map area.

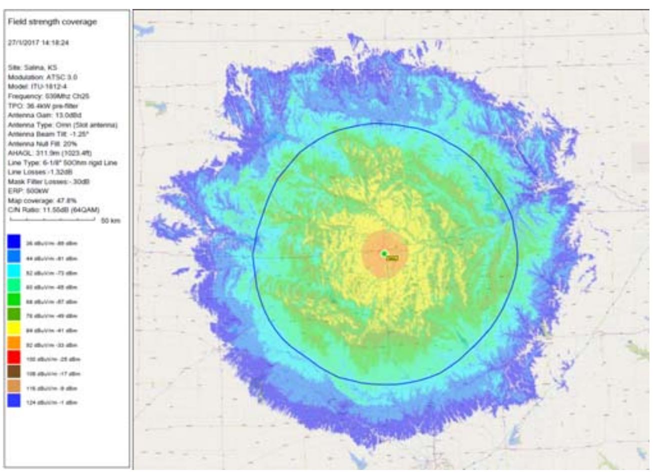


ATSC 3.0 256QAM

Changing the Parameters to 1024QAM

- 1024QAM Data Rate: 32.5Mbit/s
- Signal-to-Noise Ratio (SNR): 19.45dB
- Signal strength: -82dBm

Using 1024QAM the coverage area is calculated to be 39.2% of the total map area.

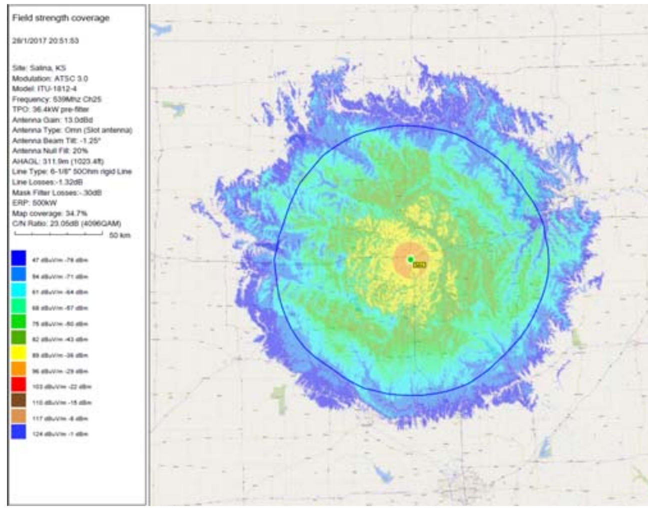


ATSC 3.0 1024QAM

Changing the Parameters to 4096QAM

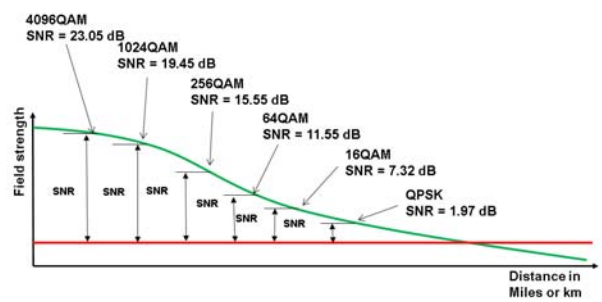
- 4096QAM Data Rate: 39.0Mbit/s
- Signal-to-Noise Ratio (SNR): 23.05dB
- Signal strength: -78dBm

Using 4096QAM the coverage area is calculated to be 34.7% of the total map area.



ATSC 3.0 4096QAM

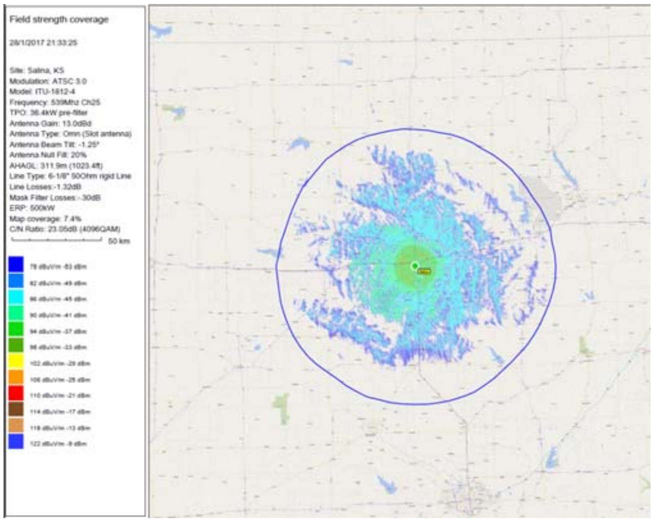
Changing the QAM changed the overall coverage from 53.7% to 34.7%. This is a coverage difference of 19%. There was also an increase in bit rate from 6.5Mbit/s to 39Mbit/s, giving a total increase of 32.5Mbit/s.



One thing to point out is, the FCC contour of 41dBuV/m never changed, yet the coverage of the ATSC signal changed based on the data rate and signal-to-noise ratio.

The coverage was done using a 10dB gain antenna at 10 meters. As you change the type of coverage from outdoor fixed to indoor fixed or to indoor portable and mobile, so does the receive antenna gain and receive antenna height change. In addition, there are also losses for building signal penetration, man-made noise and other losses that can effectively reduce the coverage. In some cases, the losses can be as high as -30dB to -35dB. For example, the plot below shows indoor coverage at 1.5m using a 0dB gain antenna.

Using 4096QAM and indoor coverage the maximum coverage area is calculated to be 7.4% of the total map area, and a signal strenth of -53dBm.



4096QAM Indoor coverage at 1.5m and
0dbgain receive antenna

Additional reduction in coverage at higher bit rates can be seen when using the Rayleigh channel model. When using the Rayleigh channel model, the signal-to-noise ratio (SNR) is higher due to the addition of multipath reception and non-directional receive antenna.

ATSC 3.0 Signal to Noise Ratio (SNR)			BCH (On)		BCH (Off)	
QAM	LDPC Length	LDPC Code Rate	AWGN SNR (dB)	Rayleigh SNR (dB)	AWGN SNR	Rayleigh SNR
1024 QAM	64800	2/15	3.23	4.65	3.23	4.65
		3/15	6.17	8.04	6.17	8.04
		4/15	8.77	10.85	8.77	10.85
		5/15	11.07	13.25	11.08	13.25
		6/15	13.46	15.91	13.39	15.94
		7/15	15.30	17.84	15.30	17.84
		8/15	17.46	20.13	17.49	20.15
		9/15	19.45	22.34	19.47	22.35
		10/15	21.35	24.47	21.37	24.47
		11/15	23.43	26.61	23.43	26.61
		12/15	25.52	28.82	25.52	28.82
		13/15	27.62	31.59	27.62	31.59
4096 QAM	64800	2/15	4.58	6.23	4.58	6.23
		3/15	7.85	9.83	7.85	9.83
		4/15	10.73	12.95	10.73	12.95
		5/15	13.45	15.75	13.45	15.75
		6/15	16.04	18.79	16.06	18.83
		7/15	18.22	21.03	18.22	21.03
		8/15	20.69	23.67	20.71	23.68
		9/15	23.05	26.37	23.08	26.39
		10/15	25.55	28.64	25.57	28.68
		11/15	28.11	31.18	28.12	31.19
		12/15	30.34	33.82	30.34	33.82
		13/15	32.83	36.54	32.84	36.54

Rayleigh and AWGN signal-to-noise ratio (SNR) for
1024QAM and 4096QAM

ATSC 3.0 Multiple Physical layer Pipe Lines (PLP)

The use of multiple physical layer pipe lines (PLP) allow the broadcaster to tailor the data or programs to specific data allocations or coverage. Tailoring each pipe line to different parameters allows for additional coverage by changing the data rate for specific targeted viewers. Ultra-high definition television (UHDTV) can be utilized for viewers close to the transmission site, where high definition television (HDTV) or standard definition television (SDTV) can be utilized for customers further away from the transmission site.

Summary

ATSC 3.0 has significant advantages over ATSC 1.0 in coverage, signal-to-noise ratio (SNR) and data rates. Remembering that the higher the data rate the higher the signal-to-noise ratio (SNR); the lower the data rate the lower the signal-to-noise ratio (SNR). This also means the higher the signal-to-noise ratio (SNR) the less robust the signal, the lower the signal-to-noise ratio (SNR) the more robust the signal.

The signal-to-noise ratio (SNR) and the data rate have a direct relationship to the distance the ATSC 3.0 signal can be received. The lower the signal-to-noise ratio (SNR) the more distance the signal can travel and be received. The higher the signal-to-noise ratio the less distance the single can travel and be received.

References

[1] ATSC Candidate Standard Physical Layer Protocol, Doc, No 230r21 28Sep 2015.

[2] ATSC Standard A/321, System Discovery and Signaling Doc. A/321:2016, 23 Mar 2016

[3] ATSC Standard Physical layer Protocol, Doc # A/322:2016, 7 Sept 2016

[4] ITU 1812-4 Propagation prediction model, July 2015

[5] ATDI coverage software ICS telcom, Web page references. www.ATDI.com

GATESAIR®