

Exhibit 21

U.S. Patent No. 11,019,509

1A 1. A communication system, comprising:	"1. A communication system, comprising:" The ATSC 3.0 standard is used by broadcast television digital communication systems. The ATSC 3.0 standard is acknowledged as utilizing the parallel decoding capacity (also referred to as BICM capacity) optimized NU-QAM constellations invented by the inventors of the '509 Patent See "Non-Uniform Constellations for ATSC 3.0" in IEEE Transactions on Broadcasting, Vol. 62, No. 1, March 2016, which is co-authored by engineers from Samsung, Sony, and LG.
--	--

"a receiver capable of receiving signals via a communication channel having a channel signal-to-noise ratio (SNR), wherein the receiver comprises:"

1B a receiver capable of receiving signals via a communication channel having a channel signal-to-noise ratio (SNR). The communication channel has a measurable signal-to-noise ratio, and the ATSC 3.0 standard is designed to support transmissions across a wide range of SNRs. It is expected that the broadcast system was tested using a receiver.

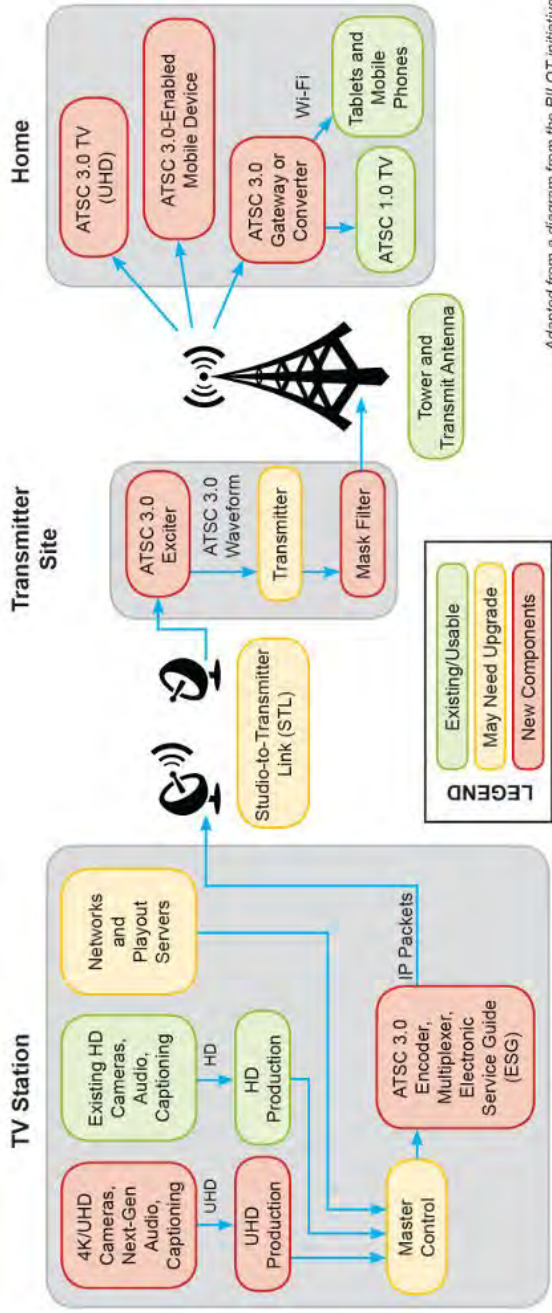
4. SYSTEM OVERVIEW AND GUIDELINES FOR PHYSICAL LAYER MODE

4.1 System Overview

The ATSC 3.0 physical layer protocol described by A/321 [2] and A/322 [3] provides distinct features and descriptions of the physical layer technologies. For a channel coding method, a well-optimized Bit-Interleaved Coded Modulation (BICM) chain, comprised of Low Density Parity Check (LDPC) codes (2/15 – 13/15 code rates), Bit Interleavers, and Non-Uniform Constellations (QPSK – 40%QAM modulation orders), is used to achieve near Shannon limit performance of channel error mitigation across a wide range of SNR values. Multiple data streams can be carried

See e.g., ATSC Recommended Practice: Guidelines for the Physical Layer Protocol (A/327), pg. 6, <https://www.atsc.org/wp-content/uploads/2018/10/A327-2018-Physical-Layer-RP.pdf>

For example, a typical ATSC communication is broadcast over the air from a TV station through transmitter sites to ATSC 3.0 receivers, such as ATSC 3.0 TVs, mobile devices, or gateways.



Adapted from a diagram from the PILOT Initiative

"a receiver capable of receiving signals via a communication channel having a channel signal-to-noise ratio (SNR), wherein the receiver comprises:"

See e.g., ATSC Newsletter, <https://www.atsc.org/newsletter/getting-from-here-to-atsc-3-0-next-gen-standard-changes-everything/>

"a demodulator capable of demodulating a received signal into a demodulated signal;"

1C a demodulator capable of demodulating a received signal into a demodulated signal;

ATSC 3.0 receivers include a demodulator capable of demodulating the received RF signal.

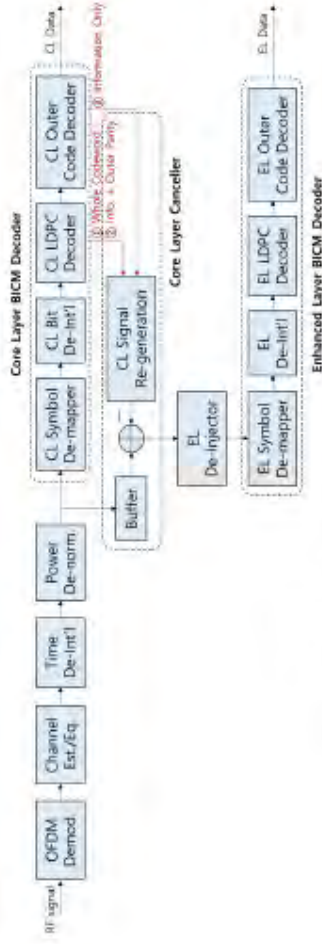


Figure 6.6 LDM decoding block diagram.

See e.g., ATSC Recommended Practice: Guidelines for the Physical Layer Protocol (A/327), pg. 71, <https://www.atsc.org/wp-content/uploads/2018/10/A327-2018-Physical-Layer-RP.pdf>

For example, the ATSC provides guidelines for receiver implementation that includes waveform demodulation for signals received by the receiver.

6.2 Waveform Demodulation

6.2.1 Channel Estimation and Equalization

ATSC 3.0 uses OFDM modulation, which is a form of multi-carrier transmission, where each carrier delivers coherently modulated complex symbols. In a receiver, the received constellation symbol for the k th carrier of the l th OFDM symbol may be expressed as:

$$\tilde{R}_l(k) = S_l(k) \cdot H_l(k) + z_l(k)$$

where $S_l(k)$ is the transmitted symbol, $H_l(k)$ is the channel response of the k th carrier in the l th OFDM symbol, and $z_l(k)$ is the system noise. Given the received symbol, equalization may be performed as:

$$\tilde{S}_l(k) = \frac{\tilde{R}_l(k)}{\tilde{H}_l(k)}$$

"a demodulator capable of demodulating a received signal into a demodulated signal;"

	See e.g., ATSC Recommended Practice: Guidelines for the Physical Layer Protocol (A/327), pg. 62, https://www.atsc.org/wp-content/uploads/2018/10/A327-2018-Physical-Layer-RP.pdf
--	--

"a demapper, coupled to the demodulator, capable of determining likelihoods using the demodulated signal and a symbol constellation that includes constellation points at a plurality of unique point locations, where: the plurality of unique point locations are unequally spaced; the constellation points each have a location and a different label; and the locations of at least two of the constellation points are the same; and"

1D ATSC 3.0 compliant receivers include a demapper, coupled to the demodulator, capable of determining likelihoods using the demodulated signal and a symbol constellation that includes constellation points at a plurality of unique point locations, where: the plurality of unique point locations are unequally spaced; the constellation points each have a location and a different label; and the locations of at least two of the constellation points are the same.

For example, the ATSC guidelines require each receiver to have a demapper.

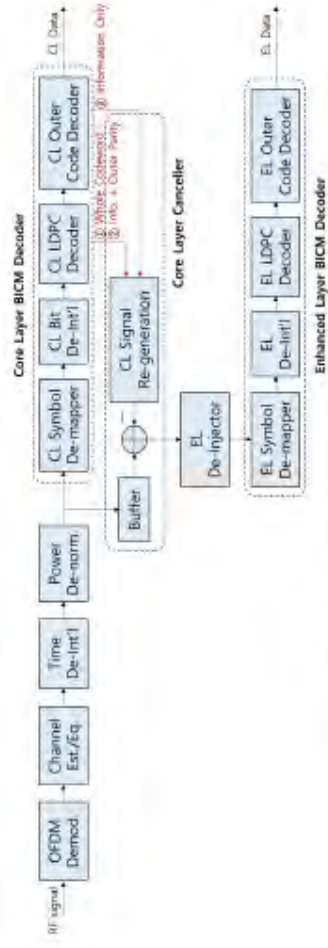


Figure 6.6 LDM decoding block diagram.

See e.g., ATSC Recommended Practice: Guidelines for the Physical Layer Protocol (A/327), pg. 71, <https://www.atsc.org/wp-content/uploads/2018/10/A327-2018-Physical-Layer-RP.pdf>

For example, the ATSC receiver guidelines specify using a demapper to calculate Log Likelihood-Ratios (LLR) from the I and Q components of the demodulated signals.

"a demapper, coupled to the demodulator, capable of determining likelihoods using the demodulated signal and a symbol constellation that includes constellation points at a plurality of unique point locations, where: the plurality of unique point locations are unequally spaced; the constellation points each have a location and a different label; and the locations of at least two of the constellation points are the same; and"

6.5 Channel Decoding

The channel decoding process includes the de-mapping of NUCs, bit de-interleaving, and inner/outer decoding. After the de-mapping of NUCs, values which correspond to the bit-interleaved codewords in the transmitter are fed to the bit de-interleaver, and then to the inner/outer decoders. Note that these values are often called channel values and they may be obtained in hard or soft decision form in receivers.

6.5.1 LLR De-Mapping for Non-Uniform Constellations

For optimal performance in decoding, the de-mapping of NUCs may be performed via soft decision such as Log Likelihood-Ratios (LLRs) calculation. In ATSC 3.0, two types of non-uniform constellations (NUC) are used: 1-dimensional (1D-NUC) and 2-dimensional (2D-NUC). When 1D-NUCs are used, the LLRs can be calculated using the well-known one-dimensional demapper described in Section 6.5.1.1. In the case of 2D-NUCs, the derivation of the LLRs is shown in Section 6.5.1.2.

6.5.1.1 De-Mapping for 1D-NUC

In the cases of 1D-NUCs (QPSK, 1024QAM and 4096QAM), a receiver may form LLRs as a function of two non-uniform 1-dimensional pulse amplitude modulation (PAM) constellations representing the in-phase (I) and quadrature (Q) components of the 1D-NUC. A 2-dimensional demapper can be also applied but with higher computational expense. Considering that a QAM constellation conveys m coded bits, i.e., each constellation component has $\sqrt{2m}$ possible states, the structure of the de-mapper is shown in Figure 6.9.

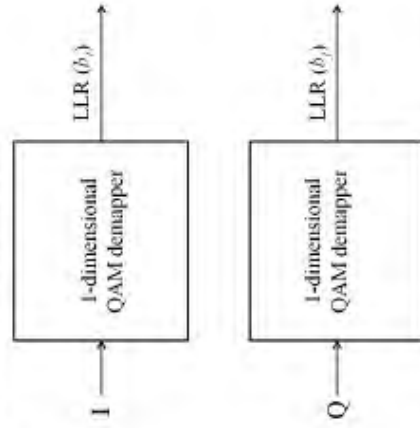


Figure 6.9 De-mapper structure for 1D-NUC.

See e.g., ATSC Recommended Practice: Guidelines for the Physical Layer Protocol (A/327), pg. 73-74, <https://www.atsc.org/wp-content/uploads/2018/10/A327-2018-Physical-Layer-RP.pdf>

"a demapper, coupled to the demodulator, capable of determining likelihoods using the demodulated signal and a symbol constellation that includes constellation points at a plurality of unique point locations, where: the plurality of unique point locations are unequally spaced; the constellation points each have a location and a different label; and the locations of at least two of the constellation points are the same; and"

6.5.1.2 De-Mapping for 2D-NUC

In the case of 2D-NUCs (16QAM, 64QAM and 256QAM), LLRs may be calculated as a 2-dimensional function. The structure of the de-mapper is shown in Figure 6.10.



Figure 6.10 De-mapper structure for 2D-NUC.

See e.g., ATSC Recommended Practice: Guidelines for the Physical Layer Protocol (A/327), pg. 76, <https://www.atsc.org/wp-content/uploads/2018/10/A327-2018-Physical-Layer-RP.pdf>

The demapper uses the ATSC 3.0 specified non-uniform constellations. The ATSC 3.0 specified constellations for the following modulation and code rate pairs include constellation points at a plurality of unique point locations that are unequally spaced. Within each of the below constellations, each of the constellation points has a different label and an associated location and at least two of the constellation points have the same location:

- 64QAM – 3/15, 4/15
- 256QAM – 3/15, 5/15, 7/15, 8/15
- 1024QAM – 2/15, 3/15, 8/15, 9/15
- 4096QAM – 2/15 through 12/15

"a demapper, coupled to the demodulator, capable of determining likelihoods using the demodulated signal and a symbol constellation that includes constellation points at a plurality of unique point locations, where: the plurality of unique point locations are unequally spaced; the constellation points each have a location and a different label; and the locations of at least two of the constellation points are the same; and"

Table C.I.4 64QAM Definition Table for Code Rates 2/15-7/15

w/cr	2/15	3/15	4/15	5/15	6/15	7/15
w0	0.6474+j0.9831	0.5472+j1.1591	0.5008+j1.2136	1.4327+j0.3305	1.4521+j0.3005	0.1567+j0.3112
w1	0.6438+j0.9829	0.5473+j1.1573	0.4994+j1.2194	1.0909+j0.2971	1.2657+j0.8178	0.1709+j0.3037
w2	0.6471+j0.9767	0.5467+j1.1599	0.5313+j1.1715	1.2484+j0.7803	1.0666+j0.2744	0.2093+j0.6562
w3	0.6444+j0.9762	0.5479+j1.1585	0.5299+j1.1788	0.9762+j0.5715	0.9500+j0.5641	0.3315+j0.6038
w4	0.9839+j0.6475	1.1578+j0.5478	1.2107+j0.5037	0.3309+j1.4326	0.3011+j1.4529	0.3112+j0.1567
w5	0.9778+j0.6474	1.1576+j0.5475	1.2209+j0.5008	0.2979+j1.0923	0.8202+j1.2651	0.3037+j0.1709
w6	0.9835+j0.6434	1.1591+j0.5475	1.1715+j0.5299	0.7829+j1.2477	0.2750+j1.0676	0.6562+j0.2093
w7	0.9777+j0.6433	1.1591+j0.5475	1.1802+j0.5270	0.5739+j0.9763	0.5656+j0.9499	0.6038+j0.3315
w8	0.4659+j0.6393	0.3163+j0.5072	0.2744+j0.4762	0.3901+j0.2112	0.3553+j0.1948	0.2959+j1.4877
w9	0.4643+j0.6386	0.3163+j0.5072	0.2729+j0.4762	0.5317+j0.2475	0.3569+j0.2094	0.8427+j1.2612
w10	0.4661+j0.6353	0.3163+j0.5072	0.2773+j0.4791	0.3945+j0.2289	0.5596+j0.2431	0.2389+j1.0228
w11	0.4639+j0.6350	0.3163+j0.5072	0.2773+j0.4791	0.5236+j0.2894	0.5410+j0.3002	0.5559+j0.8912
w12	0.6378+j0.4671	0.5087+j0.3163	0.4762+j0.2729	0.2108+j0.3911	0.1946+j0.3566	1.4877+j0.2959
w13	0.6352+j0.4673	0.5087+j0.3163	0.4762+j0.2729	0.2475+j0.5327	0.2094+j0.3579	1.2612+j0.8427
w14	0.6385+j0.4656	0.5087+j0.3163	0.4791+j0.2773	0.2287+j0.3955	0.2430+j0.5607	1.0228+j0.2389
w15	0.6353+j0.4653	0.5087+j0.3163	0.4791+j0.2758	0.2898+j0.5246	0.3004+j0.5417	0.8912+j0.5559

"a demapper, coupled to the demodulator, capable of determining likelihoods using the demodulated signal and a symbol constellation that includes constellation points at a plurality of unique point locations, where: the plurality of unique point locations are unequally spaced; the constellation points each have a location and a different label; and the locations of at least two of the constellation points are the same; and"

Table C.1.6 256QAM Definition Table for Code Rates 2/15-7/15

w/Shape	NUC_256_2/15	NUC_256_3/15	NUC_256_4/15	NUC_256_5/15	NUC_256_6/15	NUC_256_7/15
w0	0.5553+j1.1262	0.5229+j1.1810	0.2975+j1.0564	0.1524+j0.3087	0.1430+j0.3078	0.1170+j0.3003
w1	0.5673+j1.1336	0.5384+j1.1625	0.5862+j0.9617	0.1525+j0.3087	0.1430+j0.3077	0.1171+j0.3003
w2	0.5593+j1.1204	0.5148+j1.1943	0.2909+j1.0696	0.1513+j0.3043	0.1413+j0.3003	0.1204+j0.3233
w3	0.5636+j1.1321	0.5288+j1.1751	0.5796+j0.9689	0.1513+j0.3043	0.1414+j0.3002	0.1204+j0.3233
w4	0.5525+j1.1249	0.4985+j1.2202	0.2953+j1.3357	0.1682+j0.3004	0.1637+j0.2973	0.1454+j0.2877
w5	0.5637+j1.1320	0.5111+j1.1973	0.7488+j1.2365	0.1683+j0.3005	0.1636+j0.2973	0.1453+j0.2877
w6	0.5598+j1.1181	0.4889+j1.2357	0.3004+j1.5114	0.1663+j0.2964	0.1604+j0.2905	0.1566+j0.3074
w7	0.5659+j1.1274	0.5045+j1.2113	0.8151+j1.3816	0.1663+j0.2964	0.1603+j0.2905	0.1565+j0.3074
w8	0.5579+j1.1381	0.5222+j1.1817	0.3004+j1.0535	0.1964+j0.6584	0.1768+j0.6686	0.1427+j0.6856
w9	0.5617+j1.1471	0.5370+j1.1640	0.5847+j0.9631	0.1965+j0.6583	0.1793+j0.6679	0.1562+j0.6826
w10	0.5593+j1.1346	0.5133+j1.1950	0.2931+j1.0659	0.1967+j0.6652	0.1769+j0.6707	0.1422+j0.6584
w11	0.5672+j1.1430	0.5303+j1.1751	0.5825+j0.9668	0.1968+j0.6652	0.1793+j0.6700	0.1529+j0.6560
w12	0.5533+j1.1355	0.4971+j1.2216	0.2953+j1.3189	0.3371+j0.5987	0.3506+j0.5961	0.3840+j0.5856
w13	0.5632+j1.1421	0.5126+j1.1995	0.7466+j1.2168	0.3370+j0.5987	0.3484+j0.5974	0.3723+j0.5931
w14	0.5567+j1.1325	0.4882+j1.2371	0.2960+j1.4654	0.3414+j0.6039	0.3523+j0.5975	0.3651+j0.5660
w15	0.5641+j1.1363	0.5045+j1.2128	0.8297+j1.3539	0.3413+j0.6039	0.3501+j0.5987	0.3559+j0.5718
w16	1.1309+j0.5597	1.1795+j0.5251	1.0637+j0.2960	0.3087+j0.1524	0.3078+j0.1430	0.3003+j0.1170
w17	1.1405+j0.5660	1.1625+j0.5384	0.9617+j0.5811	0.3087+j0.1525	0.3077+j0.1430	0.3003+j0.1171
w18	1.1348+j0.5588	1.1914+j0.5133	1.0732+j0.2931	0.3043+j0.1513	0.3003+j0.1413	0.3233+j0.1204
w19	1.1491+j0.5638	1.1744+j0.5296	0.9682+j0.5818	0.3043+j0.1513	0.3002+j0.1414	0.3233+j0.1204
w20	1.1245+j0.5615	1.2209+j0.4993	1.3619+j0.2997	0.3004+j0.1682	0.2973+j0.1637	0.2877+j0.1454
w21	1.1333+j0.5627	1.2002+j0.5148	1.2249+j0.7546	0.3005+j0.1682	0.2973+j0.1636	0.2877+j0.1453
w22	1.1284+j0.5578	1.2342+j0.4882	1.5427+j0.3106	0.2964+j0.1663	0.2905+j0.1604	0.3074+j0.1566
w23	1.1436+j0.5636	1.2142+j0.5052	1.3969+j0.8523	0.2964+j0.1663	0.2905+j0.1603	0.3074+j0.1565
w24	1.1196+j0.5620	1.1803+j0.5229	1.0615+j0.2945	0.6584+j0.1964	0.6686+j0.1768	0.6856+j0.1427
w25	1.1347+j0.5665	1.1640+j0.5399	0.9631+j0.5818	0.6583+j0.1965	0.6679+j0.1793	0.6826+j0.1562
w26	1.1379+j0.5611	1.1921+j0.5133	1.0710+j0.2924	0.6652+j0.1967	0.6707+j0.1769	0.6584+j0.1422
w27	1.1440+j0.5638	1.1758+j0.5303	0.9675+j0.5825	0.6652+j0.1968	0.6700+j0.1793	0.6560+j0.1529
w28	1.1221+j0.5694	1.2209+j0.4971	1.3255+j0.2975	0.5987+j0.3371	0.5961+j0.3506	0.5856+j0.3940
w29	1.1318+j0.5686	1.2024+j0.5148	1.1979+j0.7495	0.5987+j0.3370	0.5974+j0.3484	0.5931+j0.3723
w30	1.1302+j0.5619	1.2349+j0.4889	1.4560+j0.3040	0.6039+j0.3414	0.5975+j0.3523	0.5660+j0.3651
w31	1.1386+j0.5662	1.2150+j0.5045	1.3269+j0.8414	0.6039+j0.3413	0.5987+j0.3501	0.5718+j0.3559
w32	0.3394+j0.5381	0.2740+j0.4771	0.2493+j0.5585	0.3183+j1.5992	0.2071+j1.6690	0.1683+j1.7041
w33	0.3397+j0.5360	0.2762+j0.4801	0.2960+j0.5344	0.3186+j1.5991	0.4482+j1.6210	0.4972+j1.6386
w34	0.3387+j0.5324	0.2733+j0.4757	0.2450+j0.5417	0.2756+j1.3848	0.2080+j1.3641	0.1495+j1.3560
w35	0.3400+j0.5335	0.2748+j0.4779	0.2873+j0.5191	0.2759+j1.3847	0.3307+j1.3397	0.3814+j1.3099
w36	0.3374+j0.5306	0.2703+j0.4742	0.2049+j0.3922	0.9060+j1.3557	1.0341+j1.3264	1.0862+j1.3238
w37	0.3405+j0.5343	0.2725+j0.4764	0.2173+j0.3806	0.9058+j1.3559	0.8297+j1.4630	0.8074+j1.5101
w38	0.3379+j0.5324	0.2696+j0.4727	0.1990+j0.3755	0.7846+j1.1739	0.8178+j1.1114	0.8534+j1.0644
w39	0.3400+j0.5317	0.2718+j0.4749	0.2107+j0.3645	0.7843+j1.1741	0.7138+j1.1809	0.6568+j1.1958
w40	0.3397+j0.5370	0.2740+j0.4779	0.2493+j0.5599	0.2257+j0.9956	0.1957+j0.9674	0.1552+j0.9481
w41	0.3400+j0.5383	0.2755+j0.4793	0.2975+j0.5351	0.2259+j0.9956	0.2170+j0.9629	0.2200+j0.9352
w42	0.3381+j0.5347	0.2725+j0.4757	0.2450+j0.5439	0.2276+j1.0326	0.1977+j1.0341	0.1577+j1.0449
w43	0.3382+j0.5347	0.2746+j0.4779	0.2887+j0.5213	0.2278+j1.0326	0.2288+j1.0277	0.2548+j1.0255
w44	0.3379+j0.5342	0.2711+j0.4734	0.2056+j0.3937	0.5446+j0.8635	0.5458+j0.8224	0.5609+j0.7800

"a demapper, coupled to the demodulator, capable of determining likelihoods using the demodulated signal and a symbol constellation that includes constellation points at a plurality of unique point locations, where: the plurality of unique point locations are unequally spaced; the constellation points each have a location and a different label; and the locations of at least two of the constellation points are the same; and"

w45	0.3389+ <i>j</i> 0.5332	0.2725+ <i>j</i> 0.4764	0.2187+ <i>j</i> 0.3820	0.5445+ <i>j</i> 0.8636	0.5276+ <i>j</i> 0.8342	0.5060+ <i>j</i> 0.8167
w46	0.3402+ <i>j</i> 0.5347	0.2696+ <i>j</i> 0.4720	0.1998+ <i>j</i> 0.3762	0.5694+ <i>j</i> 0.8910	0.5916+ <i>j</i> 0.8709	0.6276+ <i>j</i> 0.8501
w47	0.3384+ <i>j</i> 0.5340	0.2711+ <i>j</i> 0.4742	0.2122+ <i>j</i> 0.3667	0.5692+ <i>j</i> 0.8911	0.5651+ <i>j</i> 0.8883	0.5452+ <i>j</i> 0.9052
w48	0.5350+ <i>j</i> 0.3384	0.4771+ <i>j</i> 0.2740	0.5607+ <i>j</i> 0.2486	1.5982+ <i>j</i> 0.3183	1.6690+ <i>j</i> 0.2071	1.7041+ <i>j</i> 0.1883
w49	0.5363+ <i>j</i> 0.3397	0.4786+ <i>j</i> 0.2762	0.5381+ <i>j</i> 0.2960	1.5991+ <i>j</i> 0.3186	1.6210+ <i>j</i> 0.4482	1.6386+ <i>j</i> 0.4972
w50	0.5342+ <i>j</i> 0.3389	0.4764+ <i>j</i> 0.2725	0.5439+ <i>j</i> 0.2442	1.3848+ <i>j</i> 0.2756	1.3641+ <i>j</i> 0.2080	1.3660+ <i>j</i> 0.1495
w51	0.5384+ <i>j</i> 0.3380	0.4771+ <i>j</i> 0.2748	0.5220+ <i>j</i> 0.2865	1.3847+ <i>j</i> 0.2759	1.3397+ <i>j</i> 0.3307	1.3099+ <i>j</i> 0.3814
w52	0.5329+ <i>j</i> 0.3363	0.4734+ <i>j</i> 0.2703	0.3908+ <i>j</i> 0.2049	1.3557+ <i>j</i> 0.9060	1.3264+ <i>j</i> 1.0341	1.3238+ <i>j</i> 1.0862
w53	0.5330+ <i>j</i> 0.3387	0.4757+ <i>j</i> 0.2725	0.3813+ <i>j</i> 0.2173	1.3559+ <i>j</i> 0.9058	1.4630+ <i>j</i> 0.8297	1.5101+ <i>j</i> 0.8074
w54	0.5311+ <i>j</i> 0.3389	0.4734+ <i>j</i> 0.2696	0.3740+ <i>j</i> 0.1998	1.1739+ <i>j</i> 0.7846	1.1114+ <i>j</i> 0.8178	1.0644+ <i>j</i> 0.8534
w55	0.5332+ <i>j</i> 0.3380	0.4742+ <i>j</i> 0.2711	0.3653+ <i>j</i> 0.2100	1.1741+ <i>j</i> 0.7843	1.1809+ <i>j</i> 0.7138	1.1958+ <i>j</i> 0.6568
w56	0.5313+ <i>j</i> 0.3397	0.4771+ <i>j</i> 0.2740	0.5643+ <i>j</i> 0.2486	0.9956+ <i>j</i> 0.2257	0.9674+ <i>j</i> 0.1957	0.9481+ <i>j</i> 0.1552
w57	0.5324+ <i>j</i> 0.3400	0.4779+ <i>j</i> 0.2762	0.5410+ <i>j</i> 0.2967	0.9956+ <i>j</i> 0.2259	0.9629+ <i>j</i> 0.2170	0.9352+ <i>j</i> 0.2200
w58	0.5339+ <i>j</i> 0.3402	0.4764+ <i>j</i> 0.2725	0.5475+ <i>j</i> 0.2435	1.0326+ <i>j</i> 0.2276	1.0341+ <i>j</i> 0.1977	1.0449+ <i>j</i> 0.1577
w59	0.5360+ <i>j</i> 0.3405	0.4771+ <i>j</i> 0.2748	0.5257+ <i>j</i> 0.2880	1.0326+ <i>j</i> 0.2278	1.0277+ <i>j</i> 0.2288	1.0255+ <i>j</i> 0.2548
w60	0.5285+ <i>j</i> 0.3397	0.4742+ <i>j</i> 0.2703	0.3937+ <i>j</i> 0.2049	0.8635+ <i>j</i> 0.5446	0.8224+ <i>j</i> 0.5458	0.7800+ <i>j</i> 0.5609
w61	0.5317+ <i>j</i> 0.3379	0.4749+ <i>j</i> 0.2725	0.3850+ <i>j</i> 0.2187	0.8636+ <i>j</i> 0.5445	0.8342+ <i>j</i> 0.5276	0.8167+ <i>j</i> 0.5060
w62	0.5319+ <i>j</i> 0.3381	0.4734+ <i>j</i> 0.2696	0.3762+ <i>j</i> 0.1998	0.8910+ <i>j</i> 0.5694	0.8709+ <i>j</i> 0.5916	0.8501+ <i>j</i> 0.6276
w63	0.5327+ <i>j</i> 0.3395	0.4749+ <i>j</i> 0.2711	0.3689+ <i>j</i> 0.2114	0.8911+ <i>j</i> 0.5692	0.8883+ <i>j</i> 0.5651	0.9052+ <i>j</i> 0.5452

"a demapper, coupled to the demodulator, capable of determining likelihoods using the demodulated signal and a symbol constellation that includes constellation points at a plurality of unique point locations, where: the plurality of unique point locations are unequally spaced; the constellation points each have a location and a different label; and the locations of at least two of the constellation points are the same; and"

Table C.1.7 256QAM Definition Table for Code Rates 8/15-13/15

w/Shape	NUC_256_8/15	NUC_256_9/15	NUC_256_10/15	NUC_256_11/15	NUC_256_12/15	NUC_256_13/15
w0	0.0995+j0.2435	0.0899+j0.1337	0.0754+j0.2310	0.0593+j0.2193	1.1980+j1.1541	1.2412+j1.0688
w1	0.0996+j0.2434	0.0910+j0.1377	0.0768+j0.2305	0.0690+j0.3047	0.9192+j1.2082	1.2668+j0.8034
w2	0.1169+j0.3886	0.0873+j0.3862	0.0924+j0.4136	0.0663+j0.4879	1.2778+j0.8523	0.9860+j1.1758
w3	0.1179+j0.3883	0.0883+j0.3873	0.1043+j0.4125	0.1151+j0.4474	1.0390+j0.9253	1.0365+j0.9065
w4	0.1192+j0.2345	0.1115+j0.1442	0.0829+j0.1135	0.1689+j0.2163	0.6057+j1.2200	1.2111+j0.5135
w5	0.1192+j0.2345	0.1135+j0.1472	0.0836+j0.1149	0.1971+j0.2525	0.7371+j1.4217	1.4187+j0.6066
w6	0.1953+j0.3558	0.2067+j0.3591	0.2682+j0.3856	0.3096+j0.3796	0.6678+j1.0021	1.0103+j0.4879
w7	0.1944+j0.3563	0.1975+j0.3621	0.2531+j0.3906	0.2489+j0.3933	0.8412+j0.9448	1.0380+j0.6906
w8	0.1293+j0.7217	0.1048+j0.7533	0.0836+j0.7817	0.0790+j0.7970	1.2128+j0.5373	0.6963+j1.3442
w9	0.1616+j0.7151	0.1770+j0.7412	0.2052+j0.7608	0.2340+j0.7710	1.0048+j0.5165	0.7089+j1.1122
w10	0.1287+j0.6355	0.1022+j0.5904	0.0838+j0.6034	0.0723+j0.6395	1.4321+j0.6343	0.1256+j1.4745
w11	0.1456+j0.6318	0.1191+j0.5890	0.1394+j0.5961	0.1896+j0.6163	1.0245+j0.7152	0.8331+j0.9455
w12	0.4191+j0.6016	0.4264+j0.6230	0.4861+j0.6331	0.5090+j0.6272	0.6384+j0.6073	0.6615+j0.6012
w13	0.3916+j0.6198	0.3650+j0.6689	0.3661+j0.7034	0.3787+j0.7126	0.8175+j0.5684	0.6894+j0.7594
w14	0.3585+j0.5403	0.3254+j0.5153	0.3732+j0.5159	0.4079+j0.5049	0.6568+j0.7801	0.8373+j0.5633
w15	0.3439+j0.5497	0.2959+j0.5302	0.3095+j0.5511	0.3088+j0.5677	0.8311+j0.7459	0.8552+j0.7410
w16	0.2435+j0.0995	0.3256+j0.0768	0.3030+j0.0811	0.0675+j0.0626	0.1349+j1.4742	1.2666+j0.1027
w17	0.2434+j0.0996	0.3266+j0.0870	0.3017+j0.0853	0.3475+j0.0595	0.1105+j1.2309	1.4915+j0.1198
w18	0.3886+j0.1169	0.4721+j0.0994	0.4758+j0.0932	0.5482+j0.0626	0.0634+j0.9796	1.0766+j0.0945
w19	0.3883+j0.1179	0.4721+j0.1206	0.4676+j0.1242	0.4784+j0.1124	0.1891+j1.0198	0.9007+j0.0848
w20	0.2345+j0.1192	0.2927+j0.1267	0.2425+j0.1081	0.1674+j0.0751	0.4142+j1.4461	1.2454+j0.3064
w21	0.2345+j0.1192	0.2947+j0.1296	0.2447+j0.1115	0.2856+j0.1132	0.3323+j1.2279	1.4646+j0.3600
w22	0.3558+j0.1953	0.3823+j0.2592	0.3837+j0.2813	0.4134+j0.3028	0.4998+j0.9827	1.0570+j0.2995
w23	0.3563+j0.1944	0.3944+j0.2521	0.3959+j0.2642	0.4235+j0.2289	0.3467+j1.0202	0.9140+j0.2530
w24	0.7217+j0.1293	0.7755+j0.1118	0.7929+j0.0859	0.8258+j0.0840	0.0680+j0.6501	0.5461+j0.0679

"a demapper, coupled to the demodulator, capable of determining likelihoods using the demodulated signal and a symbol constellation that includes constellation points at a plurality of unique point locations, where: the plurality of unique point locations are unequally spaced; the constellation points each have a location and a different label; and the locations of at least two of the constellation points are the same; and"

w25	0.7151+j0.1616	0.7513+j0.2154	0.7652+j0.2324	0.7936+j0.2483	0.2016+j0.6464	0.5681+j0.1947
w26	0.6355+j0.1287	0.6591+j0.1033	0.6365+j0.0872	0.6788+j0.0783	0.0719+j0.8075	0.6874+j0.0537
w27	0.6318+j0.1456	0.6446+j0.1737	0.6207+j0.1757	0.6501+j0.2025	0.2088+j0.8146	0.7375+j0.1492
w28	0.6016+j0.4191	0.5906+j0.4930	0.6149+j0.5145	0.6246+j0.5211	0.4809+j0.6296	0.6290+j0.4553
w29	0.6198+j0.3916	0.6538+j0.4155	0.6987+j0.3934	0.7241+j0.3961	0.3374+j0.6412	0.6007+j0.3177
w30	0.5403+j0.3585	0.4981+j0.3921	0.5063+j0.4029	0.5144+j0.4089	0.4955+j0.8008	0.7885+j0.4231
w31	0.5497+j0.3439	0.5373+j0.3586	0.5526+j0.3356	0.5918+j0.3146	0.3431+j0.8141	0.7627+j0.2849
w32	0.1665+j1.6859	0.1630+j1.6621	0.1598+j1.6262	0.1631+j1.5801	1.2731+j0.1108	0.0816+j1.1632
w33	0.4919+j1.6211	0.4720+j1.5898	0.4733+j1.5637	0.4806+j1.5133	1.0794+j0.0977	0.0830+j0.9813
w34	0.1360+j1.3498	0.1268+j1.3488	0.1307+j1.3502	0.1260+j1.3365	1.5126+j0.1256	0.2528+j1.2315
w35	0.3914+j1.2989	0.3752+j1.2961	0.3877+j1.2983	0.3750+j1.2897	0.9029+j0.0853	0.2502+j1.0100
w36	1.0746+j1.3096	1.0398+j1.2991	1.0328+j1.2617	1.0324+j1.2029	0.5429+j0.0694	0.0732+j0.6827
w37	0.7987+j1.4940	0.7733+j1.4772	0.7675+j1.4398	0.7737+j1.3837	0.6795+j0.0559	0.0811+j0.8293
w38	0.8585+j1.0504	0.8380+j1.0552	0.8496+j1.0508	0.8350+j1.0529	0.5628+j0.1945	0.2159+j0.6673
w39	0.6419+j1.1951	0.6242+j1.2081	0.6297+j1.1967	0.6147+j1.1949	0.7326+j0.1410	0.2359+j0.8283
w40	0.1334+j0.9483	0.1103+j0.9397	0.0910+j0.9531	0.0929+j0.9596	1.2283+j0.3217	0.4302+j1.4458
w41	0.2402+j0.9271	0.2415+j0.9155	0.2649+j0.9198	0.2768+j0.9260	1.0269+j0.3261	0.5852+j0.9680
w42	0.1323+j1.0786	0.1118+j1.1163	0.1080+j1.1340	0.1095+j1.1349	1.4663+j0.3716	0.4528+j1.2074
w43	0.2910+j1.0470	0.3079+j1.0866	0.3214+j1.0926	0.3250+j1.0941	0.9085+j0.2470	0.4167+j1.0099
w44	0.5764+j0.7648	0.5647+j0.7638	0.5941+j0.7527	0.6086+j0.7556	0.6160+j0.4549	0.5035+j0.6307
w45	0.4860+j0.8252	0.4385+j0.8433	0.4371+j0.8528	0.4514+j0.8566	0.7818+j0.4247	0.5359+j0.7954
w46	0.6693+j0.8561	0.6846+j0.8841	0.7093+j0.8880	0.7161+j0.8933	0.5938+j0.3170	0.3580+j0.6532
w47	0.5348+j0.9459	0.5165+j1.0034	0.5235+j1.0090	0.5294+j1.0121	0.7600+j0.2850	0.3841+j0.8207
w48	1.6859+j0.1665	1.6489+j0.1630	1.6180+j0.1602	1.5809+j0.1471	0.0595+j0.0707	0.0576+j0.0745
w49	1.6211+j0.4919	1.5848+j0.4983	1.5540+j0.4734	1.5253+j0.4385	0.1722+j0.0706	0.0581+j0.2241
w50	1.3498+j0.1360	1.3437+j0.1389	1.3411+j0.1336	1.3380+j0.1363	0.0599+j0.2119	0.1720+j0.0742
w51	1.2989+j0.3914	1.2850+j0.4025	1.2883+j0.3955	1.2837+j0.4026	0.1748+j0.2114	0.1753+j0.2222
w52	1.3096+j1.0746	1.2728+j1.0661	1.2561+j1.0337	1.2476+j0.9785	0.4134+j0.0701	0.0652+j0.5269
w53	1.4940+j0.7987	1.4509+j0.7925	1.4311+j0.7676	1.4137+j0.7196	0.2935+j0.0705	0.0611+j0.3767
w54	1.0504+j0.8585	1.0249+j0.8794	1.0362+j0.8626	1.0246+j0.8681	0.4231+j0.2066	0.1972+j0.5178
w55	1.1951+j0.6419	1.1758+j0.6545	1.1845+j0.6419	1.1771+j0.6494	0.2979+j0.2100	0.1836+j0.3695
w56	0.9483+j0.1334	0.9629+j0.1113	0.9546+j0.0957	0.9782+j0.0985	0.0638+j0.5002	0.4145+j0.0709
w57	0.9271+j0.2402	0.9226+j0.2849	0.9163+j0.2834	0.9383+j0.2922	0.1905+j0.4966	0.4266+j0.2100
w58	1.0786+j0.1323	1.1062+j0.1118	1.1282+j0.1128	1.1455+j0.1158	0.0612+j0.3552	0.2912+j0.0730
w59	1.0470+j0.2910	1.0674+j0.3393	1.0838+j0.3340	1.0972+j0.3418	0.1810+j0.3533	0.2982+j0.2177
w60	0.7648+j0.5764	0.7234+j0.6223	0.7329+j0.6204	0.7446+j0.6273	0.4630+j0.4764	0.4766+j0.4821
w61	0.8252+j0.4860	0.8211+j0.4860	0.8428+j0.4615	0.8573+j0.4721	0.3231+j0.4895	0.4497+j0.3448
w62	0.8561+j0.6693	0.8457+j0.7260	0.8680+j0.7295	0.8767+j0.7377	0.4416+j0.3397	0.3334+j0.5025
w63	0.9459+j0.5348	0.9640+j0.5518	0.9959+j0.5426	1.0059+j0.5518	0.3083+j0.3490	0.3125+j0.3601

"a demapper, coupled to the demodulator, capable of determining likelihoods using the demodulated signal and a symbol constellation that includes constellation points at a plurality of unique point locations, where: the plurality of unique point locations are unequally spaced; the constellation points each have a location and a different label; and the locations of at least two of the constellation points are the same; and"

Table C.1.8 1024QAM Definition Table for Code Rates 2/15-7/15

w/CR	2/15	3/15	4/15	5/15	6/15	7/15
u0	0.3317	0.2382	0.1924	0.1313	0.1275	0.0951
u1	0.3321	0.2556	0.1940	0.1311	0.1276	0.0949
u2	0.3322	0.2749	0.2070	0.1269	0.1294	0.1319
u3	0.3321	0.2558	0.2050	0.1271	0.1295	0.1322
u4	0.3327	0.2748	0.3056	0.3516	0.3424	0.3170
u5	0.3328	0.2949	0.3096	0.3504	0.3431	0.3174
u6	0.3322	0.2749	0.2890	0.3569	0.3675	0.3936
u7	0.3322	0.2558	0.2854	0.3581	0.3666	0.3921
u8	0.9369	0.9486	0.7167	0.6295	0.6097	0.5786
u9	0.9418	0.8348	0.7362	0.6301	0.6072	0.5789
u10	0.9514	0.7810	0.7500	0.6953	0.7113	0.7205
u11	0.9471	0.8348	0.7326	0.6903	0.7196	0.7456
u12	0.9448	0.9463	0.9667	0.9753	0.9418	0.9299
u13	0.9492	0.8336	0.9665	1.0185	1.0048	1.0084
u14	0.9394	0.9459	1.1332	1.2021	1.2286	1.2349
u15	0.9349	1.4299	1.4761	1.4981	1.5031	1.5118

"a demapper, coupled to the demodulator, capable of determining likelihoods using the demodulated signal and a symbol constellation that includes constellation points at a plurality of unique point locations, where: the plurality of unique point locations are unequally spaced; the constellation points each have a location and a different label; and the locations of at least two of the constellation points are the same; and"

Table C.1.9 1024QAM Definition Table for Code Rates 8/15-13/15

u/CR	8/15	9/15	10/15	11/15	12/15	13/15
u0	0.0773	0.0638	0.0592	0.0502	0.0354	0.0325
u1	0.0773	0.0638	0.0594	0.0637	0.0921	0.0967
u2	0.1614	0.1757	0.1780	0.1615	0.1602	0.1623
u3	0.1614	0.1756	0.1790	0.1842	0.2185	0.2280
u4	0.3086	0.3069	0.2996	0.2760	0.2910	0.2957
u5	0.3085	0.3067	0.3041	0.3178	0.3530	0.3645
u6	0.4159	0.4333	0.4241	0.4040	0.4264	0.4361
u7	0.4163	0.4343	0.4404	0.4686	0.4947	0.5100
u8	0.5810	0.5765	0.5561	0.5535	0.5763	0.5878
u9	0.5872	0.5862	0.6008	0.6362	0.6531	0.6696
u10	0.7213	0.7282	0.7141	0.7293	0.7417	0.7566
u11	0.7604	0.7705	0.8043	0.8302	0.8324	0.8497
u12	0.9212	0.9218	0.9261	0.9432	0.9386	0.9498
u13	1.0349	1.0364	1.0639	1.0704	1.0529	1.0588
u14	1.2281	1.2234	1.2285	1.2158	1.1917	1.1795
u15	1.4800	1.4646	1.4309	1.3884	1.3675	1.3184

"a demapper, coupled to the demodulator, capable of determining likelihoods using the demodulated signal and a symbol constellation that includes constellation points at a plurality of unique point locations, where: the plurality of unique point locations are unequally spaced; the constellation points each have a location and a different label; and the locations of at least two of the constellation points are the same; and"

Table C.1.10 4096QAM Definition Table for Code Rates 2/15-7/15

u/CR	2/15	3/15	4/15	5/15	6/15	7/15
u0	0.2826	0.2038	0.1508	0.1257	0.1041	0.0810
u1	0.2885	0.2038	0.1468	0.1257	0.1041	0.0808
u2	0.2944	0.2155	0.1456	0.1257	0.1087	0.0807
u3	0.2885	0.2155	0.1479	0.1257	0.1089	0.0810
u4	0.2944	0.2155	0.1491	0.1257	0.1094	0.1456
u5	0.3003	0.2155	0.1444	0.1257	0.1094	0.1457
u6	0.2944	0.2097	0.1491	0.1257	0.1094	0.1456
u7	0.2885	0.2038	0.1508	0.1257	0.1109	0.1456
u8	0.2944	0.2796	0.3368	0.3599	0.3319	0.3059
u9	0.3003	0.2912	0.3368	0.3599	0.3319	0.3060
u10	0.3003	0.3029	0.3334	0.3484	0.3348	0.3056
u11	0.3003	0.2970	0.3363	0.3484	0.3348	0.3056
u12	0.2944	0.2970	0.3386	0.3484	0.3657	0.4043
u13	0.3003	0.3029	0.3357	0.3484	0.3657	0.4042
u14	0.2944	0.2796	0.3340	0.3599	0.3657	0.4036
u15	0.2885	0.2796	0.3374	0.3599	0.3657	0.4036
u16	0.9714	0.7222	0.6448	0.6112	0.5875	0.5684
u17	0.8596	0.7397	0.6569	0.6112	0.5876	0.5682
u18	0.7889	0.7455	0.7101	0.6969	0.5876	0.5700
u19	0.8478	0.7339	0.6979	0.7026	0.5877	0.5704
u20	0.8242	0.7397	0.6974	0.6969	0.6648	0.7155
u21	0.7771	0.7513	0.7124	0.6969	0.6651	0.7186
u22	0.8360	0.7455	0.6575	0.6112	0.6968	0.7425
u23	0.9184	0.7339	0.6465	0.6112	0.7018	0.7385
u24	1.1657	1.3046	1.3549	1.4052	0.9102	0.9163
u25	0.9479	1.0833	1.1931	1.2281	0.9102	0.9089
u26	0.8419	0.9785	1.0117	1.0054	0.9780	0.9771
u27	0.9302	1.0134	0.9857	0.9482	0.9842	1.0012
u28	0.9950	0.9901	0.9689	0.9425	1.1892	1.1766
u29	0.8713	0.9610	0.9967	0.9939	1.2411	1.2355
u30	1.0185	1.0658	1.1683	1.1882	1.4707	1.4381
u31	1.4660	1.6424	1.6391	1.6566	1.7274	1.6851

"a demapper, coupled to the demodulator, capable of determining likelihoods using the demodulated signal and a symbol constellation that includes constellation points at a plurality of unique point locations, where: the plurality of unique point locations are unequally spaced; the constellation points each have a location and a different label; and the locations of at least two of the constellation points are the same; and"

Table C.1.11 4096QAM Definition Table for Code Rates 8/15-13/15

u/CR	8/15	9/15	10/15	11/15	12/15	13/15
u0	0.0501	0.0415	0.0397	0.0253	0.0262	0.0176
u1	0.0553	0.0478	0.0397	0.0285	0.0262	0.0487
u2	0.0562	0.0592	0.0659	0.0844	0.0828	0.0781
u3	0.0562	0.0592	0.0659	0.0848	0.0842	0.1080
u4	0.1677	0.1656	0.1443	0.1460	0.1337	0.1399
u5	0.1687	0.1683	0.1453	0.1460	0.1389	0.1713
u6	0.1687	0.1683	0.1819	0.2078	0.1887	0.2053
u7	0.1718	0.1663	0.1826	0.2078	0.2018	0.2378
u8	0.2963	0.2861	0.2591	0.2708	0.2466	0.2720
u9	0.2963	0.2863	0.2591	0.2708	0.2675	0.3076
u10	0.2963	0.2877	0.3128	0.3360	0.3096	0.3412
u11	0.2968	0.2877	0.3128	0.3360	0.3393	0.3754
u12	0.4234	0.4144	0.3872	0.4051	0.3796	0.4156
u13	0.4240	0.4178	0.3872	0.4052	0.4118	0.4522
u14	0.4248	0.4204	0.4549	0.4742	0.4506	0.4893
u15	0.4248	0.4204	0.4549	0.4742	0.4897	0.5260
u16	0.5584	0.5352	0.5290	0.5417	0.5296	0.5643
u17	0.5590	0.5370	0.5302	0.5446	0.5712	0.6051
u18	0.5679	0.5673	0.6069	0.6118	0.6136	0.6469
u19	0.5729	0.5683	0.6081	0.6209	0.6586	0.6885
u20	0.7078	0.6848	0.6911	0.6857	0.7060	0.7336
u21	0.7090	0.6848	0.6969	0.7107	0.7544	0.7790
u22	0.7610	0.7694	0.7787	0.7734	0.8043	0.8255
u23	0.7640	0.7838	0.8012	0.8174	0.8624	0.8776
u24	0.8966	0.8808	0.8802	0.8791	0.9152	0.9254
u25	0.8979	0.9039	0.9248	0.9425	0.9718	0.9749
u26	1.0135	1.0050	1.0037	1.0131	1.0325	1.0276
u27	1.0393	1.0619	1.0861	1.0904	1.1017	1.0870
u28	1.1817	1.1797	1.1870	1.1787	1.1756	1.1474
u29	1.2459	1.2898	1.2894	1.2766	1.2541	1.2121
u30	1.4232	1.4381	1.4122	1.3852	1.3405	1.2835
u31	1.6336	1.6223	1.5629	1.5162	1.4431	1.3644

"a demapper, coupled to the demodulator, capable of determining likelihoods using the demodulated signal and a symbol constellation that includes constellation points at a plurality of unique point locations, where: the plurality of unique point locations are unequally spaced; the constellation points each have a location and a different label; and the locations of at least two of the constellation points are the same; and"

C.2 CONSTELLATION FIGURES

The constellations are shown graphically in Figure C.2.1 for QPSK, Figure C.2.2 for 16QAM, Figure C.2.3 for 64QAM, Figure C.2.4 for 256QAM, Figure C.2.5 for 1024QAM and Figure C.2.6 for 4096QAM.

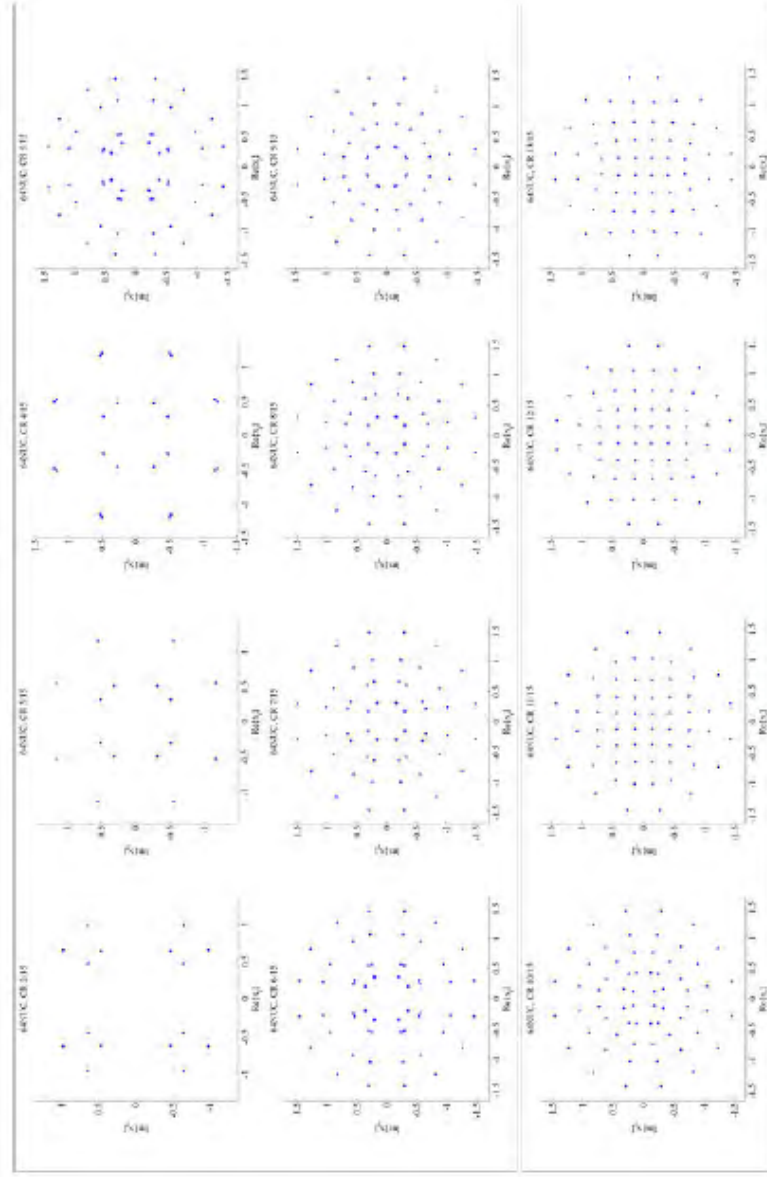


Figure C.2.3 Constellations of 64QAM.

"a demapper, coupled to the demodulator, capable of determining likelihoods using the demodulated signal and a symbol constellation that includes constellation points at a plurality of unique point locations, where: the plurality of unique point locations are unequally spaced; the constellation points each have a location and a different label; and the locations of at least two of the constellation points are the same; and"

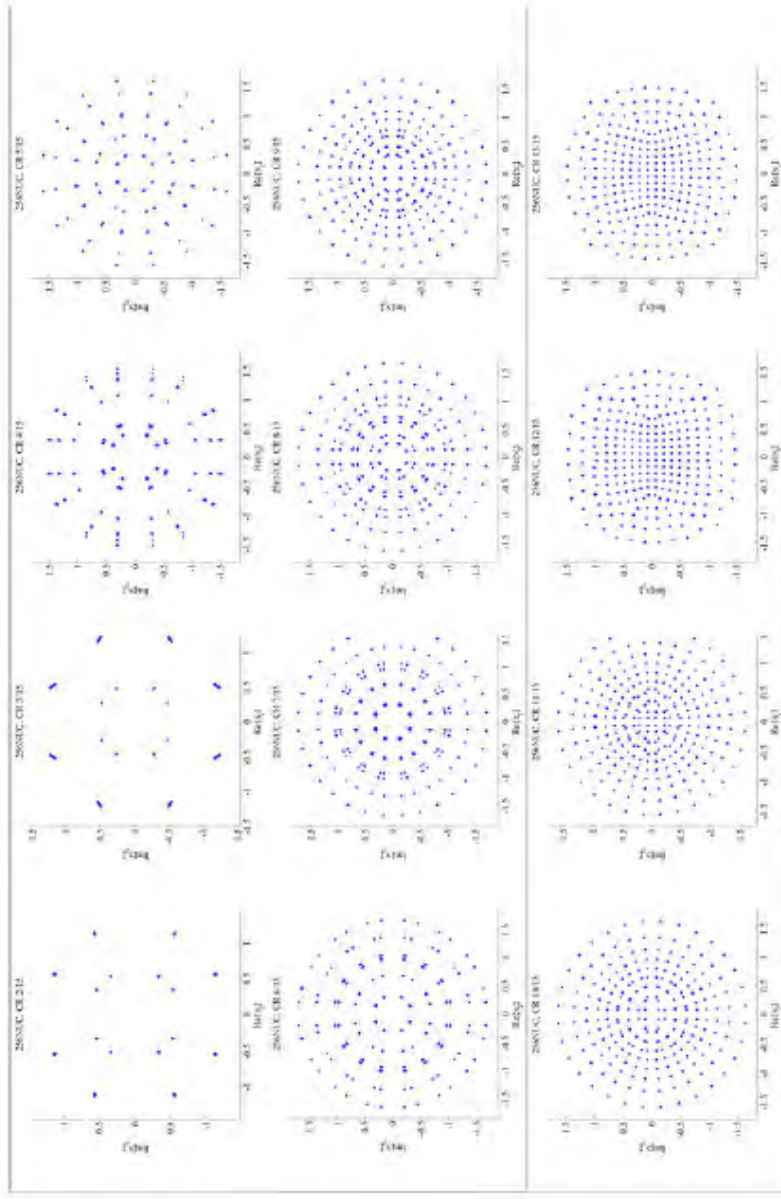
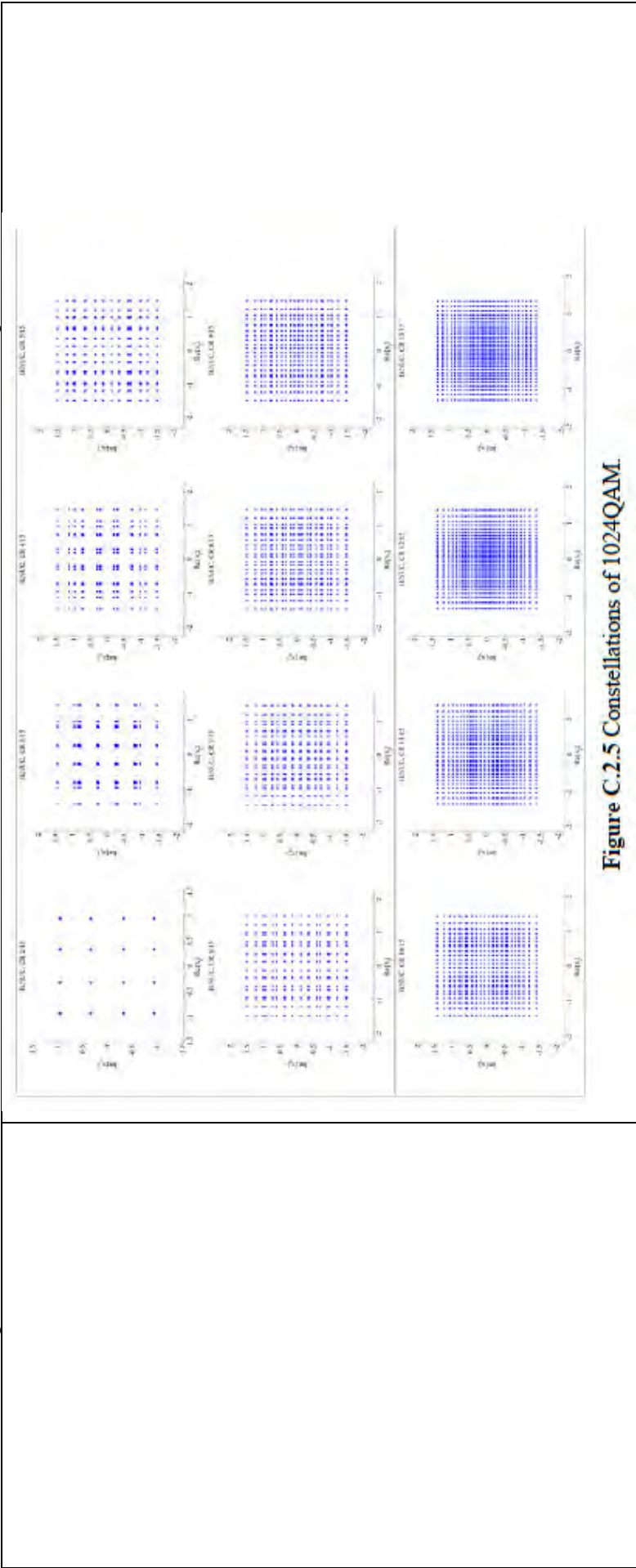


Figure C.2.4 Constellations of 256QAM.

"a demapper, coupled to the demodulator, capable of determining likelihoods using the demodulated signal and a symbol constellation that includes constellation points at a plurality of unique point locations, where: the plurality of unique point locations are unequally spaced; the constellation points each have a location and a different label; and the locations of at least two of the constellation points are the same; and"



"a demapper, coupled to the demodulator, capable of determining likelihoods using the demodulated signal and a symbol constellation that includes constellation points at a plurality of unique point locations, where: the plurality of unique point locations are unequally spaced; the constellation points each have a location and a different label; and the locations of at least two of the constellation points are the same; and"

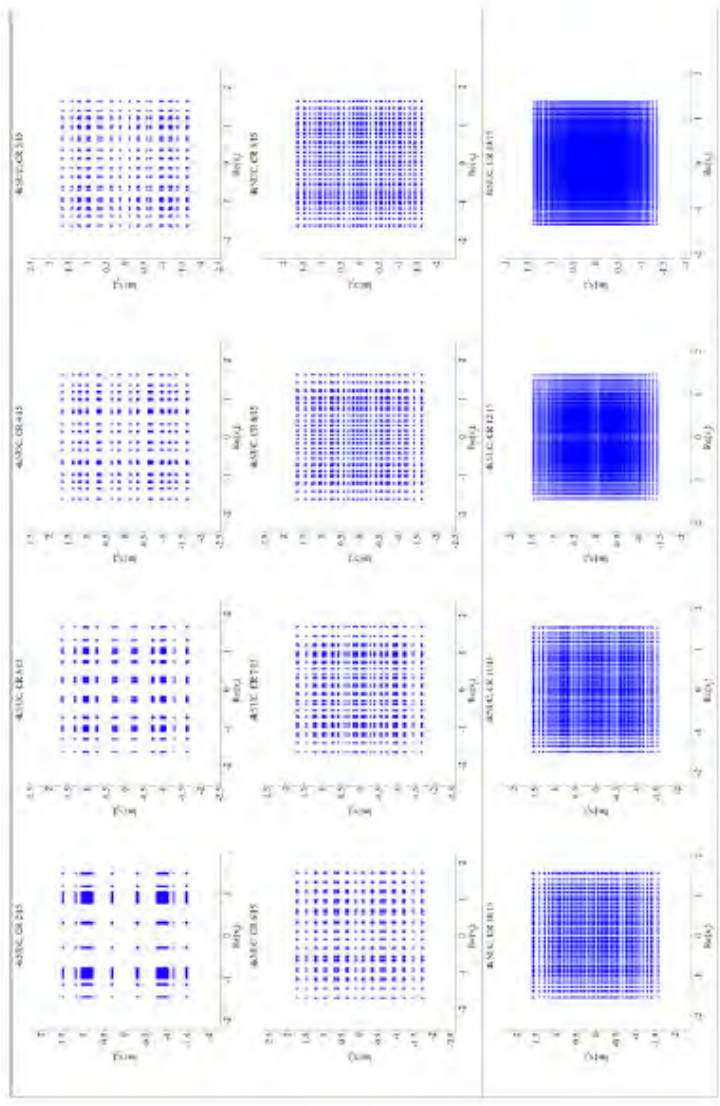


Figure C.2.6 Constellations of 4096QAM.

See e.g., ATSC 3.0 Standard: Physical Layer Protocol (A/322), Annex C, pg. 165-171, 173-174, <https://muygs2x2vnb2pjk6g160f1s8-wpengine.netdna-ssl.com/wp-content/uploads/2021/04/A322-2021-Physical-Layer-Protocol.pdf>

"a decoder, coupled to the demapper, capable of using the likelihoods determined by the demapper to provide a sequence of received bits based upon a low density parity check (LDPC) code."

For example, the ATSC receiver guidelines specify using an LDPC decoder to estimate decoded bits from the LLR values generated by the demapper. The LDPC decoder inserts LLR values for shortened or punctured bits, combines the LLR values for repeated parity bits, and performs the LDPC decoding.

6.5.4 Decoding of L1 Signaling

Decoding of L1 signaling is the reverse operation of L1 protection operation in the transmitter. First of all, receivers can acquire the information about the L1-Basic Mode from the bootstrap. Since the length of L1-Basic signaling is fixed at 200 bits, receivers can easily calculate the number of cells occupied by L1-Basic signaling bits in the first Preamble symbol. After decoding L1-Basic, ATSC 3.0 receivers acquire the information about the L1-Detail Mode and the length of L1-Detail. Note that the L1 protection mode is determined based on combination of the LDPC code rate, modulation order, and the number of punctured bits to the number of shortened bits ratio (PSR), as shown in Table 4.9 of Section 4.2.10.

Since the L1 signaling is protected by a shortened and punctured LDPC code at the transmitter, the LDPC decoder at a receiver determines the length of shortened (i.e., zero-padding) and punctured bits in an LDPC codeword as well as appropriate shortening and puncturing patterns. For each L1 protection mode, the shortening and puncturing patterns are determined based on the LDPC code rate, modulation order, and PSR. Note that the shortening and puncturing patterns are defined on a bit-group basis.

Based on the determined shortening length and pattern, the decoder inserts a fixed channel value at the positions corresponding to shortened bits. Here, the fixed channel value is usually set to the maximum LLR value defined in the LDPC decoder since a zero-padding bit can be treated as a signal with $LLR = \infty$, theoretically. Similarly, based on the determined puncturing length and pattern, the decoder inserts another fixed channel value at the punctured positions. Here, the latter fixed channel value is usually set to $LLR = 0$ since a punctured bit is an erasure, i.e., a lost signal. When the repetition of parity bits is applied at the transmitter for L1-Basic Mode 1 and L1-Detail Mode 1, the decoder combines the LLR values for the repeated parity bits. The combining of the LLR values is simply achieved by adding the LLR values of repeated parity bits for the same parity.

"a decoder, coupled to the demapper, capable of using the likelihoods determined by the demapper to provide a sequence of received bits based upon a low density parity check (LDPC) code."

Note that the length of the repeated parity bits is determined based on the size of concatenation of L1 signaling and BCH parity-check bits.

After the insertion of appropriate LLR values for the shortened and punctured bits and combining of LLR values for repeated parity bits, the LDPC decoding is performed. After the LDPC decoding and zero removal for the output of LDPC decoding, the decoder performs BCH decoding, and finally, the L1 signaling is obtained by de-scrambling the output of BCH decoding.

When the size of L1-Detail signaling exceeds a segmentation reference value K_{seg} , the L1-Detail signaling is segmented into multiple smaller blocks at the transmitter and the L1-Detail signaling is transmitted by one or more FEC Frames. Therefore, when applying the segmentation of L1-Detail signaling at the transmitter, ATSC 3.0 receivers combine the segmented multiple blocks based on the value K_{seg} after decoding each segmented block. K_{seg} for each L1-Detail mode is determined based on the LDPC code rate and PSR, as described in Section 5.2.5.2.

When additional parity is configured at the transmitter and the number of additional parity bits exceeds the number of punctured bits, the repeated bits are selected. Then, similar to the repetition of parity, the decoder combines the LLR values for the repeated parity. The combining of the LLR values is simply achieved by adding the LLR values of repeated parity bits for the same parity.

See e.g., ATSC Recommended Practice: Guidelines for the Physical Layer Protocol (A/327), pg. 82-83, <https://www.atsc.org/wp-content/uploads/2018/10/A327-2018-Physical-Layer-RP.pdf>

"The communication system of claim 1, wherein: the symbol constellation is selected from a plurality of unequally spaced symbol constellations;"

2A The communication system of claim 1, wherein: the symbol constellation is selected from a plurality of unequally spaced symbol constellations;	As shown above, ATSC 3.0 specifies certain symbol constellations to be used, including a plurality of unequally spaced symbol constellations. As shown in more detail above with reference to claim element 1D, the non-uniform symbol constellation that the demapper is capable of using to determine likelihoods (that includes at least two constellation points that have identical locations and different labels) is selected from a plurality of non-uniform symbol constellations specified in ATSC 3.0. For brevity, those constellations are not repeated here. ATSC 3.0 specifies a plurality of constellations including non-uniform 16QAM, 64QAM, 256QAM, 1024QAM and 4096QAM constellations. 6.3.1 Constellation Overview Six different modulation orders are defined: uniform QPSK modulation and five non-uniform constellation (NUC) sizes: 16QAM, 64QAM, 256QAM, 1024QAM and 4096QAM respectively. For each combination of NUC modulation order and code rate a different constellation exists. However, the constellation does not vary with code length, the same constellation is used for both $N_{inner}=64800$ and $N_{inner}=16200$ codes when the code rate and modulation order are held constant. The same QPSK constellation is used for all code rates. The QPSK constellation is a 1-dimensional QAM form. The non-uniform constellations 16QAM, 64QAM and 256QAM are 2-dimensional (2D) quadrant-symmetric QAM constellations and are constructed by symmetry from a single quadrant. To reduce the complexity during QAM de-mapping at the receiver, the 1024QAM and 4096QAM constellations are derived from non-uniform 1-dimensional (1D) PAM (pulse amplitude modulation) constellations for both in-phase (I) and quadrature (Q) components. 6.3.2 Modulation and Coding Combinations In order to reduce the implementation complexity, implementation of all the modulation and coding combinations is not mandatory. Table 6.12 and Table 6.13 show the mandatory modulation and coding combinations that must be implemented. Mandatory combinations are shown with a check mark ✓
--	--

"The communication system of claim 1, wherein: the symbol constellation is selected from a plurality of unequally spaced symbol constellations;"

Table 6.12 Mandatory Modulation and Coding Combinations $N_{inner} = 64800$ Bits

Code Rate/ Constellation	2/ 15	3/ 15	4/ 15	5/ 15	6/ 15	7/ 15	8/ 15	9/ 15	10/ 15	11/ 15	12/ 15	13/ 15
QPSK	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		
16QAM			✓	✓		✓	✓	✓		✓		
64QAM				✓	✓	✓	✓	✓	✓	✓		
256QAM				✓	✓	✓	✓	✓	✓	✓	✓	✓
1024QAM				✓		✓	✓	✓	✓	✓	✓	✓
4096QAM						✓		✓		✓	✓	✓

Table 6.13 Mandatory Modulation and Coding Combinations $N_{inner} = 16200$ Bits

Code Rate/ Constellation	2/ 15	3/ 15	4/ 15	5/ 15	6/ 15	7/ 15	8/ 15	9/ 15	10/ 15	11/ 15	12/ 15	13/ 15
QPSK	✓	✓	✓	✓	✓	✓	✓	✓				
16QAM				✓	✓	✓	✓			✓		
64QAM				✓	✓	✓	✓	✓	✓	✓		
256QAM				✓		✓	✓	✓	✓	✓	✓	✓

See e.g., ATSC 3.0 Standard: Physical Layer Protocol (A/322), Annex C, pg. 30-31; see also Annex C, pg. 164-174, <https://muygs2x2vhhb2pjk6g160f1s8-wpengine.netdna-ssl.com/wp-content/uploads/2021/04/A322-2021-Physical-Layer-Protocol.pdf>

" the plurality of unequally spaced symbol constellations includes a plurality of unequally spaced constellations of a first type that comprise multiple different sixty-four-point symbol constellations, multiple different two-hundred-fifty-six-point symbol constellations, and multiple different one-thousand-twenty-four-point symbol constellations, where unequally spaced symbol constellations of the first type include at least two constellation points having locations that are the same and different labels;"

2B the plurality of unequally spaced symbol constellations includes a plurality of unequally spaced constellations of a first type that comprise multiple different sixty-four-point symbol constellations, multiple different two-hundred-fifty-six-point symbol constellations, and multiple different one-thousand-twenty-four-point symbol constellations, where unequally spaced symbol constellations of the first type include at least two constellation points having locations that are the same and different labels;	The plurality of ATSC 3.0 constellations identified above include a plurality of non-uniform symbol constellations of a first type that comprises multiple different sixty-four-point symbol constellations, multiple different two-hundred-fifty-six-point symbol constellations, and multiple different one-thousand-twenty-four-point symbol constellations. As shown above, the following ATSC 3.0 specified non-uniform symbol constellations include at least two constellation points having locations that are the same and different labels. Therefore the ATSC specified constellations of the first type (that include at least two constellation points having locations that are the same and different labels), include the following (identified by code rate/constellation pair): 64QAM – 3/15, 4/15 256QAM – 3/15, 5/15, 7/15, 8/15 1024QAM – 2/15, 3/15, 8/15, 9/15
--	--

"the receiver is capable of selecting an LDPC code rate and the unequally spaced symbol constellation as a pair from a plurality of predetermined LDPC code rate and unequally spaced symbol constellation pairs; and"

2C
the receiver is capable of selecting an LDPC code rate and the unequally spaced symbol constellation as a pair from a plurality of predetermined LDPC code rate and unequally spaced symbol constellation pairs; and

ATSC 3.0 compliant receivers are capable of selecting an LDPC code rate and the unequally spaced symbol constellation as a pair from a plurality of predetermined LDPC code rate and unequally spaced symbol constellation pairs specified by the ATSC 3.0 specification.

Table 6.12 Mandatory Modulation and Coding Combinations $N_{inner} = 64800$ Bits

Code Rate/ Constellation	2/ 15	3/ 15	4/ 15	5/ 15	6/ 15	7/ 15	8/ 15	9/ 15	10/ 15	11/ 15	12/ 15	13/ 15
QPSK	✓		✓	✓	✓	✓	✓	✓		✓		
16QAM			✓	✓	✓	✓	✓	✓		✓		
64QAM				✓	✓	✓	✓	✓	✓	✓		
256QAM						✓	✓	✓	✓	✓	✓	✓
1024QAM							✓	✓	✓	✓	✓	✓
4096QAM								✓	✓	✓	✓	✓

Table 6.13 Mandatory Modulation and Coding Combinations $N_{inner} = 16200$ Bits

Code Rate/ Constellation	2/ 15	3/ 15	4/ 15	5/ 15	6/ 15	7/ 15	8/ 15	9/ 15	10/ 15	11/ 15	12/ 15	13/ 15
QPSK	✓		✓	✓	✓	✓	✓	✓				
16QAM				✓	✓	✓	✓	✓		✓		
64QAM					✓	✓	✓	✓	✓	✓		
256QAM						✓	✓	✓	✓	✓	✓	✓

See e.g., ATSC 3.0 Standard: Physical Layer Protocol (A/322), pg. 30-31,

<https://muygs2x2vzb2pik6g160f1s8-wpengine.netdna-ssl.com/wp-content/uploads/2021/04/A322-2021-Physical-Layer-Protocol.pdf>

6.3.1 Constellation Overview

Six different modulation orders are defined: uniform QPSK modulation and five non-uniform constellation (NUC) sizes: 16QAM, 64QAM, 256QAM, 1024QAM and 4096QAM respectively. For each combination of NUC modulation order and code rate a different constellation exists.

See e.g., ATSC 3.0 Standard: Physical Layer Protocol (A/322), pg. 30, <https://muygs2x2vzb2pik6g160f1s8-wpengine.netdna-ssl.com/wp-content/uploads/2021/04/A322-2021-Physical-Layer-Protocol.pdf>

"each of the plurality of unequally spaced symbol constellations is only included in one of the plurality of predetermined LDPC code rate and unequally spaced symbol constellation pairs."

2D each of the plurality of unequally spaced symbol constellations is only included in one of the plurality of predetermined LDPC code rate and unequally spaced symbol constellation pairs.	Each of the plurality of specified ATSC 3.0 unequally spaced symbol constellations is only included in one of the predetermined LDPC code rate and unequally spaced symbol constellation pairs. 6.3.1 Constellation Overview Six different modulation orders are defined: uniform QPSK modulation and five non-uniform constellation (NUC) sizes: 16QAM, 64QAM, 256QAM, 1024QAM and 4096QAM respectively. For each combination of NUC modulation order and code rate a different constellation exists. See e.g., ATSC 3.0 Standard: Physical Layer Protocol (A/322), pg. 30, https://muygs2xvhhb2pik6g160f1s8-wpengine.netdna-ssl.com/wp-content/uploads/2021/04/A322-2021-Physical-Layer-Protocol.pdf The ATSC Guidelines further describe that there is only one non-uniform constellation defined for each code rate/constellation pair. 5.2.3 Constellation Mapping There is one non-uniform constellation (NUC) defined for each ModCod combination (see Section 6.3 and Annex C of [3]). The interleaved LDPC codeword as the output bits of the block interleaver is mapped onto the defined constellation points. For implementation, a look-up table with the defined constellation mapping for each ModCod combination can be used. See e.g., ATSC Recommended Practice: Guidelines for the Physical Layer Protocol (A/327), pg. 32, https://www.atsc.org/wp-content/uploads/2018/10/A327-2018-Physical-Layer-RP.pdf
---	--

" The communication system of claim 2, wherein the plurality of predetermined LDPC code rate and unequally spaced symbol constellation pairs includes: multiple LDPC code rate and unequally spaced constellation pairs that each include an LDPC code rate below 1/3 and a sixty-four-point unequally spaced symbol constellation of the first type;"

3A The communication system of claim 2, wherein the plurality of predetermined LDPC code rate and unequally spaced symbol constellation pairs includes: multiple LDPC code rate and unequally spaced constellation pairs that each include an LDPC code rate below 1/3 and a sixty-four-point unequally spaced symbol constellation of the first type;	The plurality of predetermined code rate/constellation pairs specified by ATSC 3.0 includes multiple code rate/constellation pairs that have an LDPC code rate below 1/3, and a 64QAM constellation that has at least two constellation points having locations that are the same and different labels (the first type). For example, as confirmed in detail in the constellation tables and figures cited above, ATSC 3.0 specifies at least two code rate/constellations pairs with 64 point symbol constellations of the first type: 64QAM at code rate 3/15, and 64 QAM at code rate 4/15. Both of these pairs include a code rate below 1/3, which is equivalent to 5/15. See e.g., ATSC 3.0 Standard: Physical Layer Protocol (A/322), Annex C, pg. 165, 173, https://muygs2x2vhhb2pik6g160f1s8-wpengine.netdna-ssl.com/wp-content/uploads/2021/04/A322-2021-Physical-Layer-Protocol.pdf
---	--

"multiple LDPC code rate and unequally spaced symbol constellation pairs that each include an LDPC code rate below $5/8$ and a two-hundred-and-fifty-six-point unequally spaced symbol constellation of the first type; and"

3B multiple LDPC code rate and unequally spaced symbol constellation pairs that each include an LDPC code rate below $5/8$ and a two-hundred-and-fifty-six-point unequally spaced symbol constellation of the first type; and	The plurality of predetermined code rate/constellation pairs specified by ATSC 3.0 includes multiple code rate/constellation pairs that have an LDPC code rate below $5/8$, and a 256 point constellation that has at least two constellation points having locations that are the same and different labels (the first type). For example, as confirmed in detail in the constellation tables and figures cited above, ATSC 3.0 specifies at least four code rate/constellations pairs with 256 point symbol constellations of the first type: 256QAM at code rate $3/15$, 256QAM at code rate $5/15$, 256QAM at code rate $7/15$, and 256QAM at code rate $8/15$. All of these pairs include a code rate below $5/8$, which has a decimal equivalent of 0.625. See e.g., ATSC 3.0 Standard: Physical Layer Protocol (A/322), Annex C, pg. 166-168, 173, https://muygs2x2vnb2pjk6g160f1s8-wpengine.netdna-ssl.com/wp-content/uploads/2021/04/A322-2021-Physical-Layer-Protocol.pdf
--	--

" multiple LDPC code rate and unequally spaced symbol constellation pairs that each include an LDPC code rate below 7/10 and a one-thousand-twenty-four-point unequally spaced symbol constellation of the first type."

3C multiple LDPC code rate and unequally spaced symbol constellation pairs that each include an LDPC code rate below 7/10 and a one-thousand-twenty-four-point unequally spaced symbol constellation of the first type.	The plurality of predetermined code rate/constellation pairs specified by ATSC 3.0 includes multiple code rate/constellation pairs that have an LDPC code rate below 7/10, and a 1024 point constellation that has at least two constellation points having locations that are the same and different labels (the first type). For example, as confirmed in detail in the constellation tables and figures cited above, ATSC 3.0 specifies at least four code rate/constellations pairs with 1024 point symbol constellations of the first type: 1024QAM at code rate 2/15, 1024QAM at code rate 3/15, 1024QAM at code rate 8/15, and 1024QAM at code rate 9/15. All of these pairs include a code rate below 7/10, which has a decimal equivalent of 0.7. See e.g., ATSC 3.0 Standard: Physical Layer Protocol (A/322), Annex C, pg. 169, 174, https://muygs2xvhb2pjk6g160f1s8-wpengine.netdna-ssl.com/wp-content/uploads/2021/04/A322-2021-Physical-Layer-Protocol.pdf
--	--

"4. The communication system of claim 3, wherein the receiver is capable of decoding the signals received over the communication channel when the SNR of the communication channel is: equal to or less than 5.27dB while using an LDPC code rate and unequally spaced symbol constellation pair that includes an LDPC code rate that is below 1/3 and a sixty-four-point unequally spaced symbol constellation of the first type;"

4A

The communication system of claim 3, wherein the receiver is capable of decoding the signals received over the communication channel when the SNR of the communication channel is: equal to or less than 5.27dB while using an LDPC code rate and unequally spaced symbol constellation pair that includes an LDPC code rate that is below 1/3 and a sixty-four-point unequally spaced symbol constellation of the first type;

ATSC 3.0 specifies specific code rate/constellation pairs. Required SNRs are also specified for those pairs. When the SNR of the communication channel is at the required SNR, an ATSC 3.0 compliant receiver is capable of decoding the signals received over the communication channel. For those pairs identified as having an LDPC code rate below 1/3, and a 64 point constellation of the first type, the specified SNRs are equal or less than 5.27 dB.

64QAM – 3/15, 4/15

Table 4.3 Required SNRs (dB) for all ModCod Combinations, Long LDPC codes (64800 bits) and AWGN Channel

Constellation	Code Rate													
	2/15	3/15	4/15	5/15	6/15	7/15	8/15	9/15	10/15	11/15	12/15	13/15	14/15	15/15
QPSK	-8.23	-4.32	-2.89	-1.70	-0.54	0.30	1.16	1.97	2.77	3.60	4.49	5.53	6.53	7.53
16QAM	-2.73	-0.25	1.48	2.82	4.21	5.21	6.30	7.32	8.36	9.50	10.57	11.83	13.03	14.28
64QAM	-0.26	2.27	4.15	5.96	7.66	8.92	10.31	11.55	12.68	14.28	15.57	17.03	18.33	19.58

...

Table 4.5 Required SNRs (dB) for all ModCod Combinations, Short LDPC Codes (16200 bits) and AWGN Channel

Constellation	Code Rate													
	2/15	3/15	4/15	5/15	6/15	7/15	8/15	9/15	10/15	11/15	12/15	13/15	14/15	15/15
QPSK	-5.55	-3.73	-2.32	-1.30	-0.33	0.56	1.38	2.20	2.94	3.82	4.70	5.78	6.78	7.78
16QAM	-2.15	0.35	1.99	3.16	4.45	5.51	6.51	7.58	8.55	9.74	10.81	12.09	13.33	14.52
64QAM	0.35	2.85	4.65	6.30	7.93	9.29	10.56	11.83	13.13	14.52	15.96	17.33	18.63	19.88

...

See e.g., ATSC Recommended Practice: Guidelines for the Physical Layer Protocol (A/327), pg. 18-19, <https://www.atsc.org/wp-content/uploads/2018/10/A327-2018-Physical-Layer-RP.pdf>

"equal to or less than 15.42dB while using an LDPC code rate and unequally spaced symbol constellation pair that includes an LDPC code rate below 5/8 and a two-hundred-fifty-six-point unequally spaced symbol constellation of the first type; and"

4B equal to or less than 15.42dB while using an LDPC code rate and unequally spaced symbol constellation pair that includes an LDPC code rate below 5/8 and a two-hundred-fifty-six-point unequally spaced symbol constellation of the first type; and

ATSC 3.0 specifies specific code rate/constellation pairs. Required SNRs are also specified for those pairs. When the SNR of the communication channel is at the required SNR, an ATSC 3.0 compliant receiver is capable of decoding the signals received over the communication channel. For those pairs identified as having an LDPC code rate below 5/8, and a 256 point constellation of the first type, the specified SNRs are equal or less than 15.42 dB.

256QAM – 3/15, 5/15, 7/15, 8/15

Table 4.3 Required SNRs (dB) for all ModCod Combinations, Long LDPC codes (64800 bits) and AWGN Channel

Constellation	Code Rate											
	2/15	3/15	4/15	5/15	6/15	7/15	8/15	9/15	10/15	11/15	12/15	13/15
...												
256QAM	1.80	4.30	8.57	13.53	18.81	24.10	29.91	35.55	41.13	46.78	52.44	58.22
...												

Table 4.5 Required SNRs (dB) for all ModCod Combinations, Short LDPC Codes (16200 bits) and AWGN Channel

Constellation	Code Rate											
	2/15	3/15	4/15	5/15	6/15	7/15	8/15	9/15	10/15	11/15	12/15	13/15
...												
256QAM	2.27	4.78	7.19	9.93	12.91	15.80	18.78	21.75	24.78	27.78	30.78	33.78
...												

See e.g., ATSC Recommended Practice: Guidelines for the Physical Layer Protocol (A/327), pg. 18-19, <https://www.atsc.org/wp-content/uploads/2018/10/A327-2018-Physical-Layer-RP.pdf>

" equal to or less than 21.52dB while using an LDPC code rate and unequally spaced symbol constellation pair that includes an LDPC code rate below 7/10 and a one-thousand-and-twenty-four-point unequally spaced symbol constellations of the first type."

4C equal to or less than 21.52dB while using an LDPC code rate and unequally spaced symbol constellation pair that includes an LDPC code rate below 7/10 and a one-thousand-and-twenty-four-point unequally spaced symbol constellations of the first type.

1024QAM – 2/15, 3/15, 8/15, 9/15

Table 4.3 Required SNRs (dB) for all ModCod Combinations, Long LDPC codes (64800 bits) and AWGN Channel

Constellation	Code Rate											
	2/15	3/15	4/15	5/15	6/15	7/15	8/15	9/15	10/15	11/15	12/15	13/15
...												
1024QAM	13.23	15.17	16.77	11.07	13.46	15.30	17.48	19.45	21.35	23.43	25.52	27.62
...												

See e.g., ATSC Recommended Practice: Guidelines for the Physical Layer Protocol (A/327), pg. 18-19, <https://www.atsc.org/wp-content/uploads/2018/10/A327-2018-Physical-Layer-RP.pdf>

"5. The communication system of claim 4, wherein: the plurality of unequally spaced symbol constellations include a plurality of unequally spaced constellations of a second type that comprises multiple different sixteen-point symbol constellations, multiple different sixty-four-point symbol constellations, multiple different two-hundred-fifty-six-point symbol constellations, and multiple different one-thousand-twenty-four-point symbol constellations;"

5A 5. The communication system of claim 4, wherein: the plurality of unequally spaced symbol constellations include a plurality of unequally spaced constellations of a second type that comprises multiple different sixteen-point symbol constellations, multiple different sixty-four-point symbol constellations, multiple different two-hundred-fifty-six-point symbol constellations, and multiple different one-thousand-twenty-four-point symbol constellations;	As shown above, ATSC 3.0 specifies certain unequally spaced symbol constellations to be used, including a plurality of unequally spaced symbol constellations. The unequally spaced constellations specified in ATSC 3.0 include a plurality of unequally spaced symbol constellations of a second type that comprises multiple different 16QAM, 64QAM, 256QAM and 1024QAM constellations. For brevity, those constellations are not repeated here. ATSC 3.0 specifies a plurality of constellations including non-uniform 16QAM, 64QAM, 256QAM, 1024QAM and 4096QAM constellations. 6.3.1 Constellation Overview Six different modulation orders are defined: uniform QPSK modulation and five non-uniform constellation (NUC) sizes: 16QAM, 64QAM, 256QAM, 1024QAM and 4096QAM respectively. For each combination of NUC modulation order and code rate a different constellation exists. However, the constellation does not vary with code length, the same constellation is used for both $N_{inner}=64800$ and $N_{inner}=16200$ codes when the code rate and modulation order are held constant. The same QPSK constellation is used for all code rates. The QPSK constellation is a 1-dimensional QAM form. The non-uniform constellations 16QAM, 64QAM and 256QAM are 2-dimensional (2D) quadrant-symmetric QAM constellations and are constructed by symmetry from a single quadrant. To reduce the complexity during QAM de-mapping at the receiver, the 1024QAM and 4096QAM constellations are derived from non-uniform 1-dimensional (1D) PAM (pulse amplitude modulation) constellations for both in-phase (I) and quadrature (Q) components. 6.3.2 Modulation and Coding Combinations In order to reduce the implementation complexity, implementation of all the modulation and coding combinations is not mandatory. Table 6.12 and Table 6.13 show the mandatory modulation and coding combinations that must be implemented. Mandatory combinations are shown with a check mark ✓.
---	---

- "5. The communication system of claim 4, wherein: the plurality of unequally spaced symbol constellations include a plurality of unequally spaced constellations of a second type that comprises multiple different sixteen-point symbol constellations, multiple different sixty-four-point symbol constellations, multiple different two-hundred-fifty-six-point symbol constellations, and multiple different one-thousand-twenty-four-point symbol constellations;"

Table 6.12 Mandatory Modulation and Coding Combinations $N_{inner} = 64800$ Bits

Code Rate/ Constellation	2/ 15	3/ 15	4/ 15	5/ 15	6/ 15	7/ 15	8/ 15	9/ 15	10/ 15	11/ 15	12/ 15	13/ 15
QPSK	✓	✓	✓	✓	✓	✓	✓	✓		✓		
16QAM			✓	✓		✓	✓	✓		✓		
64QAM		✓	✓	✓	✓	✓	✓	✓	✓	✓		
256QAM			✓	✓		✓	✓	✓	✓	✓	✓	✓
1024QAM				✓		✓	✓	✓	✓	✓	✓	✓
4096QAM						✓	✓	✓		✓	✓	✓

Table 6.13 Mandatory Modulation and Coding Combinations $N_{inner} = 16200$ Bits

Code Rate/ Constellation	2/ 15	3/ 15	4/ 15	5/ 15	6/ 15	7/ 15	8/ 15	9/ 15	10/ 15	11/ 15	12/ 15	13/ 15
QPSK	✓	✓	✓	✓	✓	✓	✓	✓				
16QAM				✓	✓	✓	✓			✓		
64QAM				✓	✓	✓	✓	✓	✓	✓		
256QAM				✓		✓	✓	✓	✓	✓	✓	✓

See e.g., ATSC 3.0 Standard: Physical Layer Protocol (A/322), Annex C, pg. 30-31; see also Annex C, pg. 164-174, <https://muygs2x2vnb2pjk6g160f1s8-wpengine.netdna-ssl.com/wp-content/uploads/2021/04/A322-2021-Physical-Layer-Protocol.pdf>

" no two constellation points within an unequally spaced symbol constellation of the second type share locations that are the same "

5B no two constellation points within an unequally spaced symbol constellation of the second type share locations that are the same;	The ATSC 3.0 specified unequally spaced constellations include 16QAM, 64QAM, 256QAM and 1024 QAM constellations where no two constellation points share locations that are the same (second type). These include the following constellations (identified by code rate/constellation pair): 16QAM – 2/15 through 13/15 64QAM – 2/15, 5/15 through 13/15 256QAM – 2/15, 4/15, 6/15, 9/15 through 13/15 1024QAM – 4/15, 5/15, 6/15, 7/15, 10/15, 11/15, 12/15, 13/15
--	---

" the demapper is also capable of determining likelihoods using the demodulated signal and an unequally spaced symbol constellation of the second type; and "

5C the demapper is also capable of determining likelihoods using the demodulated signal and an unequally spaced symbol constellation of the second type; and

ATSC 3.0 specifies specific unequally spaced constellations, including the unequally spaced constellations of the second type identified above. The demapper in an ATSC compliant receiver is capable of determining likelihoods using the demodulated signal and an unequally spaced symbol constellation having no points sharing the same location (the second type).

ATSC 3.0 compliant receivers include a demapper (CL Symbol De-mapper), coupled to the demodulator (OFDM Demod) that is capable of estimating likelihoods (Log Likelihood-Ratios, LLR) using the demodulated signal and a non-uniform symbol constellation of the second type.

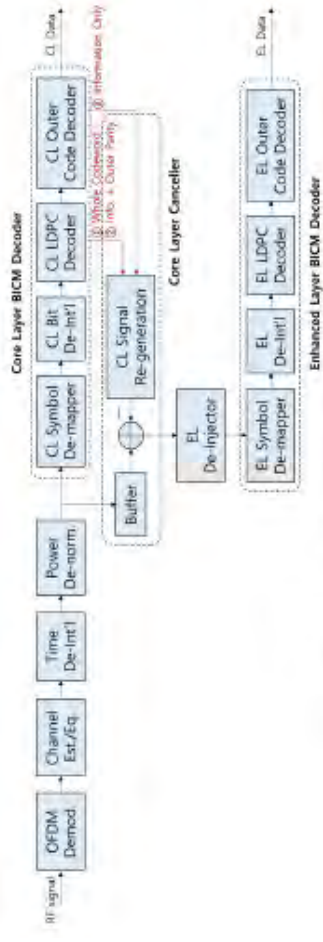


Figure 6.6 LDM decoding block diagram.

See e.g., ATSC Recommended Practice: Guidelines for the Physical Layer Protocol (A/327), pg. 71, <https://www.atsc.org/wp-content/uploads/2018/10/A327-2018-Physical-Layer-RP.pdf>

For example, the ATSC receiver guidelines specify using a demapper to calculate Log Likelihood-Ratios (LLR) from the I and Q components of the demodulated signals.

" the demapper is also capable of determining likelihoods using the demodulated signal and an unequally spaced symbol constellation of the second type; and "

6.5 Channel Decoding

The channel decoding process includes the de-mapping of NUCs, bit de-interleaving, and inner/outer decoding. After the de-mapping of NUCs, values which correspond to the bit-interleaved code words in the transmitter are fed to the bit de-interleaver, and then to the inner/outer decoders. Note that these values are often called channel values and they may be obtained in hard or soft decision form in receivers.

6.5.1 LLR De-Mapping for Non-Uniform Constellations

For optimal performance in decoding, the de-mapping of NUCs may be performed via soft decision such as Log Likelihood-Ratios (LLRs) calculation. In ATSC 3.0, two types of non-uniform constellations (NUC) are used: 1-dimensional (1D-NUC) and 2-dimensional (2D-NUC). When 1D-NUCs are used, the LLRs can be calculated using the well-known one-dimensional demapper described in Section 6.5.1.1. In the case of 2D-NUCs, the derivation of the LLRs is shown in Section 6.5.1.2.

6.5.1.1 De-Mapping for 1D-NUC

In the cases of 1D-NUCs (QPSK, 1024QAM and 4096QAM), a receiver may form LLRs as a function of two non-uniform 1-dimensional pulse amplitude modulation (PAM) constellations representing the in-phase (I) and quadrature (Q) components of the 1D-NUC. A 2-dimensional demapper can be also applied but with higher computational expense. Considering that a QAM constellation conveys m coded bits, i.e., each constellation component has $\sqrt{2^m}$ possible states, the structure of the de-mapper is shown in Figure 6.9.

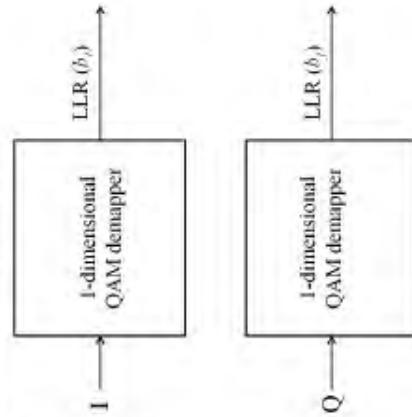


Figure 6.9 De-mapper structure for 1D-NUC.

See e.g., ATSC Recommended Practice: Guidelines for the Physical Layer Protocol (A/327), pg. 73-74, <https://www.atsc.org/wp-content/uploads/2018/10/A327-2018-Physical-Layer-RP.pdf>

" the demapper is also capable of determining likelihoods using the demodulated signal and an unequally spaced symbol constellation of the second type; and "

6.5.1.2 De-Mapping for 2D-NUC

In the case of 2D-NUCs (16QAM, 64QAM and 256QAM), LLRs may be calculated as a 2-dimensional function. The structure of the de-mapper is shown in Figure 6.10.



Figure 6.10 De-mapper structure for 2D-NUC.

See e.g., ATSC Recommended Practice: Guidelines for the Physical Layer Protocol (A/327), pg. 76, <https://www.atsc.org/wp-content/uploads/2018/10/A327-2018-Physical-Layer-RP.pdf>

" the plurality of predetermined LDPC code rate and unequally spaced symbol constellation pairs include: multiple LDPC code rate and unequally spaced symbol constellation pairs that each include an LDPC code rate that is equal to or greater than 3/8 and less than or equal to 6/8 and a sixteen-point unequally spaced symbol constellation of the second type;"

5D the plurality of predetermined LDPC code rate and unequally spaced symbol constellation pairs include: multiple LDPC code rate and unequally spaced symbol constellation pairs that each include an LDPC code rate that is equal to or greater than 3/8 and less than or equal to 6/8 and a sixteen-point unequally spaced symbol constellation of the second type;

The plurality of predetermined ATSC 3.0 code rate/constellation pairs of a second type include multiple code rate/constellation pairs that each include an LDPC code rate that is equal to or greater than 3/8 (0.375) and less than or equal to 6/8 (0.75) and a 16QAM symbol constellation.

16QAM – 6/15 through 11/15

For example, as confirmed in detail in the constellation tables and figures cited above, ATSC 3.0 specifies multiple code rate/constellations pairs with 16 point symbol constellations of the second type: 16QAM at code rate 6/15, 16QAM at code rate 7/15, 16QAM at code rate 8/15, 16QAM at code rate 9/15, 16QAM at code rate 10/15, and 16QAM at code rate 11/15. All of these pairs include a code rate that is equal to or greater than 3/8 (0.375) and less than or equal to 6/8 (0.75).

Table C.I.2 16QAM Definition Table for Code Rates 2/15-7/15

w/CR	2/15	3/15	4/15	5/15	6/15	7/15
w0	0.7062+j0.7075	0.3620+j0.5634	0.3412+j0.5241	0.3192+j0.5011	0.5115+j1.2092	0.2592+j0.4888
w1	0.7075+j0.7062	0.5634+j0.3620	0.5241+j0.3412	0.5011+j0.3192	1.2092+j0.5115	0.4888+j0.2592
w2	0.7072+j0.7077	0.5840+j1.1000	0.5797+j1.1282	0.5575+j1.1559	0.2863+j0.4530	0.5072+j1.1980
w3	0.7077+j0.7072	1.1000+j0.5840	1.1282+j0.5797	1.1559+j0.5575	0.4530+j0.2863	1.1980+j0.5072

Table C.I.3 16QAM Definition Table for Code Rates 8/15-13/15

w/CR	8/15	9/15	10/15	11/15	12/15	13/15
w0	0.2535+j0.4923	0.2386+j0.5286	0.4487+j1.1657	0.9342+j0.9947	0.9555+j0.9555	0.9517+j0.9511
w1	0.4923+j0.2535	0.5286+j0.2386	1.2080+j0.5377	0.9886+j0.2903	0.9555+j0.2949	0.9524+j0.3061
w2	0.4927+j1.2044	0.4882+j1.1934	0.2213+j0.4416	0.2716+j0.9325	0.2949+j0.9555	0.3087+j0.9524
w3	1.2044+j0.4927	1.1934+j0.4882	0.6186+j0.2544	0.2901+j0.2885	0.2949+j0.2949	0.3061+j0.3067

...

" the plurality of predetermined LDPC code rate and unequally spaced symbol constellation pairs include: multiple LDPC code rate and unequally spaced symbol constellation pairs that each include an LDPC code rate that is equal to or greater than 3/8 and less than or equal to 6/8 and a sixteen-point unequally spaced symbol constellation of the second type;"

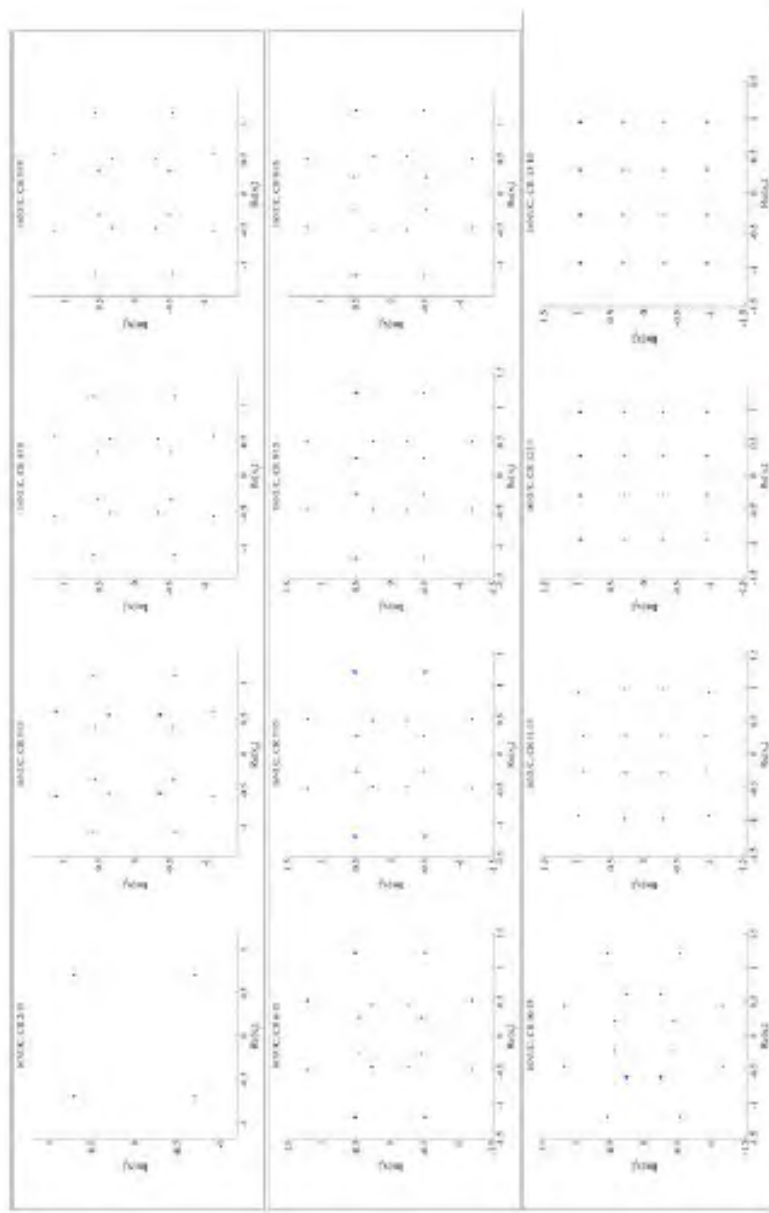


Figure C.2.2 Constellations of 16QAM.

See e.g., ATSC 3.0 Standard: Physical Layer Protocol (A/322), Annex C, pg. 164, 172,
<https://muygs2x2vnb2pjk6g160f1s8-wpengine.netdna-ssl.com/wp-content/uploads/2021/04/A322-2021-Physical-Layer-Protocol.pdf>

"multiple LDPC code rate and unequally spaced symbol constellation pairs that each include an LDPC code rate that is equal to or greater than 3/6 and less than or equal to 5/6 and a sixty-four-point unequally spaced symbol constellation of the second type;"

The plurality of predetermined ATSC 3.0 code rate/constellation pairs of a second type include multiple code rate/constellation pairs that each include an LDPC code rate that is equal to or greater than 3/6 (0.50) and less than or equal to 5/6 (0.833) and a 64QAM symbol constellation

For example, as confirmed in detail in the constellation tables and figures cited above, ATSC 3.0 specifies multiple code rate/constellations pairs with 64 point symbol constellations of the second type: 64QAM at code rate 8/15, 64QAM at code rate 9/15, 64QAM at code rate 10/15, 64QAM at code rate 11/15, and 64QAM at code rate 12/15. All of these pairs include a code rate that is equal to or greater than 3/6 (0.50) and less than or equal to 5/6 (0.833).

Table C.1.5 64QAM Definition Table for Code Rates 8/15-13/15

w/cr	8/15	9/15	10/15	11/15	12/15	13/15
w0	1.4827+j0.2920	0.1305+j0.3311	0.1177+j0.1729	1.4443+j0.2683	1.4480+j0.2403	1.4319+j0.2300
w1	1.2563+j0.8411	0.1633+j0.3162	0.1601+j0.3212	0.7471+j1.2243	0.6406+j1.1995	1.0762+j0.9250
w2	1.0211+j0.2174	0.1622+j0.7113	0.1352+j0.7279	1.1749+j0.7734	1.0952+j0.9115	0.6290+j1.1820
w3	0.8798+j0.5702	0.3905+j0.6163	0.3246+j0.6148	0.7138+j0.8201	0.6868+j0.8108	0.6851+j0.8072
w4	0.2920+j1.4827	0.3311+j0.1305	0.4192+j0.1179	0.1638+j1.0769	1.0500+j0.1642	1.0443+j0.1688
w5	0.8410+j1.2563	0.3162+j0.1633	0.4033+j0.2421	0.2927+j1.4217	0.7170+j0.1473	1.0635+j0.5305
w6	0.2174+j1.0211	0.7113+j0.1622	0.7524+j0.1581	0.1462+j0.7457	1.0519+j0.5188	0.7220+j0.1540
w7	0.5702+j0.8798	0.6163+j0.3905	0.5996+j0.4330	0.4134+j0.7408	0.7146+j0.4532	0.7151+j0.4711
w8	0.3040+j0.1475	0.2909+j1.4626	0.2902+j1.4611	1.0203+j0.1517	0.1677+j1.0405	0.2099+j1.4205
w9	0.3028+j0.1691	0.8285+j1.2399	0.8180+j1.2291	0.6653+j0.1357	0.2402+j1.4087	0.1190+j0.6677
w10	0.6855+j0.1871	0.2062+j1.0367	0.2036+j1.0575	0.9639+j0.4465	0.1369+j0.7073	0.2031+j1.0551
w11	0.6126+j0.3563	0.5872+j0.8789	0.5641+j0.8965	0.6746+j0.4339	0.4044+j0.7057	0.3722+j0.7548
w12	0.1475+j0.3040	1.4626+j0.2909	1.4453+j0.2907	0.1271+j0.1428	0.1374+j0.1295	0.1438+j0.1287
w13	0.1691+j0.3028	1.2399+j0.8285	1.2157+j0.8186	0.3782+j0.1406	0.4186+j0.1357	0.1432+j0.3903
w14	0.1871+j0.6855	1.0367+j0.2062	1.0447+j0.2242	0.1311+j0.4288	0.1325+j0.3998	0.4298+j0.1384
w15	0.3563+j0.6126	0.8789+j0.5872	0.8497+j0.6176	0.3919+j0.4276	0.4122+j0.4120	0.4215+j0.4279

...

"multiple LDPC code rate and unequally spaced symbol constellation pairs that each include an LDPC code rate that is equal to or greater than 3/6 and less than or equal to 5/6 and a sixty-four-point unequally spaced symbol constellation of the second type;"

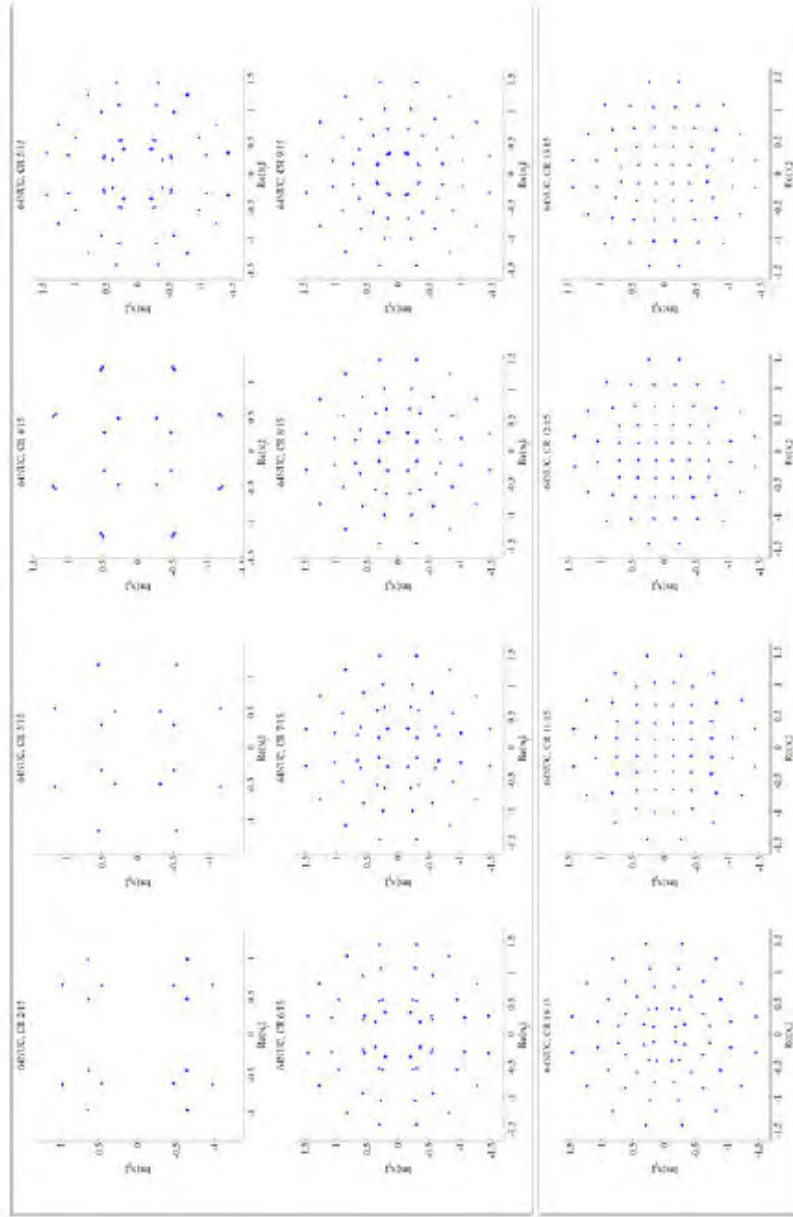


Figure C.2.3 Constellations of 64QAM.

See e.g., ATSC 3.0 Standard: Physical Layer Protocol (A/322), Annex C, pg. 165, 173,
<https://muygs2x2vzb2pjk6g160f1s8-wpengine.netdna-ssl.com/wp-content/uploads/2021/04/A322-2021-Physical-Layer-Protocol.pdf>

"multiple LDPC code rate and unequally spaced symbol constellation pairs that each include an LDPC code rate that is equal to or greater than 6/8 and less than or equal to 7/8 and a two-hundred-and-fifty-six-point unequally spaced symbol constellation of the second type; and"

5F

multiple LDPC code rate and unequally spaced symbol constellation pairs that each include an LDPC code rate that is equal to or greater than 6/8 and less than or equal to 7/8 and a two-hundred-and-fifty-six-point unequally spaced symbol constellation of the second type; and

The plurality of predetermined ATSC 3.0 code rate/constellation pairs of a second type include multiple code rate/constellation pairs that each include an LDPC code rate that is equal to or greater than 6/8 (0.75) and less than or equal to 7/8 (0.875) and a 256QAM symbol constellation

For example, as confirmed in detail in the constellation tables and figures cited above, ATSC 3.0 specifies multiple code rate/constellations pairs with 256 point symbol constellations of the second type: 256QAM at code rate 12/15, and 256QAM at code rate 13/15. All of these pairs include a code rate that is equal to or greater than 6/8 (0.75) and less than or equal to 7/8 (0.875).

Table C.1.7 256QAM Definition Table for Code Rates 8/15-13/15

w/Shape	NUC_256_8/15	NUC_256_9/15	NUC_256_10/15	NUC_256_11/15	NUC_256_12/15	NUC_256_13/15
w0	0.0995+j0.2435	0.0899+j0.1337	0.0754+j0.2310	0.0593+j0.2193	1.1980+j1.1541	1.2412+j1.0688
w1	0.0996+j0.2434	0.0910+j0.1377	0.0768+j0.2305	0.0690+j0.3047	0.9192+j1.2082	1.2668+j0.8034
w2	0.1169+j0.3886	0.0873+j0.3862	0.0924+j0.4136	0.0663+j0.4879	1.2778+j0.8523	0.9860+j1.1758
w3	0.1179+j0.3883	0.0883+j0.3873	0.1043+j0.4125	0.1151+j0.4474	1.0390+j0.9253	1.0365+j0.9065
w4	0.1192+j0.2345	0.1115+j0.1442	0.0829+j0.1135	0.1689+j0.2163	0.6057+j1.2200	1.2111+j0.5135
w5	0.1192+j0.2345	0.1135+j0.1472	0.0836+j0.1149	0.1971+j0.2525	0.7371+j1.4217	1.4187+j0.6066
w6	0.1953+j0.3558	0.2067+j0.3591	0.2682+j0.3856	0.3096+j0.3796	0.6678+j1.0021	1.0103+j0.4879
w7	0.1944+j0.3563	0.1975+j0.3621	0.2531+j0.3906	0.2489+j0.3933	0.8412+j0.9448	1.0380+j0.6906
w8	0.1293+j0.7217	0.1048+j0.7533	0.0836+j0.7817	0.0790+j0.7970	1.2128+j0.5373	0.6963+j1.3442
w9	0.1616+j0.7151	0.1770+j0.7412	0.2052+j0.7608	0.2340+j0.7710	1.0048+j0.5165	0.7089+j1.1122
w10	0.1287+j0.6355	0.1022+j0.5904	0.0838+j0.6034	0.0723+j0.6395	1.4321+j0.6343	0.1256+j1.4745
w11	0.1456+j0.6318	0.1191+j0.5890	0.1394+j0.5961	0.1896+j0.6163	1.0245+j0.7152	0.8331+j0.9455
w12	0.4191+j0.6016	0.4264+j0.6230	0.4861+j0.6331	0.5090+j0.6272	0.6384+j0.6073	0.6615+j0.6012
w13	0.3916+j0.6198	0.3650+j0.6689	0.3661+j0.7034	0.3787+j0.7126	0.8175+j0.5684	0.6894+j0.7594
w14	0.3585+j0.5403	0.3254+j0.5153	0.3732+j0.5159	0.4079+j0.5049	0.6568+j0.7801	0.8373+j0.5633
w15	0.3439+j0.5497	0.2959+j0.5302	0.3095+j0.5511	0.3088+j0.5677	0.8311+j0.7459	0.8552+j0.7410
w16	0.2435+j0.0995	0.3256+j0.0768	0.3030+j0.0811	0.0675+j0.0626	0.1349+j1.4742	1.2666+j0.1027
w17	0.2434+j0.0996	0.3266+j0.0870	0.3017+j0.0853	0.3475+j0.0595	0.1105+j1.2309	1.4915+j0.1198
w18	0.3886+j0.1169	0.4721+j0.0994	0.4758+j0.0932	0.5482+j0.0626	0.0634+j0.9796	1.0766+j0.0945
w19	0.3883+j0.1179	0.4721+j0.1206	0.4676+j0.1242	0.4784+j0.1124	0.1891+j1.0198	0.9007+j0.0848
w20	0.2345+j0.1192	0.2927+j0.1267	0.2425+j0.1081	0.1674+j0.0751	0.4142+j1.4461	1.2454+j0.3064
w21	0.2345+j0.1192	0.2947+j0.1296	0.2447+j0.1115	0.2856+j0.1132	0.3323+j1.2279	1.4646+j0.3600
w22	0.3558+j0.1953	0.3823+j0.2592	0.3837+j0.2813	0.4134+j0.3028	0.4998+j0.9827	1.0570+j0.2995
w23	0.3563+j0.1944	0.3944+j0.2521	0.3959+j0.2642	0.4235+j0.2289	0.3467+j1.0202	0.9140+j0.2530
w24	0.7217+j0.1293	0.7755+j0.1118	0.7929+j0.0859	0.8258+j0.0840	0.0680+j0.6501	0.5461+j0.0679

"multiple LDPC code rate and unequally spaced symbol constellation pairs that each include an LDPC code rate that is equal to or greater than 6/8 and less than or equal to 7/8 and a two-hundred-and-fifty-six-point unequally spaced symbol constellation of the second type; and"

w25	0.7151+j0.1616	0.7513+j0.2154	0.7662+j0.2324	0.7936+j0.2483	0.2016+j0.6464	0.5681+j0.1947
w26	0.6355+j0.1287	0.6591+j0.1033	0.6365+j0.0872	0.6788+j0.0783	0.0719+j0.8075	0.6874+j0.0537
w27	0.6318+j0.1456	0.6446+j0.1737	0.6207+j0.1757	0.6501+j0.2025	0.2088+j0.8146	0.7375+j0.1492
w28	0.6016+j0.4191	0.5906+j0.4930	0.6149+j0.5145	0.6246+j0.5211	0.4809+j0.6296	0.6290+j0.4553
w29	0.6198+j0.3916	0.6538+j0.4155	0.6987+j0.3934	0.7241+j0.3961	0.3374+j0.6412	0.6007+j0.3177
w30	0.5403+j0.3585	0.4981+j0.3921	0.5063+j0.4029	0.5144+j0.4089	0.4965+j0.8008	0.7886+j0.4231
w31	0.5497+j0.3439	0.5373+j0.3586	0.5526+j0.3356	0.5918+j0.3146	0.3431+j0.8141	0.7627+j0.2849
w32	0.1685+j1.6869	0.1630+j1.6621	0.1598+j1.6262	0.1631+j1.5801	1.2731+j0.1108	0.0816+j1.1632
w33	0.4919+j1.6211	0.4720+j1.5898	0.4733+j1.5637	0.4806+j1.5133	1.0794+j0.0977	0.0830+j0.9813
w34	0.1360+j1.3498	0.1268+j1.3488	0.1307+j1.3502	0.1260+j1.3365	1.5126+j0.1256	0.2528+j1.2315
w35	0.3914+j1.2989	0.3752+j1.2961	0.3877+j1.2983	0.3750+j1.2897	0.9029+j0.0853	0.2502+j1.0100
w36	1.0746+j1.3096	1.0398+j1.2991	1.0328+j1.2617	1.0324+j1.2029	0.5429+j0.0694	0.0732+j0.6827
w37	0.7987+j1.4940	0.7733+j1.4772	0.7675+j1.4398	0.7737+j1.3837	0.6796+j0.0559	0.0811+j0.8293
w38	0.8585+j1.0504	0.8380+j1.0552	0.8496+j1.0508	0.8350+j1.0529	0.5628+j0.1945	0.2159+j0.6673
w39	0.6419+j1.1951	0.6242+j1.2081	0.6297+j1.1967	0.6147+j1.1949	0.7326+j0.1410	0.2359+j0.8283
w40	0.1334+j0.9483	0.1103+j0.9397	0.0910+j0.9531	0.0929+j0.9596	1.2283+j0.3217	0.4302+j1.4458
w41	0.2402+j0.9271	0.2415+j0.9155	0.2649+j0.9198	0.2768+j0.9260	1.0269+j0.3261	0.5852+j0.9680
w42	0.1323+j1.0786	0.1118+j1.1163	0.1080+j1.1340	0.1095+j1.1349	1.4663+j0.3716	0.4528+j1.2074
w43	0.2910+j1.0470	0.3079+j1.0866	0.3214+j1.0926	0.3250+j1.0941	0.9085+j0.2470	0.4167+j1.0099
w44	0.5764+j0.7648	0.5647+j0.7638	0.5941+j0.7527	0.6086+j0.7556	0.6160+j0.4549	0.5035+j0.6307
w45	0.4860+j0.8252	0.4385+j0.8433	0.4371+j0.8528	0.4514+j0.8566	0.7818+j0.4247	0.5359+j0.7954
w46	0.6693+j0.8561	0.6846+j0.8841	0.7093+j0.8880	0.7161+j0.8933	0.5938+j0.3170	0.3580+j0.6532
w47	0.5348+j0.9459	0.5165+j1.0034	0.5235+j1.0090	0.5294+j1.0121	0.7600+j0.2850	0.3841+j0.8207
w48	1.6859+j0.1665	1.6489+j0.1630	1.6180+j0.1602	1.5809+j0.1471	0.0595+j0.0707	0.0576+j0.0745
w49	1.6211+j0.4919	1.5848+j0.4983	1.5540+j0.4734	1.5253+j0.4385	0.1722+j0.0706	0.0581+j0.2241
w50	1.3498+j0.1360	1.3437+j0.1389	1.3411+j0.1336	1.3380+j0.1363	0.0599+j0.2119	0.1720+j0.0742
w51	1.2989+j0.3914	1.2850+j0.4025	1.2883+j0.3955	1.2837+j0.4026	0.1748+j0.2114	0.1753+j0.2222
w52	1.3096+j1.0746	1.2728+j1.0661	1.2561+j1.0337	1.2476+j0.9785	0.4134+j0.0701	0.0652+j0.5269
w53	1.4940+j0.7987	1.4509+j0.7925	1.4311+j0.7676	1.4137+j0.7196	0.2935+j0.0705	0.0611+j0.3767
w54	1.0504+j0.8585	1.0249+j0.8794	1.0362+j0.8626	1.0246+j0.8681	0.4231+j0.2066	0.1972+j0.5178
w55	1.1951+j0.6419	1.1758+j0.6545	1.1845+j0.6419	1.1771+j0.6494	0.2979+j0.2100	0.1836+j0.3695
w56	0.9483+j0.1334	0.9629+j0.1113	0.9546+j0.0957	0.9782+j0.0985	0.0638+j0.5002	0.4145+j0.0709
w57	0.9271+j0.2402	0.9226+j0.2849	0.9163+j0.2834	0.9383+j0.2922	0.1905+j0.4966	0.4266+j0.2100
w58	1.0786+j0.1323	1.1062+j0.1118	1.1282+j0.1128	1.1455+j0.1158	0.0612+j0.3552	0.2912+j0.0730
w59	1.0470+j0.2910	1.0674+j0.3393	1.0838+j0.3340	1.0972+j0.3418	0.1810+j0.3533	0.2982+j0.2177
w60	0.7648+j0.5764	0.7234+j0.6223	0.7329+j0.6204	0.7446+j0.6273	0.4630+j0.4764	0.4766+j0.4821
w61	0.8252+j0.4860	0.8211+j0.4860	0.8428+j0.4615	0.8573+j0.4721	0.3231+j0.4895	0.4497+j0.3448
w62	0.8561+j0.6693	0.8457+j0.7260	0.8680+j0.7295	0.8767+j0.7377	0.4416+j0.3397	0.3334+j0.5025
w63	0.9459+j0.5348	0.9640+j0.5518	0.9959+j0.5426	1.0059+j0.5518	0.3083+j0.3490	0.3125+j0.3601

...

"multiple LDPC code rate and unequally spaced symbol constellation pairs that each include an LDPC code rate that is equal to or greater than 6/8 and less than or equal to 7/8 and a two-hundred-and-fifty-six-point unequally spaced symbol constellation of the second type; and"

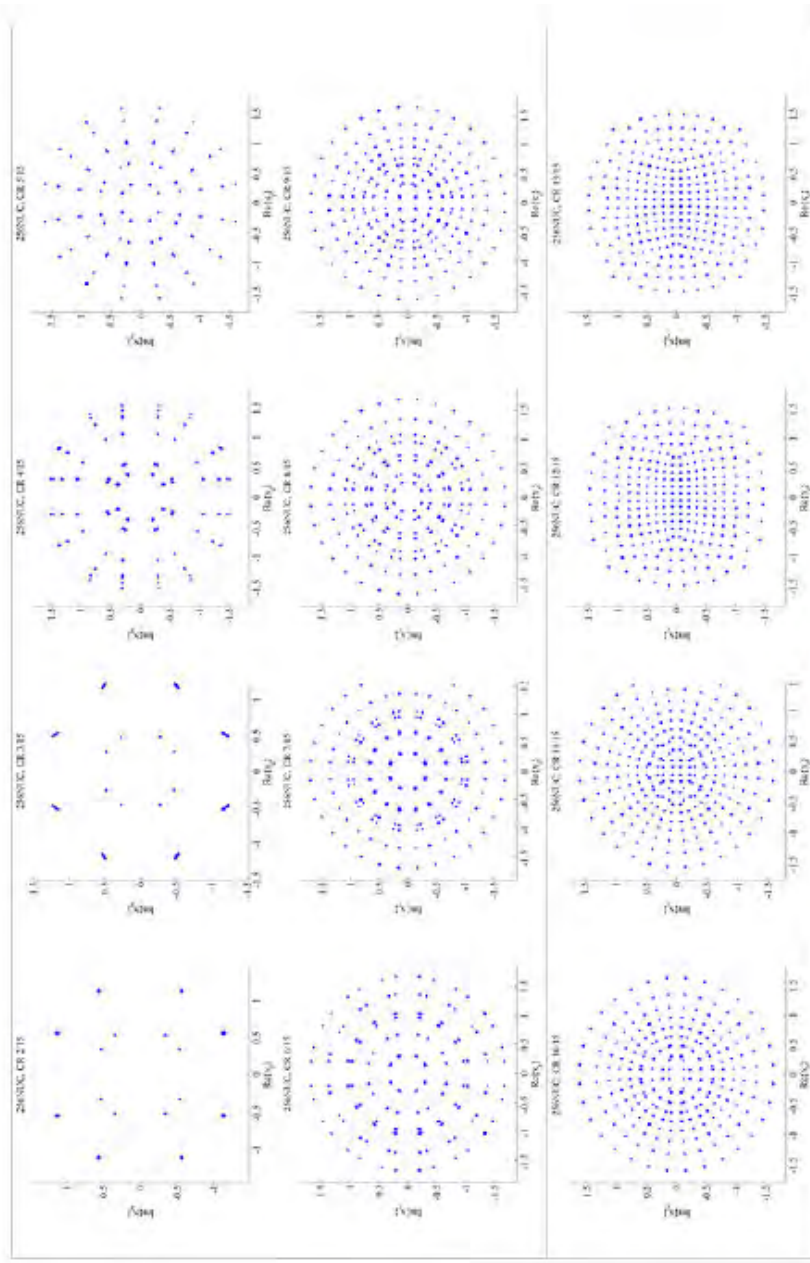


Figure C.2.4 Constellations of 256QAM.

See e.g., ATSC 3.0 Standard: Physical Layer Protocol (A/322), Annex C, pg. 166-168, 173,
<https://muygs2x2vnb2pjk6g160f1s8-wpengine.netdna-ssl.com/wp-content/uploads/2021/04/A322-2021-Physical-Layer-Protocol.pdf>

"multiple LDPC code rate and unequally spaced symbol constellation pairs that each include an LDPC code rate that is equal to or greater than 8/10 and less than or equal to 9/10 and a one-thousand-twenty-four-point unequally spaced symbol constellation of the second type;"

5G The plurality of predetermined ATSC 3.0 code rate/constellation pairs of a second type include multiple code rate/constellation pairs that each include an LDPC code rate that is equal to or greater than 8/10 (0.80) and less than or equal to 9/10 (0.90) and a 1024QAM symbol constellation

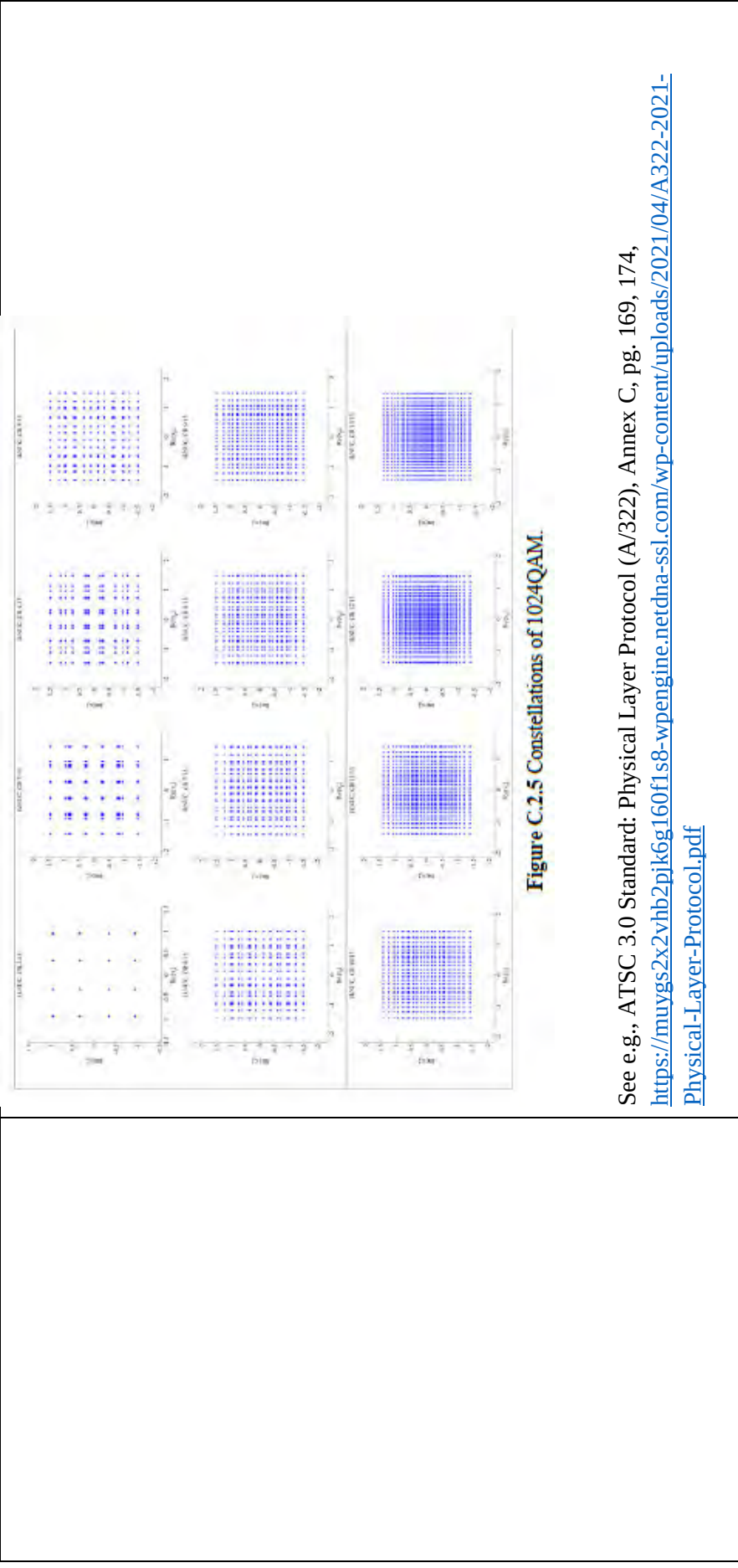
For example, as confirmed in detail in the constellation tables and figures cited above, ATSC 3.0 specifies multiple code rate/constellations pairs with 1024 point symbol constellations of the second type: 1024QAM at code rate 12/15, and 1024QAM at code rate 13/15. All of these pairs include a code rate that is equal to or greater than 8/10 (0.80) and less than or equal to 9/10 (0.90).

Table C.1.9 1024QAM Definition Table for Code Rates 8/15-13/15

w/CR	8/15	9/15	10/15	11/15	12/15	13/15
u0	0.0773	0.0638	0.0592	0.0502	0.0354	0.0325
u1	0.0773	0.0638	0.0594	0.0637	0.0921	0.0967
u2	0.1614	0.1757	0.1780	0.1615	0.1602	0.1623
u3	0.1614	0.1756	0.1790	0.1842	0.2185	0.2280
u4	0.3086	0.3069	0.2896	0.2760	0.2910	0.2957
u5	0.3085	0.3067	0.3041	0.3178	0.3530	0.3645
u6	0.4159	0.4333	0.4241	0.4040	0.4264	0.4361
u7	0.4163	0.4343	0.4404	0.4686	0.4947	0.5100
u8	0.5910	0.5765	0.5561	0.5535	0.5763	0.5878
u9	0.5872	0.5862	0.6008	0.6362	0.6531	0.6696
u10	0.7213	0.7282	0.7141	0.7293	0.7417	0.7566
u11	0.7604	0.7705	0.8043	0.8302	0.8324	0.8497
u12	0.9212	0.9218	0.9261	0.9432	0.9386	0.9498
u13	1.0349	1.0364	1.0639	1.0704	1.0529	1.0588
u14	1.2281	1.2234	1.2285	1.2158	1.1917	1.1795
u15	1.4900	1.4646	1.4309	1.3884	1.3675	1.3184

...

"multiple LDPC code rate and unequally spaced symbol constellation pairs that each include an LDPC code rate that is equal to or greater than 8/10 and less than or equal to 9/10 and a one-thousand-twenty-four-point unequally spaced symbol constellation of the second type;"



" the receiver is capable of decoding the signals received over the communication channel when the SNR of the communication channel is: between 3.11dB and 9.25dB while using at least one of the multiple LDPC code rate and unequally spaced symbol constellation pairs that each include an LDPC code rate that is equal to or greater than 3/8 and less than or equal to 6/8 and a sixteen-point unequally spaced symbol constellation of the second type;"

5H

the receiver is capable of decoding the signals received over the communication channel when the SNR of the communication channel is: between 3.11dB and 9.25dB while using at least one of the multiple LDPC code rate and unequally spaced symbol constellation pairs that each include an LDPC code rate that is equal to or greater than 3/8 and less than or equal to 6/8 and a sixteen-point unequally spaced symbol constellation of the second type;

ATSC 3.0 specifies specific code rate/constellation pairs. Required SNRs are also specified for those pairs. When the SNR of the communication channel is at the required SNR, an ATSC 3.0 compliant receiver is capable of decoding the signals received over the communication channel. For those pairs identified as having an LDPC code rate that is equal to or greater than 3/8 and less than or equal to 6/8 and a 16 point unequally spaced symbol constellation of the second type, the specified SNRs are between 3.11dB and 9.25dB.

16QAM – 6/15 through 10/15

Table 4.3 Required SNRs (dB) for all ModCod Combinations, Long LDPC codes (64800 bits) and AWGN Channel

Constellation	Code Rate											
	2/15	3/15	4/15	5/15	6/15	7/15	8/15	9/15	10/15	11/15	12/15	13/15
QPSK	-8.23	-4.32	-2.89	-1.70	-0.54	0.30	1.16	1.97	2.77	3.60	4.49	5.53
16QAM	-2.73	-0.25	1.46	2.82	4.21	5.21	6.30	7.32	8.36	9.50	10.57	11.83

...

Table 4.5 Required SNRs (dB) for all ModCod Combinations, Short LDPC Codes (16200 bits) and AWGN Channel

Constellation	Code Rate											
	2/15	3/15	4/15	5/15	6/15	7/15	8/15	9/15	10/15	11/15	12/15	13/15
QPSK	-5.55	-3.73	-2.32	-1.30	-0.33	0.58	1.38	2.20	2.94	3.82	4.70	5.78
16QAM	-2.15	0.35	1.99	3.16	4.45	5.51	6.51	7.58	8.59	9.74	10.81	12.09

...

See e.g., ATSC Recommended Practice: Guidelines for the Physical Layer Protocol (A/327), pg. 18-19, <https://www.atsc.org/wp-content/uploads/2018/10/A327-2018-Physical-Layer-RP.pdf>

" between 9.00dB and 15.93dB while using at least one of the multiple LDPC code rate and unequally spaced symbol constellation pairs that each include an LDPC code rate that is equal to or greater than 3/6 and less than or equal to 5/6 and a sixty-four-point unequally spaced symbol constellation of the second type;"

51 between 9.00dB and 15.93dB while using at least one of the multiple LDPC code rate and unequally spaced symbol constellation pairs that each include an LDPC code rate that is equal to or greater than 3/6 and less than or equal to 5/6 and a sixty-four-point unequally spaced symbol constellation of the second type;

ATSC 3.0 specifies specific code rate/constellation pairs. Required SNRs are also specified for those pairs. When the SNR of the communication channel is at the required SNR, an ATSC 3.0 compliant receiver is capable of decoding the signals received over the communication channel. For those pairs identified as having an LDPC code rate that is equal to or greater than 3/6 and less than or equal to 5/6 and a 64 point unequally spaced symbol constellation of the second type, the specified SNRs are between 9.00dB and 15.93dB.

64QAM – 8/15 through 12/15

Table 4.3 Required SNRs (dB) for all ModCod Combinations, Long LDPC codes (64800 bits) and AWGN Channel

Constellation	Code Rate											
	2/15	3/15	4/15	5/15	6/15	7/15	8/15	9/15	10/15	11/15	12/15	13/15
QPSK	-8.23	-4.32	-2.89	-1.70	-0.54	0.30	1.16	1.97	2.77	3.60	4.49	5.53
16QAM	-2.73	-0.25	1.46	2.82	4.21	5.21	6.30	7.32	8.36	9.50	10.57	1.83
64QAM	-0.26	2.27	4.15	5.96	7.68	8.92	10.31	11.55	12.84	14.28	15.57	17.03

...

Table 4.5 Required SNRs (dB) for all ModCod Combinations, Short LDPC Codes (16200 bits) and AWGN Channel

Constellation	Code Rate											
	2/15	3/15	4/15	5/15	6/15	7/15	8/15	9/15	10/15	11/15	12/15	13/15
QPSK	-5.55	-3.73	-2.32	-1.30	-0.33	0.56	1.38	2.20	2.94	3.82	4.70	7.0
16QAM	-2.15	0.35	1.99	3.16	4.45	5.51	6.51	7.58	8.59	9.74	10.81	2.09
64QAM	0.35	2.85	4.65	6.30	7.93	9.29	10.56	11.83	13.13	14.52	15.96	17.33

...

See e.g., ATSC Recommended Practice: Guidelines for the Physical Layer Protocol (A/327), pg. 18-19, <https://www.atsc.org/wp-content/uploads/2018/10/A327-2018-Physical-Layer-RP.pdf>

"between 18.72dB and 22.13dB while using at least one of the multiple LDPC code rate and unequally spaced symbol constellation pairs that each include an LDPC code rate that is equal to or greater than 6/8 and less than or equal to 7/8 and a two-hundred-and-fifty-six-point constellation of the second type"

5J between 18.72dB and 22.13dB while using at least one of the multiple LDPC code rate and unequally spaced symbol constellation pairs that each include an LDPC code rate that is equal to or greater than 6/8 and less than or equal to 7/8 and a 256 point unequally spaced symbol constellation of the second type, the specified SNRs are between 18.72dB and 22.13dB.

256QAM – 12/15

Table 4.3 Required SNRs (dB) for all ModCod Combinations, Long LDPC codes (64800 bits) and AWGN Channel

Constellation	Code Rate											
	2/15	3/15	4/15	5/15	6/15	7/15	8/15	9/15	10/15	11/15	12/15	13/15
256QAM	1.80	4.30	6.57	8.53	10.61	12.10	13.91	15.55	17.13	18.76	20.44	22.22

Table 4.5 Required SNRs (dB) for all ModCod Combinations, Short LDPC Codes (16200 bits) and AWGN Channel

Constellation	Code Rate											
	2/15	3/15	4/15	5/15	6/15	7/15	8/15	9/15	10/15	11/15	12/15	13/15
256QAM	2.27	4.78	7.19	9.33	10.91	12.57	14.25	15.80	17.45	19.08	20.78	22.55

See e.g., ATSC Recommended Practice: Guidelines for the Physical Layer Protocol (A/327), pg. 18-19, <https://www.atsc.org/wp-content/uploads/2018/10/A327-2018-Physical-Layer-RP.pdf>

" between 24.79dB and 28.20dB while using at least one of the multiple LDPC code rate and unequally spaced symbol constellation pairs that each include an LDPC code rate that is equal to or greater than 8/10 and less than or equal to 9/10 and a one-thousand-twenty-four-point unequally spaced symbol constellation of the second type."

5K between 24.79dB and 28.20dB while using at least one of the multiple LDPC code rate and unequally spaced symbol constellation pairs that each include an LDPC code rate that is equal to or greater than 8/10 and less than or equal to 9/10 and a one-thousand-twenty-four-point unequally spaced symbol constellation of the second type.

ATSC 3.0 specifies specific code rate/constellation pairs. Required SNRs are also specified for those pairs. When the SNR of the communication channel is at the required SNR, an ATSC 3.0 compliant receiver is capable of decoding the signals received over the communication channel. For those pairs identified as having an LDPC code rate that is equal to or greater than 8/10 and less than or equal to 9/10 and a 1024 point unequally spaced symbol constellation of the second type, the specified SNRs are between 24.79dB and 28.20dB.

1024QAM – 12/15, 13/15

Table 4.3 Required SNRs (dB) for all ModCod Combinations, Long LDPC codes (64800 bits) and AWGN Channel

Constellation	Code Rate											
	2/15	3/15	4/15	5/15	6/15	7/15	8/15	9/15	10/15	11/15	12/15	13/15
1024QAM	3.23	6.17	8.77	11.07	13.49	15.30	17.46	19.46	21.35	23.43	25.52	27.62

See e.g., ATSC Recommended Practice: Guidelines for the Physical Layer Protocol (A/327), pg. 18-19, <https://www.atsc.org/wp-content/uploads/2018/10/A327-2018-Physical-Layer-RP.pdf>

U.S. Patent No. 11,019,509; Claim 6

the non-uniform symbol constellation is selected from a plurality of unequally spaced symbol constellations; and "

6A 6. The communication system of claim 1, wherein: the non-uniform symbol constellation is selected from a plurality of unequally spaced symbol constellations; and	As shown above, ATSC 3.0 specifies certain non-uniform symbol constellations to be used, including a plurality of unequally spaced symbol constellations. As shown in more detail above with reference to claim element 1D, the non-uniform symbol constellation that the demapper is capable using to determine likelihoods (that includes at least two constellation points that have identical locations and different labels) is selected from a plurality of non-uniform symbol constellations specified in ATSC 3.0. For brevity, those constellations are not repeated here. ATSC 3.0 specifies a plurality of constellations including non-uniform 16QAM, 64QAM, 256QAM, 1024QAM and 4096QAM constellations, some of which include constellations with at least two constellation points that have the same locations and different labels. 6.3.1 Constellation Overview Six different modulation orders are defined: uniform QPSK modulation and five non-uniform constellation (NUC) sizes: 16QAM, 64QAM, 256QAM, 1024QAM and 4096QAM respectively. For each combination of NUC modulation order and code rate a different constellation exists. However, the constellation does not vary with code length, the same constellation is used for both $N_{inner}=64800$ and $N_{inner}=16200$ codes when the code rate and modulation order are held constant. The same QPSK constellation is used for all code rates. The QPSK constellation is a 1-dimensional QAM form. The non-uniform constellations 16QAM, 64QAM and 256QAM are 2-dimensional (2D) quadrant-symmetric QAM constellations and are constructed by symmetry from a single quadrant. To reduce the complexity during QAM de-mapping at the receiver, the 1024QAM and 4096QAM constellations are derived from non-uniform 1-dimensional (1D) PAM (pulse amplitude modulation) constellations for both in-phase (I) and quadrature (Q) components. 6.3.2 Modulation and Coding Combinations In order to reduce the implementation complexity, implementation of all the modulation and coding combinations is not mandatory. Table 6.12 and Table 6.13 show the mandatory modulation and coding combinations that must be implemented. Mandatory combinations are shown with a check mark ✓.
---	---

"6. The communication system of claim 1, wherein:
the non-uniform symbol constellation is selected from a plurality of unequally spaced symbol constellations; and "

Table 6.12 Mandatory Modulation and Coding Combinations $N_{inner} = 64800$ Bits

Code Rate/ Constellation	2/ 15	3/ 15	4/ 15	5/ 15	6/ 15	7/ 15	8/ 15	9/ 15	10/ 15	11/ 15	12/ 15	13/ 15
QPSK	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
16QAM			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
64QAM		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
256QAM			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
1024QAM				✓	✓	✓	✓	✓	✓	✓	✓	✓
4096QAM						✓	✓	✓	✓	✓	✓	✓

Table 6.13 Mandatory Modulation and Coding Combinations $N_{inner} = 16200$ Bits

Code Rate/ Constellation	2/ 15	3/ 15	4/ 15	5/ 15	6/ 15	7/ 15	8/ 15	9/ 15	10/ 15	11/ 15	12/ 15	13/ 15
QPSK	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
16QAM				✓	✓	✓	✓	✓	✓	✓	✓	✓
64QAM				✓	✓	✓	✓	✓	✓	✓	✓	✓
256QAM				✓	✓	✓	✓	✓	✓	✓	✓	✓

See e.g., ATSC 3.0 Standard: Physical Layer Protocol (A/322), Annex C, pg. 30-31; see also Annex C, pg. 164-174, <https://muygs2x2vnb2pjk6g160f1s8-wpengine.netdna-ssl.com/wp-content/uploads/2021/04/A322-2021-Physical-Layer-Protocol.pdf>

" each of the plurality of unequally spaced symbol constellations is characterized by the assignment of labels and spacing of the constellation points such that each of the plurality of unequally spaced symbol constellations is capable of providing greater parallel decoding capacity when operated at a symbol constellation operating SNR than the other plurality of unequally spaced symbol constellations when operated at the same SNR."

6B each of the plurality of unequally spaced symbol constellations is characterized by the assignment of labels and spacing of the constellation points such that each of the plurality of unequally spaced symbol constellations is capable of providing greater parallel decoding capacity when operated at a symbol constellation operating SNR than the other plurality of unequally spaced symbol constellations when operated at the same SNR.	Each of the plurality of ATSC 3.0 unequally spaced QAM constellations is characterized by the assignment of labels and spacing of the constellation points such that each of the plurality of unequally spaced symbol constellations is capable of providing greater parallel decoding capacity when operated at a symbol constellation operating SNR than the other of the plurality of unequally spaced symbol constellations when operated at the same SNR. The ATSC 3.0 constellations were optimized to maximize parallel decoding capacity (or "BICM capacity"). III. OPTIMIZATION OF NON-UNIFORM CONSTELLATIONS When optimizing NUCs of a given constellation size m for a transmission system using a BICM chain, we need to maximize the BICM capacity C_B. The only constraint on the constellation is that the average transmit power should be constant, usually normalized to unity, i.e., the transmit symbols need to fulfil the following power constraint $P_x = \frac{1}{m} \sum_{l=0}^{m-1} x_l ^2 = 1. \quad (1)$ The task is to maximize C_B by modifying the QAM symbols x_l, considering constraint (1). Since C_B depends on the channel transition probabilities $p(r_k s_k = x_l)$, this optimization has to be performed for each particular channel. In particular, a different optimum NUC may result for an AWGN channel for each SNR value. For modern FEC codes, such as LDPC, See e.g., Non-Uniform Constellations for ATSC 3.0, Loghin et al., IEEE Transactions on Broadcasting, Vol. 62, No. 1, March 2016, pg. 199. The constellations are designed to have greater parallel decoding capacity when operated at the specified SNR.
--	--

" each of the plurality of unequally spaced symbol constellations is characterized by the assignment of labels and spacing of the constellation points such that each of the plurality of unequally spaced symbol constellations is capable of providing greater parallel decoding capacity when operated at a symbol constellation operating SNR than the other plurality of unequally spaced symbol constellations when operated at the same SNR."

Table 4.3 Required SNRs (dB) for all ModCod Combinations, Long LDPC codes (64800 bits) and AWGN Channel

Constellation	Code Rate															
	2/15	3/15	4/15	5/15	6/15	7/15	8/15	9/15	10/15	11/15	12/15	13/15	14/15	15/15	16/15	17/15
QPSK	-6.23	-4.32	-2.89	-1.70	-0.54	0.30	1.16	1.97	2.77	3.60	4.48	5.53	6.78	8.23	9.88	11.73
16QAM	-2.73	-0.25	1.46	2.82	4.21	5.21	6.30	7.32	8.36	9.50	10.57	11.83	13.20	14.68	16.27	17.97
64QAM	-0.25	2.27	4.15	5.95	7.66	8.82	10.31	11.55	12.86	14.28	15.57	17.03	18.57	20.14	21.82	23.62
256QAM	1.80	4.30	6.57	8.53	10.61	12.10	13.91	15.55	17.13	18.76	20.44	22.22	24.01	25.52	27.62	29.82
1024QAM	3.23	6.17	8.77	11.07	13.45	15.30	17.48	19.45	21.35	23.43	25.52	27.62	29.82	32.03	34.34	36.83
4096QAM	4.58	7.95	10.73	13.45	16.04	18.22	20.69	23.05	25.55	28.11	30.34	32.83	35.34	37.97	40.73	43.62

Table 4.4 Required SNRs (dB) for all ModCod Combinations, Long LDPC Codes (64800 bits) and i.i.d. Rayleigh Channel

Constellation	Code Rate															
	2/15	3/15	4/15	5/15	6/15	7/15	8/15	9/15	10/15	11/15	12/15	13/15	14/15	15/15	16/15	17/15
QPSK	-5.72	-3.62	-1.97	-0.55	0.95	1.95	3.16	4.35	5.62	7.05	8.76	10.97	13.20	15.53	17.97	20.53
16QAM	-1.84	0.81	2.69	4.32	5.98	7.21	8.83	9.94	11.40	12.78	14.80	16.85	18.85	20.82	22.82	24.82
64QAM	0.86	3.61	5.88	7.74	9.72	11.10	12.75	14.25	15.51	17.44	19.39	21.82	24.01	26.62	29.14	31.59
256QAM	2.89	5.97	8.46	10.59	12.82	14.58	16.54	18.23	20.06	21.94	24.01	26.62	29.14	31.59	34.14	36.54
1024QAM	4.65	8.04	10.95	13.25	15.81	17.84	20.13	22.34	24.47	26.81	28.82	31.59	34.14	36.54	39.14	41.59
4096QAM	6.23	9.83	12.95	15.75	18.79	21.03	23.67	26.37	28.64	31.18	33.82	36.54	39.14	41.59	44.14	46.59

Table 4.5 Required SNRs (dB) for all ModCod Combinations, Short LDPC Codes (16200 bits) and AWGN Channel

Constellation	Code Rate															
	2/15	3/15	4/15	5/15	6/15	7/15	8/15	9/15	10/15	11/15	12/15	13/15	14/15	15/15	16/15	17/15
QPSK	-5.55	-3.73	-2.32	-1.30	-0.33	0.58	1.38	2.20	2.94	3.82	4.70	5.78	6.78	7.78	8.78	9.78
16QAM	-2.15	0.35	1.99	3.16	4.45	5.51	6.51	7.58	8.59	9.74	10.81	12.09	13.33	14.52	15.86	17.33
64QAM	0.35	2.85	4.65	6.30	7.93	9.29	10.56	11.83	13.13	14.52	15.86	17.33	18.82	20.78	22.65	24.59
256QAM	2.27	4.78	7.19	9.33	10.81	12.57	14.25	15.80	17.45	19.08	20.78	22.65	24.59	26.54	28.54	30.54

" each of the plurality of unequally spaced symbol constellations is characterized by the assignment of labels and spacing of the constellation points such that each of the plurality of unequally spaced symbol constellations is capable of providing greater parallel decoding capacity when operated at a symbol constellation operating SNR than the other plurality of unequally spaced symbol constellations when operated at the same SNR."

		Code Rate													
Constellation		2/15	3/15	4/15	5/15	6/15	7/15	8/15	9/15	10/15	11/15	12/15	13/15	14/15	15/15
QPSK	16QAM	-5.06	-2.97	-1.36	-0.08	1.15	2.30	3.44	4.70	5.97	7.45	9.15	11.56	14.97	17.44
	64QAM	-1.14	1.45	3.41	4.78	6.27	7.58	8.96	10.28	11.73	13.22	14.97	17.44	19.82	22.44
	256QAM	1.60	4.30	6.55	8.29	10.05	11.54	13.09	14.62	16.20	17.87	19.82	22.44	24.54	27.23

See e.g., ATSC Recommended Practice: Guidelines for the Physical Layer Protocol (A/327), pg. 18-19, <https://www.atsc.org/wp-content/uploads/2018/10/A327-2018-Physical-Layer-RP.pdf>

"7. The communication system of claim 6, wherein the symbol constellation operating SNR is a channel SNR where the receiver is capable of using the respective unequally spaced symbol constellation to receive data at a frame error rate (FER) of 10^{-2} or lower."

7. The communication system of claim 6, wherein the symbol constellation operating SNR is a channel SNR where the receiver is capable of using the respective unequally spaced symbol constellation to receive data at a frame error rate (FER) of 10^{-2} or lower."

7. The communication system of claim 6, wherein the symbol constellation operating SNR is a channel SNR where the receiver is capable of using the respective unequally spaced symbol constellation to receive data at a frame error rate (FER) of 10^{-2} or lower.

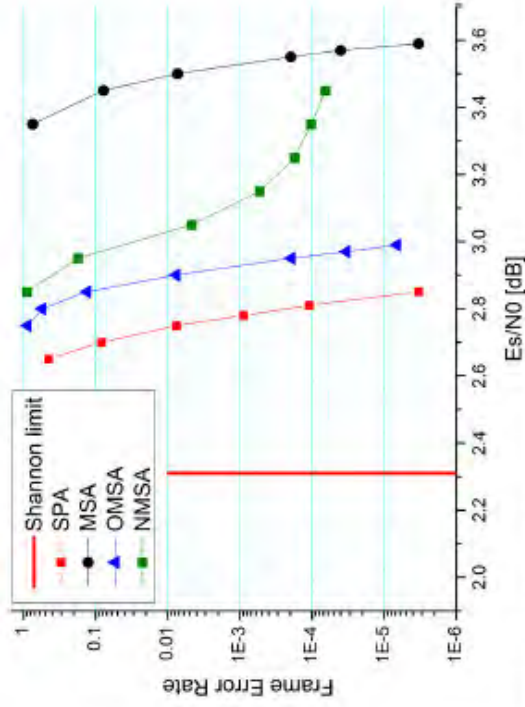


Figure 6.12 LDPC code performance based on various decoding algorithms (Code rate = 10/15, Code length = 64800, AWGN channel).

See e.g., ATSC Recommended Practice: Guidelines for the Physical Layer Protocol (A/327), pg. 82, <https://www.atsc.org/wp-content/uploads/2018/10/A327-2018-Physical-Layer-RP.pdf>

"7. The communication system of claim 6, wherein the symbol constellation operating SNR is a channel SNR where the receiver is capable of using the respective unequally spaced symbol constellation to receive data at a frame error rate (FER) of 10^{-2} or lower."

6.5.3 Inner and Outer Decoding

For inner decoding, the LDPC decoding corresponding to the PCM is performed to correct errors over a physical channel. There are a number of LDPC decoding algorithms which may provide trade-offs between the decoding performance and hardware complexity.

The sum-product algorithm (SPA) is known as the best performing and the most complex decoding algorithm. In order to reduce decoding complexity of the SPA, simplified decoding schemes can be used. First, the min-sum algorithm (MSA) is a simplified method that can greatly reduce decoding complexity compared to the SPA, but it may introduce substantial performance degradation in terms of bit error rate (BER) or frame error rate (FER). The modified MSAs can be used to improve the BER and FER performance of the MSA, and there are the normalized min-sum algorithm (NMSA) and offset min-sum algorithm (OMSA), which use normalization and offset terms for the output of check node operations, respectively.

Given the four different LDPC decoding algorithms (i.e., SPA, MSA, OMSA, and NMSA), the simulation performance of ATSC 3.0 LDPC codes in an AWGN channel was analyzed. For the NMSA and OMSA algorithms, decoding parameters for each combination of code rate and code length should be appropriately determined. Table 6.1 shows the optimized scaling and offset values of OMSA and NMSA that support the best decoding performance with extensive simulation.

See e.g., ATSC Recommended Practice: Guidelines for the Physical Layer Protocol (A/327), pg. 80-81, <https://www.atsc.org/wp-content/uploads/2018/10/A327-2018-Physical-Layer-RP.pdf>

"7. The communication system of claim 6, wherein the symbol constellation operating SNR is a channel SNR where the receiver is capable of using the respective unequally spaced symbol constellation to receive data at a frame error rate (FER) of 10^{-2} or lower."

The performance of ATSC 3.0 LDPC codes was analyzed given the theoretical thresholds and computer simulation results. Note that the theoretical thresholds of each code were calculated by Density Evolution algorithm, and the computer simulation results were obtained using 50 iterations for LDPC decoding. Note also that a threshold is defined as the theoretical performance limit that a given LDPC code can achieve when the code length goes to infinity. Table 6.2 and Table 6.3 show the performance differences from the Shannon limits to the theoretical thresholds and simulation results in the cases of ATSC 3.0 short and long codes, respectively. Note that the target FER for LDPC codes in computer simulation was set to 10^{-4} since the concatenation of LDPC and BCH codes provides overall FER performance lower than 10^{-6} .

Table 6.2 Performance Difference from the Shannon Capacity Limit to the Theoretical Thresholds and Simulation Results (Short Code Cases)

Code Rate	Performance Difference from Theoretical Thresholds (dB)				Performance Difference from Simulation Results (dB) @ FER= 10^{-4}			
	SPA	MSA	OMSA	NMSA	SPA	MSA	OMSA	NMSA
2/15	0.5	2.47	0.78	0.86	1.35	2.09	1.58	1.69
3/15	0.5	2.07	0.9	0.86	1.14	2.52	1.48	1.48
4/15	0.58	1.85	0.86	0.82	1.1	2.07	1.37	1.34
5/15	0.41	1.61	0.89	0.71	0.93	2.18	1.35	1.34
6/15	0.24	1.66	0.58	1.1	0.91	2.09	1.18	2.32*
7/15	0.23	1.52	0.54	0.84	0.82	1.93	1.08	2.18*
8/15	0.16	1.37	0.41	0.8	0.74	1.78	0.95	1.96*
9/15	0.25	1.16	0.4	0.54	0.72	1.5	0.86	1.04*
10/15	0.15	1.12	0.32	0.49	0.65	1.49	0.77	1.44*
11/15	0.25	0.91	0.35	0.36	0.64	1.22	0.72	0.82*
12/15	0.19	0.8	0.28	0.29	0.62	1.12	0.68	0.75
13/15	0.23	0.75	0.31	0.29	0.62	1.08	0.68	0.71*

"7. The communication system of claim 6, wherein the symbol constellation operating SNR is a channel SNR where the receiver is capable of using the respective unequally spaced symbol constellation to receive data at a frame error rate (FER) of 10^{-2} or lower."

Table 6.3 Performance Difference from the Shannon Capacity Limit to the Theoretical Thresholds and Simulation Results (Long Code Cases)

Code Rate	Performance Difference from Theoretical Thresholds (dB)			Performance Difference from Simulation Results (dB) @ FER= 10^{-4}		
	SPA	MSA	OMSA	NMSA	SPA	MSA
2/15	0.19	2.28	0.70	1.00	0.71	2.82
3/15	0.19	2.00	0.57	0.65	0.63	2.27
4/15	0.21	1.75	0.50	0.47	0.6	1.99
5/15	0.22	1.58	0.46	0.44	0.6	1.79
6/15	0.29	1.67	0.58	1.09	0.73	1.87
7/15	0.25	1.23	0.43	0.45	0.58	1.39
8/15	0.24	1.38	0.44	0.76	0.58	1.56
9/15	0.19	1.17	0.36	0.64	0.53	1.35
10/15	0.18	1.08	0.33	0.47	0.5	1.25
11/15	0.18	0.90	0.29	0.33	0.46	1.05
12/15	0.17	0.82	0.27	0.30	0.43	0.99
13/15	0.17	0.68	0.24	0.25	0.41	0.85

See e.g., ATSC Recommended Practice: Guidelines for the Physical Layer Protocol (A/327), pg. 80-81, <https://www.atsc.org/wp-content/uploads/2018/10/A327-2018-Physical-Layer-RP.pdf>

"8. The communication system of claim 1, wherein:

the symbol constellation is selected from a plurality of unequally spaced symbol constellations; and "

8A

The communication system of claim 1, wherein:

the symbol constellation is selected from a plurality of unequally spaced symbol constellations; and

As shown above, ATSC 3.0 specifies certain unequally spaced symbol constellations to be used, including a plurality of unequally spaced symbol constellations.

As shown in more detail above with reference to claim element 1D, the non-uniform symbol constellation that the demapper is capable using to determine likelihoods (that includes at least two constellation points that have identical locations and different labels) is selected from a plurality of non-uniform symbol constellations specified in ATSC 3.0. For brevity, those constellations are not repeated here.

ATSC 3.0 specifies a plurality of constellations including non-uniform 16QAM, 64QAM, 256QAM, 1024QAM and 4096QAM constellations, some of which include constellations with at least two constellation points that have locations that are the same and different labels.

6.3.1 Constellation Overview

Six different modulation orders are defined: uniform QPSK modulation and five non-uniform constellation (NUC) sizes: 16QAM, 64QAM, 256QAM, 1024QAM and 4096QAM respectively. For each combination of NUC modulation order and code rate a different constellation exists. However, the constellation does not vary with code length, the same constellation is used for both $N_{inner}=64800$ and $N_{inner}=16200$ codes when the code rate and modulation order are held constant. The same QPSK constellation is used for all code rates.

The QPSK constellation is a 1-dimensional QAM form.

The non-uniform constellations 16QAM, 64QAM and 256QAM are 2-dimensional (2D) quadrant-symmetric QAM constellations and are constructed by symmetry from a single quadrant. To reduce the complexity during QAM de-mapping at the receiver, the 1024QAM and 4096QAM constellations are derived from non-uniform 1-dimensional (1D) PAM (pulse amplitude modulation) constellations for both in-phase (I) and quadrature (Q) components.

6.3.2 Modulation and Coding Combinations

In order to reduce the implementation complexity, implementation of all the modulation and coding combinations is not mandatory. Table 6.12 and Table 6.13 show the mandatory modulation and coding combinations that must be implemented. Mandatory combinations are shown with a

check mark ✓.

"8. The communication system of claim 1, wherein:
the symbol constellation is selected from a plurality of unequally spaced symbol constellations; and "

Table 6.12 Mandatory Modulation and Coding Combinations $N_{inner} = 64800$ Bits

Code Rate/ Constellation	2/ 15	3/ 15	4/ 15	5/ 15	6/ 15	7/ 15	8/ 15	9/ 15	10/ 15	11/ 15	12/ 15	13/ 15
QPSK	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
16QAM			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
64QAM		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
256QAM			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
1024QAM				✓	✓	✓	✓	✓	✓	✓	✓	✓
4096QAM						✓	✓	✓	✓	✓	✓	✓

Table 6.13 Mandatory Modulation and Coding Combinations $N_{inner} = 16200$ Bits

Code Rate/ Constellation	2/ 15	3/ 15	4/ 15	5/ 15	6/ 15	7/ 15	8/ 15	9/ 15	10/ 15	11/ 15	12/ 15	13/ 15
QPSK	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
16QAM				✓	✓	✓	✓	✓	✓	✓	✓	✓
64QAM				✓	✓	✓	✓	✓	✓	✓	✓	✓
256QAM				✓	✓	✓	✓	✓	✓	✓	✓	✓

See e.g., ATSC 3.0 Standard: Physical Layer Protocol (A/322), Annex C, pg. 30-31; see also Annex C, pg. 164-174, <https://muygs2x2vnb2pjk6g160f1s8-wpengine.netdna-ssl.com/wp-content/uploads/2021/04/A322-2021-Physical-Layer-Protocol.pdf>

" each of the plurality of unequally spaced symbol constellations is characterized by the assignment of labels and spacing of constellation points so as to maximize parallel decoding capacity at a symbol constellation operating SNR subject to at least one constraint."

8B each of the plurality of unequally spaced symbol constellations is characterized by the assignment of labels and spacing of constellation points so as to maximize parallel decoding capacity at a symbol constellation operating SNR subject to at least one constraint.	ATSC 3.0 provides a plurality of unequally spaced symbol constellations to be used. Each of the plurality of unequally spaced symbol constellations is characterized in that the labels have been assigned, and the spacing of the constellation points in the constellations have been determined and assigned such that parallel decoding capacity (or "BICM capacity") is maximized at a particular SNR, subject to an average transmit power constraint. In ATSC 3.0, the parallel decoding capacity, or BICM capacity, is maximized for particular SNRs, subject to an average transmit power constraint. III. OPTIMIZATION OF NON-UNIFORM CONSTELLATIONS When optimizing NUCs of a given constellation size m for a transmission system using a BICM chain, we need to maximize the BICM capacity C_B. The only constraint on the constellation is that the average transmit power should be constant, usually normalized to unity, i.e., the transmit symbols need to fulfil the following power constraint $\mathcal{P}_x = \frac{1}{m} \sum_{l=0}^{m-1} x_l ^2 = 1. \quad (1)$ The task is to maximize C_B by modifying the QAM symbols x_l, considering constraint (1). Since C_B depends on the channel transition probabilities $p(r_k x_k = x_l)$, this optimization has to be performed for each particular channel. In particular, a different optimum NUC may result for an AWGN channel for each SNR value. For modern FEC codes, such as LDPC, See e.g., Non-Uniform Constellations for ATSC 3.0, Loghin et al., IEEE Transactions on Broadcasting, Vol. 62, No. 1, March 2016, pg. 199. ATSC 3.0 sets out the required SNRs for the constellations:
---	---

" each of the plurality of unequally spaced symbol constellations is characterized by the assignment of labels and spacing of constellation points so as to maximize parallel decoding capacity at a symbol constellation operating SNR subject to at least one constraint."

Table 4.3 Required SNRs (dB) for all ModCod Combinations, Long LDPC codes (64800 bits) and AWGN Channel

Constellation	Code Rate													
	2/15	3/15	4/15	5/15	6/15	7/15	8/15	9/15	10/15	11/15	12/15	13/15	14/15	15/15
QPSK	-8.23	-4.32	-2.89	-1.70	-0.54	0.30	1.16	1.97	2.77	3.60	4.49	5.53	6.57	7.62
16QAM	-2.73	-0.25	1.46	2.82	4.21	5.21	6.30	7.32	8.36	9.50	10.57	11.83	13.13	14.44
64QAM	-0.26	2.27	4.15	5.36	7.06	8.82	10.31	11.55	12.86	14.28	15.57	17.03	18.76	20.44
256QAM	1.80	4.30	6.57	9.53	10.81	12.10	13.91	15.55	17.13	18.76	20.44	22.22	24.22	26.22
1024QAM	3.23	6.17	9.77	11.07	13.45	15.30	17.48	19.45	21.35	23.43	25.52	27.62	29.83	32.83
4096QAM	4.58	7.85	10.73	13.45	16.04	18.22	20.69	23.05	25.55	28.11	30.34	32.83	35.44	38.83

Table 4.4 Required SNRs (dB) for all ModCod Combinations, Long LDPC Codes (64800 bits) and i.i.d. Rayleigh Channel

Constellation	Code Rate													
	2/15	3/15	4/15	5/15	6/15	7/15	8/15	9/15	10/15	11/15	12/15	13/15	14/15	15/15
QPSK	-5.72	-3.62	-1.97	-0.55	0.86	1.95	3.16	4.35	5.62	7.05	8.76	10.97	13.13	15.83
16QAM	-1.84	0.81	2.69	4.32	5.98	7.21	8.63	9.94	11.40	12.78	14.80	16.85	18.85	21.82
64QAM	0.86	3.61	5.88	7.74	9.72	11.10	12.75	14.25	15.91	17.44	19.39	21.82	24.01	26.62
256QAM	2.89	5.97	8.46	10.59	12.92	14.58	16.54	18.23	20.06	21.94	24.01	26.62	29.83	32.83
1024QAM	4.85	8.04	10.85	13.25	15.91	17.84	20.13	22.34	24.47	26.81	28.82	31.59	34.83	38.54
4096QAM	6.23	9.83	12.95	15.75	18.79	21.03	23.67	26.37	28.64	31.18	33.82	36.54	39.83	43.83

Table 4.5 Required SNRs (dB) for all ModCod Combinations, Short LDPC Codes (16200 bits) and AWGN Channel

Constellation	Code Rate													
	2/15	3/15	4/15	5/15	6/15	7/15	8/15	9/15	10/15	11/15	12/15	13/15	14/15	15/15
QPSK	-5.55	-3.73	-2.32	-1.30	-0.33	0.58	1.38	2.20	2.94	3.82	4.70	5.78	6.57	7.62
16QAM	-2.15	0.35	1.99	3.16	4.45	5.51	6.51	7.58	8.59	9.74	10.81	12.09	13.13	14.44
64QAM	0.35	2.85	4.65	6.30	7.93	9.29	10.56	11.83	13.13	14.52	15.86	17.33	18.76	20.44
256QAM	2.27	4.78	7.19	9.93	10.91	12.57	14.25	15.80	17.45	19.08	20.78	22.55	24.22	26.22

" each of the plurality of unequally spaced symbol constellations is characterized by the assignment of labels and spacing of constellation points so as to maximize parallel decoding capacity at a symbol constellation operating SNR subject to at least one constraint."

Table 4.6 Required SNRs (dB) for all ModCod Combinations, Short LDPC

Constellation	Code Rate															
	2/15	3/15	4/15	5/15	6/15	7/15	8/15	9/15	10/15	11/15	12/15	13/15	14/15	15/15	16/15	17/15
QPSK	-5.08	-2.97	-1.36	-0.08	1.15	2.30	3.44	4.70	5.97	7.46	9.15	11.56	14.97	17.44	20.44	22.44
16QAM	-1.14	1.45	3.41	4.78	6.27	7.58	8.96	10.28	11.73	13.22	14.97	17.44	20.44	22.44	24.54	27.23
64QAM	1.60	4.30	6.55	8.29	10.05	11.54	13.09	14.62	16.20	17.87	19.82	22.44	24.54	27.23	30.44	33.44
256QAM	3.80	6.79	9.32	11.16	13.28	15.15	16.85	18.64	20.50	22.40	24.54	27.23	30.44	33.44	36.44	39.44

See e.g., ATSC Recommended Practice: Guidelines for the Physical Layer Protocol (A/327), pg. 18-19, <https://www.atsc.org/wp-content/uploads/2018/10/A327-2018-Physical-Layer-RP.pdf>

The term parallel decode capacity is equivalent to the term Bit Interleaved Coding Modulation (BICM) capacity. The ATSC 3.0 working group, including engineers from Samsung, Sony, and LG, acknowledged the inventors of the '509 patent were the first group to optimize constellations with respect to BICM capacity.

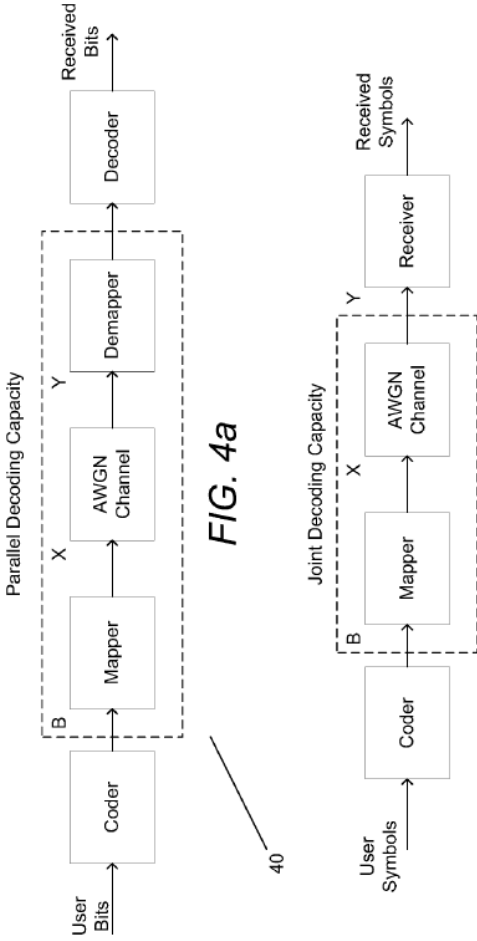
The optimization of constellations in the 1-dimensional space with respect to BICM capacity was first described in [10].

[10] M. F. Barsoum, C. Jones, and M. Fitz, "Constellation design via capacity maximization," in *Proc. IEEE Int. Symp. Inf. Theory*, Nice, France, Jun. 2007, pp. 1821-1825.

See e.g., Non-Uniform Constellations for ATSC 3.0, Loghin et al., IEEE Transactions on Broadcasting, Vol. 62, No. 1, March 2016, pg. 197, 202.

Similarly, the parallel decode capacity as described by the patent specification and the BICM capacity as described by the ATSC working group paper are measured as the capacity over the mapper, the channel, and the demapper.

" each of the plurality of unequally spaced symbol constellations is characterized by the assignment of labels and spacing of constellation points so as to maximize parallel decoding capacity at a symbol constellation operating SNR subject to at least one constraint."



See e.g., '509 Patent, Figs. 4a and 4b.

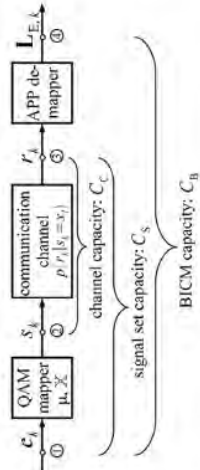


Fig. 1. Definition of channel, signal set and BICM capacity.

Further, papers in the industry have cited the inventor's original paper and stated that the term BICM capacity is equivalent to parallel decoding capacity.

" each of the plurality of unequally spaced symbol constellations is characterized by the assignment of labels and spacing of constellation points so as to maximize parallel decoding capacity at a symbol constellation operating SNR subject to at least one constraint."

	The capacities defined above can be found in the literature under different names. The UN capacity is called joint capacity in [11]. (constellation) constrained capacity in [12], or coded modulation capacity in [6]. The BICM capacity is referred as parallel decoding capacity in [11], or receiver constrained capacity in [12]. Furthermore, we recognize that we use the See e.g., "On the capacity of BICM with QAM Constellations," Alvarado et al., 2009, https://www.researchgate.net/profile/Arne_Svensson/publication/220762163_On_the_capacity_of_BICM_with_QAM_constellations/links/0912f513df5e4c1370000000/On-the-capacity-of-BICM-with-QAM-constellations.pdf [11] M. Barsoun, C. Jones, and M. Fitz, "Constellation design via capacity maximization," in <i>IEEE International Symposium on Information Theory, ISIT 2007</i>, Nice, France, Jun. 2007, pp. 1821–1825.
--	--

"9. The communication system of claim 1, further comprising a transmitter capable of transmitting signals via the communication channel, where the transmitter comprises:"

9A

The communication system of claim 1, further comprising a transmitter capable of transmitting signals via the communication channel, where the transmitter comprises:

Digital communication systems implementing the ATSC 3.0 standard include transmitters capable of transmitting signals via a communication channel.

For example, a typical ATSC communication is broadcast over the air from a TV station through transmitter sites to ATSC 3.0 receivers, such as ATSC 3.0 TVs, mobile devices, or gateways.

Adapted from a diagram from the PILOT initiative

See e.g., ATSC Newsletter, <https://www.atsc.org/newsletter/getting-from-here-to-atsc-3-0-next-gen-standard-changes-everything/>

The ATSC 3.0 Standard also describes the system architecture for transmitters.

"9. The communication system of claim 1, further comprising a transmitter capable of transmitting signals via the communication channel, where the transmitter comprises:"

4.2 System Architecture

A block diagram of the main data flow for the total transmitter system architecture is shown in Figure 4.1. The system architecture consists of four main parts: Input Formatting, Bit Interleaved and Coded Modulation (BICM), Framing and Interleaving, and Waveform Generation. For simplicity, control and signaling information flow is not shown in this diagram.

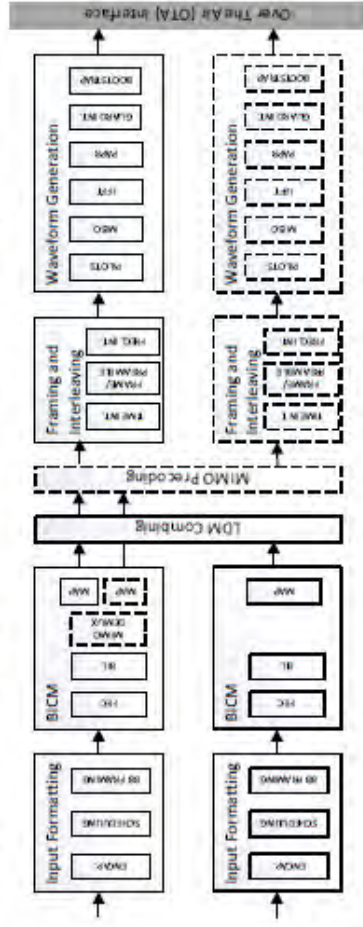


Figure 4.1 Block diagram of the system architecture for one RF channel.

See e.g., ATSC 3.0 Standard: Physical Layer Protocol (A/322), pg. 7, <https://muygs2x2vnb2pik6g160f1s8-wpengine.netdna-ssl.com/wp-content/uploads/2021/04/A322-2021-Physical-Layer-Protocol.pdf>

The transmit process is further described in the ATSC 3.0 Physical Layer documentation.

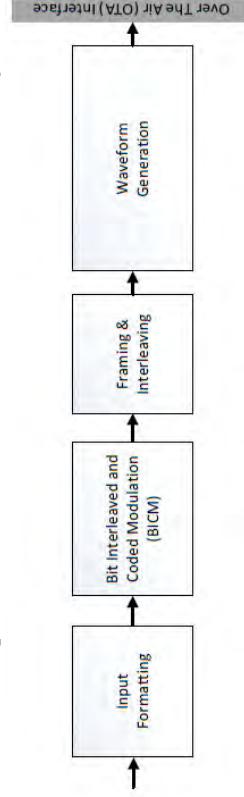


Figure 4.2 Block diagram (simplified) of a single PLP system architecture.

See e.g., ATSC 3.0 Standard: Physical Layer Protocol (A/322), pg. 8, <https://muygs2x2vnb2pik6g160f1s8-wpengine.netdna-ssl.com/wp-content/uploads/2021/04/A322-2021-Physical-Layer-Protocol.pdf>

"a coder capable of receiving bits and outputting encoded bits using a Low Density Parity Check (LDPC) code;"

9B a coder capable of receiving bits and outputting encoded bits using a Low Density Parity Check (LDPC) code;	ATSC 3.0 compliant transmitters include a coder capable of receiving bits and outputting encoded bits using a Low Density Parity Check (LDPC) code. According to the ATSC's system overview ATSC 3.0 transmitters utilize channel coding including Low Density Parity Check (LDPC) codes (2/15 – 13/15 code rates): 4. SYSTEM OVERVIEW AND GUIDELINES FOR PHYSICAL LAYER MODE 4.1 System Overview The ATSC 3.0 physical layer protocol described by A/321 [2] and A/322 [3] provides distinct features and descriptions of the physical layer technologies. For a channel coding method, a well-optimized Bit-Interleaved Coded Modulation (BICM) chain, comprised of Low Density Parity Check (LDPC) codes (2/15 – 13/15 code rates), Bit Interleavers, and Non-Uniform Constellations (QPSK – 4096QAM modulation orders), is used to achieve near Shannon limit performance of channel error mitigation across a wide range of SNR values. Multiple data streams can be carried See e.g., ATSC Recommended Practice: Guidelines for the Physical Layer Protocol (A/327), pg. 6, https://www.atsc.org/wp-content/uploads/2018/10/A327-2018-Physical-Layer-RP.pdf Further description of the use of LDPC codes is found in Section 4.2.9, and Tables 4.3-4.8. ATSC Recommended Practice: Guidelines for the Physical Layer Protocol (A/327), pg. 18-19, https://www.atsc.org/wp-content/uploads/2018/10/A327-2018-Physical-Layer-RP.pdf Encoding using LDPC is performed by the Inner Encoder:
---	--

"a coder capable of receiving bits and outputting encoded bits using a Low Density Parity Check (LDPC) code;"

6. BIT INTERLEAVED CODING AND MODULATION (BICM)

A simple block diagram of the Bit Interleaved Coding and Modulation (BICM) block is shown in Figure 6.1. The BICM block consists of three parts: The Forward Error Correction (FEC), the Bit Interleaver and the Mapper. The BICM block operates per PLP.

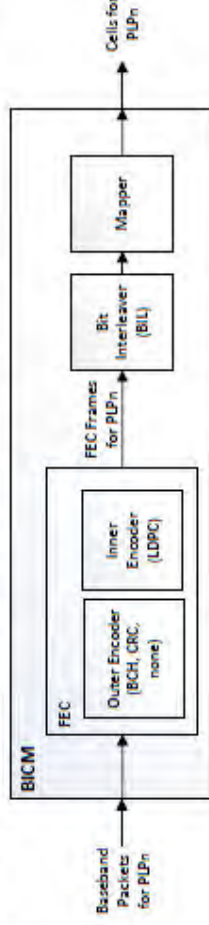


Figure 6.1 Block diagram of BICM.

See e.g., ATSC 3.0 Standard: Physical Layer Protocol (A/322), pg. 17, <https://muygs2x2vzb2pjk6g160f1s8-wpengine.netdna-ssl.com/wp-content/uploads/2021/04/A322-2021-Physical-Layer-Protocol.pdf>

The coder's use of LDPC codes is further described at 6.1.3:

"a coder capable of receiving bits and outputting encoded bits using a Low Density Parity Check (LDPC) code;"

6.1.3 Inner Encoding

LDPC codes are used to create parity bits which are appended to the payload in each Baseband Packet. Cyclic-structured LDPC codes are employed. The indices list for each encoding can be found in Annex A.

There are two different coding structures used. These are called Type A (defined in Section 6.1.3.1) and Type B (defined in Section 6.1.3.2). The type used for each code rate and code length shall be as shown in Table 6.4. Type A has a code structure that shows better performance at low code rates while Type B code structure shows better performance at high code rates.

Table 6.4 Structure of LDPC Encoding Used for Each of the Code Rates and Lengths

Code Rate	LDPC Code Structure Type	
	$N_{inner}=64800$	$N_{inner}=16200$
2/15	A	A
3/15	A	A
4/15	A	A
5/15	A	A
6/15	B	B
7/15	A	B
8/15	B	B
9/15	B	B
10/15	B	B
11/15	B	B
12/15	B	B
13/15	B	B

See e.g., ATSC 3.0 Standard: Physical Layer Protocol (A/322), pg. 21, <https://muygs2x2vhh2pjk6g160f1s8-wpengine.netdna-ssl.com/wp-content/uploads/2021/04/A322-2021-Physical-Layer-Protocol.pdf>

The Inner Encoder's use of LDPC codes is also described in the ATSC Guidelines:

5.2.1 Forward Error Correction (FEC)

The FEC of the BICM is formed by concatenation of an outer code and an inner code with the information part. The outer code is either a Bose, Chaudhuri, Hocquenghem (BCH) code, a Cyclic Redundancy Check (CRC) or none, while the inner code is a Low-Density Parity Check (LDPC) code. Both BCH and LDPC codes are systematic codes, such that the information part is contained within the codeword. The resulting codeword is thus a concatenation of information or payload part, BCH or CRC parities and LDPC parities, as shown in Figure 5.1 (top). The codeword when no BCH or CRC parity is used is also depicted in Figure 5.1 (bottom).

See e.g., ATSC Recommended Practice: Guidelines for the Physical Layer Protocol (A/327), pg. 29, <https://www.atsc.org/wp-content/uploads/2018/10/A327-2018-Physical-Layer-RP.pdf>

" a mapper, coupled to the coder, capable of mapping the encoded bits to symbols in the unequally spaced symbol constellation; and "

9C

a mapper, coupled to the coder, capable of mapping the encoded bits to symbols in the unequally spaced symbol constellation; and

ATSC 3.0 compliant transmitters include a mapper coupled to the coder (Inner Encoder). The mapper is coupled to the coder, and is capable of mapping the encoded bits to symbols in a non-uniform symbol constellation.

6. BIT INTERLEAVED CODING AND MODULATION (BICM)

A simple block diagram of the Bit Interleaved Coding and Modulation (BICM) block is shown in Figure 6.1. The BICM block consists of three parts: The Forward Error Correction (FEC), the Bit Interleaver and the Mapper. The BICM block operates per PLP.

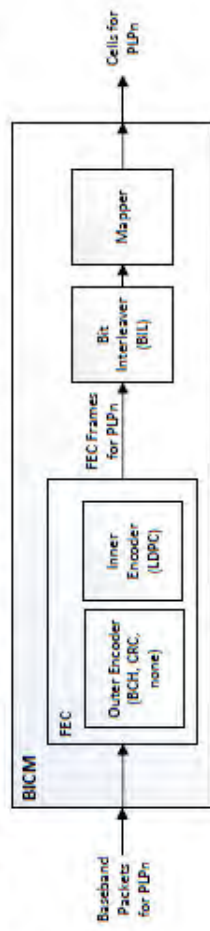


Figure 6.1 Block diagram of BICM.

See e.g., ATSC 3.0 Standard: Physical Layer Protocol (A/322), pg. 17, <https://muygs2x2vzb2pjk6g160f1s8-wpengine.netdna-ssl.com/wp-content/uploads/2021/04/A322-2021-Physical-Layer-Protocol.pdf>

The ATSC Guidelines further describe the constellation mapping performed by the mapper:

5.2.3 Constellation Mapping

There is one non-uniform constellation (NUC) defined for each ModCod combination (see Section 6.3 and Annex C of [3]). The interleaved LDPC codeword as the output bits of the block interleaver is mapped onto the defined constellation points. For implementation, a look-up table with the defined constellation mapping for each ModCod combination can be used.

See e.g., ATSC Recommended Practice: Guidelines for the Physical Layer Protocol (A/327), pg. 32, <https://www.atsc.org/wp-content/uploads/2018/10/A327-2018-Physical-Layer-RP.pdf>

Constellation Mapping by the Mapper is also described at Section 6.3 of the ATSC 3.0 Physical Layer Protocol specification:

" a mapper, coupled to the coder, capable of mapping the encoded bits to symbols in the unequally spaced symbol constellation; and "

6.3 Constellation Mapping

This section describes the mapping of FEC encoded and bit interleaved bits to complex valued quadrature amplitude modulation (QAM) constellation points on the IQ plane. The input to the constellation mapping block is a stream of bit-interleaved FEC Frames and the output is cells, grouped as a FEC Block when necessary.

The mapper consists of a DeMultiplexer block which followed by a bit-to-IQ mapping block. A block diagram of the Mapper is shown in Figure 6.10. The following sections describe the details to map the input FEC Frame bits to the constellation. First, the bits comprising a FEC Frame shall be demultiplexed into parallel streams as described in Section 6.3.3 to generate data cells. Next the data cells shall be mapped to constellation values, this is described in Section 6.3.4. The details for each type of modulation is described in Section 6.3.4.1 for QPSK, Section 6.3.4.2 for 16QAM to 256QAM and Section 6.3.4.3 for 1024 and 4096 QAM.

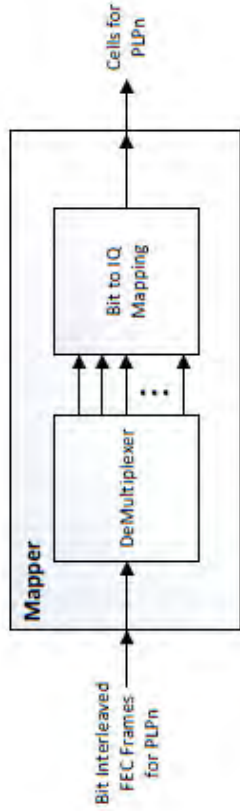


Figure 6.10 Mapper structure.

See e.g., ATSC 3.0 Standard: Physical Layer Protocol (A/322), pg. 29-30,

<https://muygs2x2vzb2pjk6g160f1s8-wpengine.netdna-ssl.com/wp-content/uploads/2021/04/A322-2021-Physical-Layer-Protocol.pdf>

"a modulator, coupled to the mapper, capable of generating a signal for transmission via the communication channel based upon symbols selected by the mapper, coupled to the mapper."

D a modulator, coupled to the mapper, capable of generating a signal for transmission via the communication channel based upon symbols selected by the mapper.	ATSC 3.0 uses OFDM modulation. ATSC compliant transmitters include a modulator coupled to the mapper, and capable of generating a signal for transmission via the communication channel based on symbols selected by the mapper. 4. SYSTEM OVERVIEW 4.1 Features The ATSC physical layer protocol is intended to offer the flexibility to choose among many different operating modes depending on desired robustness/efficiency tradeoffs. It is built on the foundation of OFDM modulation with a suite of LDPC FEC codes, of which there are 2 code lengths and 12 code rates defined. There are three basic modes of multiplexing: time, layered and frequency, along with three subframe types of SISO, MISO and MIMO. Signal protection starts with 12 selectable guard interval lengths to offer long echo protection lengths. Channel estimation can be done with 16 scattered pilot patterns along with continual pilot patterns. Three FFT sizes (8K, 16K and 32K) offer a choice of Doppler protection depending on the anticipated device mobility. See e.g., ATSC 3.0 Standard: Physical Layer Protocol (A/322), pg. 6, https://muygs2x2vnb2plk6g160f1s8-wpengine.netdna-ssl.com/wp-content/uploads/2021/04/A322-2021-Physical-Layer-Protocol.pdf 4. SYSTEM OVERVIEW AND GUIDELINES FOR PHYSICAL LAYER MODE 4.1 System Overview The ATSC 3.0 physical layer protocol described by A/321 [2] and A/322 [3] provides distinct features and descriptions of the physical layer technologies. For a channel coding method, a well-optimized Bit-Interleaved Coded Modulation (BICM) chain, comprised of Low Density Parity Check (LDPC) codes (2/15 – 13/15 code rates), Bit Interleavers, and Non-Uniform Constellations (QPSK – 4096QAM modulation orders), is used to achieve near Shannon limit performance of channel error mitigation across a wide range of SNR values. Multiple data streams can be carried by one or multiple Physical Layer Pipes (PLPs) using flexible choices of framing and multiplexing techniques including Time Division Multiplexing (TDM), SubSlice Multiplexing (SSM), Frequency Division Multiplexing (FDM), and Layered Division Multiplexing (LDM). Waveform parameters based on Orthogonal Frequency Division Multiplexing (OFDM) modulation also support a wide range of guard intervals, pilot patterns, and FFT sizes for broadcasters to select optimal system performance of intended services. Optional technologies such as channel bonding, Multiple-Input Single-Output (MISO), Multiple-Input Multiple-Output (MIMO), and Transmitter Identification (TxID) are included as additional features in the ATSC 3.0 physical layer protocol.
---	--

"a modulator, coupled to the mapper, capable of generating a signal for transmission via the communication channel based upon symbols selected by the mapper."

See e.g., ATSC Recommended Practice: Guidelines for the Physical Layer Protocol (A/327), pg. 6, <https://www.atsc.org/wp-content/uploads/2018/10/A327-2018-Physical-Layer-RP.pdf>

The transmitter includes a modulator to generate a signal (waveform) as shown in the ATSC 3.0 Physical Layer documentation. The output of the Mapper, in the BICM module, is passed to the modulator for Waveform Generation.

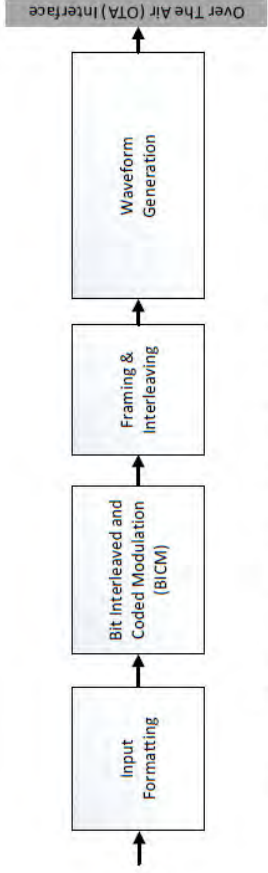


Figure 4.2 Block diagram (simplified) of a single PLP system architecture.

6. BIT INTERLEAVED CODING AND MODULATION (BICM)

A simple block diagram of the Bit Interleaved Coding and Modulation (BICM) block is shown in Figure 6.1. The BICM block consists of three parts: The Forward Error Correction (FEC), the Bit Interleaver and the Mapper. The BICM block operates per PLP.

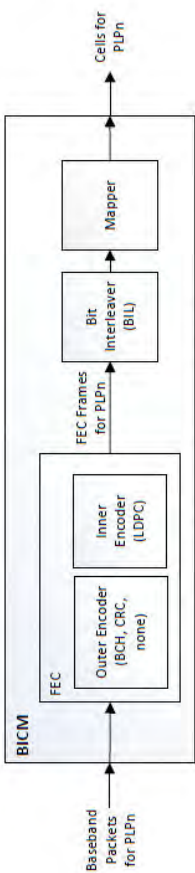


Figure 6.1 Block diagram of BICM.

See e.g., ATSC 3.0 Standard: Physical Layer Protocol (A/322), pg. 8, 17, <https://muygs2x2vnb2pk6g160f1s8-wpengine.netdna-ssl.com/wp-content/uploads/2021/04/A322-2021-Physical-Layer-Protocol.pdf>

"10. The communication system of claim 1, wherein: the symbol constellation is selected from a plurality of symbol constellations each having a same number of constellation points; a first of the plurality of symbol constellations includes constellation points at a first set of unique point locations that are unequally spaced; a second of the plurality of symbol constellations includes constellation points at a second set of unique point locations that are unequally spaced; and the number of unique point locations in the first set of unique point locations is different from the number of unique point locations in the second set of unique point locations."

10. The communication system of claim 1, wherein:
the symbol constellation is selected from a plurality of symbol constellations each having a same number of constellation points;
a first of the plurality of symbol constellations includes constellation points at a first set of unique point locations that are unequally spaced;
a second of the plurality of symbol constellations includes constellation points at a second set of unique point locations in the first set of unique point locations is different from the number of unique point locations in the second set of unique point locations.

ATSC 3.0 receivers select a symbol constellation from a plurality of symbol constellations each having a same number of constellation points; a first of the plurality of symbol constellations includes constellation points at a first set of unique point locations that are unequally spaced; a second of the plurality of symbol constellations includes constellation points at a second set of unique point locations that are unequally spaced; and the number of unique point locations in the first set of unique point locations is different from the number of unique point locations in the second set of unique point locations.

For example, the ATSC 3.0 specification requires support for at least 5 different constellations per cardinality. Each QAM constellation in a cardinality has a unique set of point locations that are unequally spaced.

Table 6.12 Mandatory Modulation and Coding Combinations $N_{inner} = 64800$ Bits

Code Rate/ Constellation	2/ 15	3/ 15	4/ 15	5/ 15	6/ 15	7/ 15	8/ 15	9/ 15	10/ 15	11/ 15	12/ 15	13/ 15
QPSK	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
16QAM			✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
64QAM				✓	✓	✓	✓	✓	✓	✓	✓	✓
256QAM					✓	✓	✓	✓	✓	✓	✓	✓
1024QAM						✓	✓	✓	✓	✓	✓	✓
4096QAM							✓	✓	✓	✓	✓	✓

Table 6.13 Mandatory Modulation and Coding Combinations $N_{inner} = 16200$ Bits

Code Rate/ Constellation	2/ 15	3/ 15	4/ 15	5/ 15	6/ 15	7/ 15	8/ 15	9/ 15	10/ 15	11/ 15	12/ 15	13/ 15
QPSK	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
16QAM				✓	✓	✓	✓	✓	✓	✓	✓	✓
64QAM					✓	✓	✓	✓	✓	✓	✓	✓
256QAM						✓	✓	✓	✓	✓	✓	✓

"10. The communication system of claim 1, wherein: the symbol constellation is selected from a plurality of symbol constellations each having a same number of constellation points; a first of the plurality of symbol constellations includes constellation points at a first set of unique point locations that are unequally spaced; a second of the plurality of symbol constellations includes constellation points at a second set of unique point locations that are unequally spaced; and the number of unique point locations in the first set of unique point locations is different from the number of unique point locations in the second set of unique point locations."

	See e.g., ATSC 3.0 Standard: Physical Layer Protocol (A/322), Annex C, pg. 30-31; see also Annex C, pg. 164-174, https://muygs2x2vhh2pjk6g160f1s8-wpengine.netdna-ssl.com/wp-content/uploads/2021/04/A322-2021-Physical-Layer-Protocol.pdf As described in element 1D, the following constellations include constellation points with different labels and the same location: 64QAM – 3/15, 4/15 256QAM – 3/15, 5/15, 7/15, 8/15 1024QAM – 2/15, 3/15, 8/15, 9/15 4096QAM – 2/15 through 12/15 The number of unique point locations is different as across constellations of the same cardinality. For example, the 64QAM constellations are defined by the 16 points in the upper right quadrant. Since the constellation is symmetrical, the remaining 48 constellations points are obtained by varying the signs of the real and imaginary components of each constellation point. The 64QAM constellations have a different number of unique point locations. For example, the 64QAM constellations for code rate 2/15, 3/15, and 4/15 have 16, 9, and 14 unique point locations in the first quadrant, respectively. As shown in the constellation point tables in Element 1D above, the 256, 1024, and 4096 constellations also have a differing number of unique point locations within the constellations of the same cardinality.
--	---

"10. The communication system of claim 1, wherein: the symbol constellations is selected from a plurality of symbol constellations each having a same number of constellation points; a first of the plurality of symbol constellations includes constellation points at a first set of unique point locations that are unequally spaced; a second of the plurality of symbol constellations includes constellation points at a second set of unique point locations that are unequally spaced; and the number of unique point locations in the first set of unique point locations is different from the number of unique point locations in the second set of unique point locations."

Table C.1.4 64QAM Definition Table for Code Rates 2/15-7/15

w/CR	2/15	3/15	4/15	5/15	6/15	7/15
w0	0.6474+j0.9831	0.5472+j1.1591	0.5008+j1.2136	1.4327+j0.3305	1.4521+j0.3005	0.1567+j0.3112
w1	0.6438+j0.9829	0.5473+j1.1573	0.4994+j1.2194	1.0909+j0.2971	1.2657+j0.8178	0.1709+j0.3037
w2	0.6471+j0.9767	0.5467+j1.1599	0.5313+j1.1715	1.2484+j0.7803	1.0666+j0.2744	0.2093+j0.6562
w3	0.6444+j0.9762	0.5479+j1.1585	0.5299+j1.1788	0.9762+j0.5715	0.9500+j0.5641	0.3315+j0.6038
w4	0.9839+j0.6475	1.1578+j0.5478	1.2107+j0.5037	0.3309+j1.4326	0.3011+j1.4529	0.3112+j0.1567
w5	0.9778+j0.6474	1.1576+j0.5475	1.2209+j0.5008	0.2979+j1.0923	0.8202+j1.2651	0.3037+j0.1709
w6	0.9835+j0.6434	1.1591+j0.5475	1.1715+j0.5299	0.7829+j1.2477	0.2750+j1.0676	0.6562+j0.2093
w7	0.9777+j0.6433	1.1591+j0.5475	1.1802+j0.5270	0.5739+j0.9763	0.5656+j0.9499	0.6038+j0.3315
w8	0.4659+j0.6393	0.3163+j0.5072	0.2744+j0.4762	0.3901+j0.2112	0.3553+j0.1948	0.2959+j1.4877
w9	0.4643+j0.6386	0.3163+j0.5072	0.2729+j0.4762	0.5317+j0.2475	0.3569+j0.2094	0.8427+j1.2612
w10	0.4661+j0.6353	0.3163+j0.5072	0.2773+j0.4791	0.3945+j0.2289	0.5596+j0.2431	0.2389+j1.0228
w11	0.4639+j0.6350	0.3163+j0.5072	0.2773+j0.4791	0.5236+j0.2894	0.5410+j0.3002	0.5559+j0.8912
w12	0.6378+j0.4671	0.5087+j0.3163	0.4762+j0.2729	0.2108+j0.3911	0.1946+j0.3566	1.4877+j0.2959
w13	0.6352+j0.4673	0.5087+j0.3163	0.4762+j0.2729	0.2475+j0.5327	0.2094+j0.3579	1.2612+j0.8427
w14	0.6385+j0.4656	0.5087+j0.3163	0.4791+j0.2773	0.2287+j0.3955	0.2430+j0.5607	1.0228+j0.2389
w15	0.6353+j0.4653	0.5087+j0.3163	0.4791+j0.2758	0.2898+j0.5246	0.3004+j0.5417	0.8912+j0.5559

See e.g., ATSC 3.0 Standard: Physical Layer Protocol (A/322), Annex C, pg. 165-171, 173-174,
<https://muvgs2x2vnb2pik6g160fls8-wpengine.netdna-ssl.com/wp-content/uploads/2021/04/A322-2021-Physical-Layer-Protocol.pdf>