DOCSIS 3.1 Basics

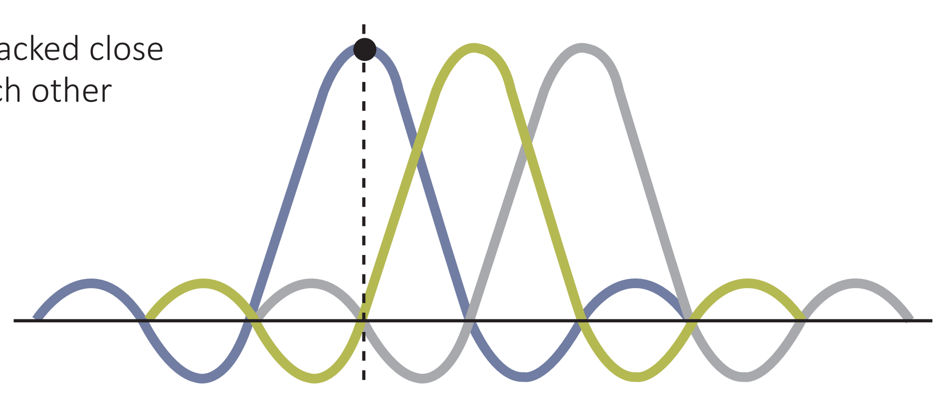
OFDM BASICS

Orthogonal Frequency Division Multiplexing

- OFDM is a transmission technique that consists of multiplexing multiple individual Sub-carriers with precise frequency spacing
  - For DOCSIS 3.1, these Sub-carriers are QAM modulated
- Orthogonality enables Sub-carriers to be closely spaced together, without interfering with each other
- Precise control of Spectrum usage
- OFDM is used in other transmission technologies: Wireless LAN, LTE, Digital Broadcasting DAB/DVB, DSL

OFDM Sub-Carriers

- Multiple OFDM Sub-carriers can be packed close together, without interfering with each other
- Sub-carriers have precise frequency
- Much more spectrum control:
  - 25 kHz or 50 kHz Sub-carriers
  - Sub-carriers are grouped to form an OFDM channel that can be from 24 to 192 MHz wide



OFDMA Upstream

- Orthogonal Frequency Division Multiple Access
- DOCSIS 3.1 replaces ATDMA with OFDMA
- Flexibility: Can shut on/off OFDMA Sub-carriers to adapt legacy US channels with D3.1 US
- Time and frequency methods are used to support multi-user transmission and for backwards compatibility with D3.0 US channel bonding
- More efficient US bandwidth

LDPC

Low Density Parity Check

- Advanced FEC technology which provides performance close to the Shannon Theoretical Limit
- Uses frequency and time interleaving for robustness against interferers and bursts
- Greater spectral efficiency

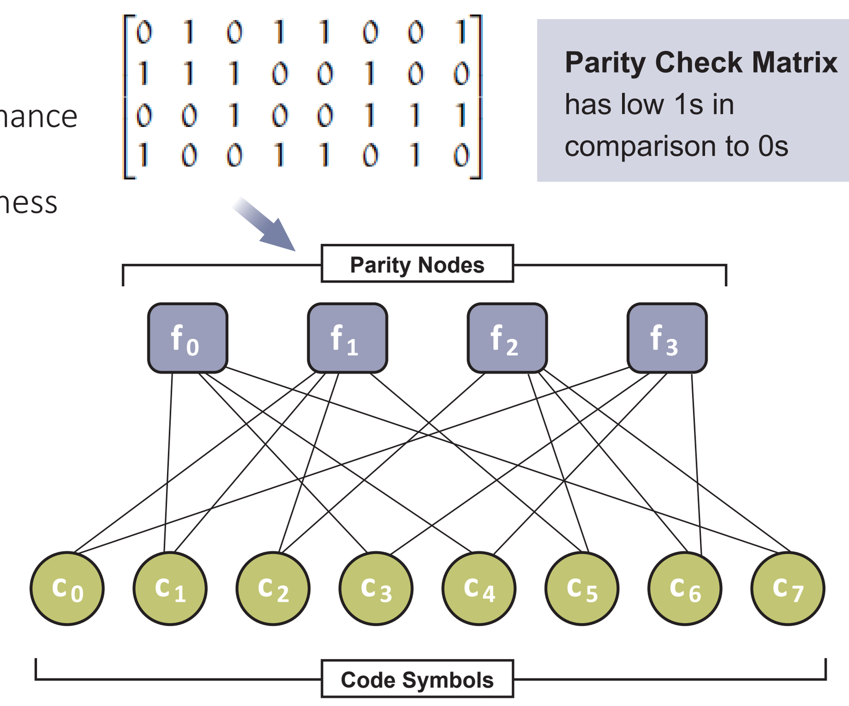
Parity Check Matrix has low 1s in comparison to 0s

Bit Node vs. Parity Node Graph

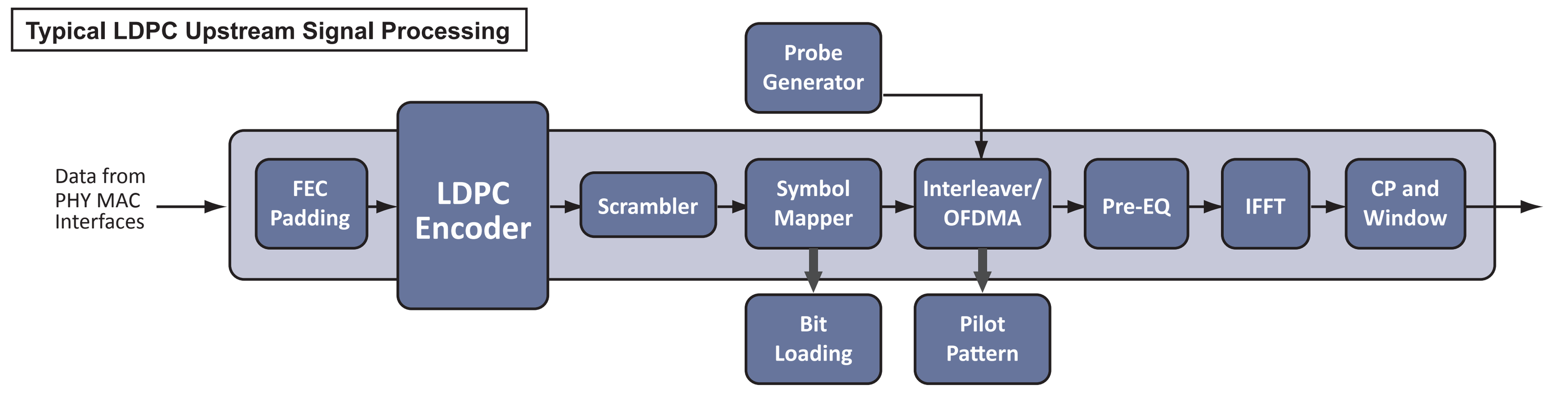
Bit Node = Code Symbol

Parity Node = Parity Equation

A line is drawn between Nodes only if the bit is involved in the parity equation

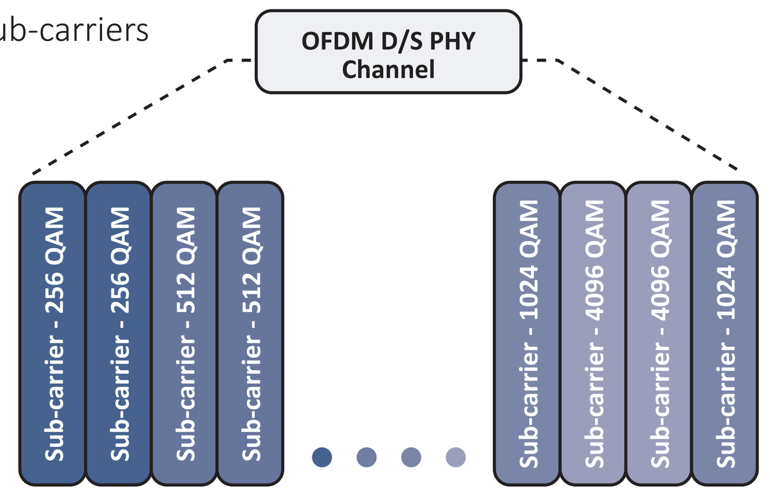


Typical LDPC Upstream Signal Processing



MULTIPLE OFDM SUB-CARRIERS

- OFDM PHY Channel consists of multiplexed Sub-carriers
  - Can be from 24 to 192 MHz wide
- Sub-carriers are individually configurable
  - 25 kHz or 50 kHz Sub-carriers
  - Modulation order: QAM-256, QAM-512, QAM-1024, QAM-2048, QAM-4096
- Sub-carriers can be On or Off depending on:
  - Spectrum availability: co-existence with legacy services
  - Plant conditions
  - Noise disturbers, such as LTE interference



SPECTRUM and CAPACITY

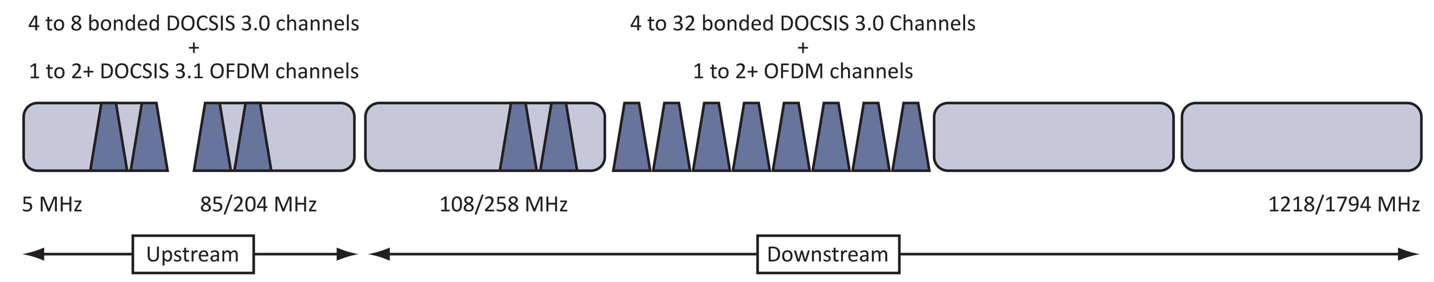
Spectrum Usage

- Backwards compatibility support of D3.0 bonded channels

Spectrum Usage Evolution Example

	Parameter	DOCSIS 3.0 Current	DOCSIS 3.0 Stage 1	DOCSIS 3.1 Stage 2	DOCSIS 3.1 Stage 3
Downstream	Spectrum (MHz)	54 to 1002	108 to 1002	258 to 1218 with Amp upgrade	500 to 1794 with Tap upgrade
	Modulation	QAM-256	QAM-256	QAM-1024 and higher	QAM-1024 and higher
	Equivalent # of Channels	8	24	158	200
	Throughput (bps)	300M	1G	7G	10G+
Upstream	Spectrum (MHz)	5 to 42/65	5 to 85	5 to 204	5 to 400
	Modulation	QAM-64	QAM-64	QAM-256 and higher	QAM-1024 and higher
	Equivalent # of Channels	4	12	32	60
	Throughput (bps)	100M	300M	1G+	2G+

HFC Network Expansion



OFDM Channel Capacity

Channel Capacity = Spectral Efficiency x Channel Bandwidth

Sample Channel Bandwidth

Channel Width	Spectral Efficiency	Channel Capacity
192	8.1996	1.5 Gbps
96	8.1996	787 Mbps
48	8.1996	394 Mbps
24	8.1966	197 Mbps

RF TABLE

RF Channel Transmission Characteristics

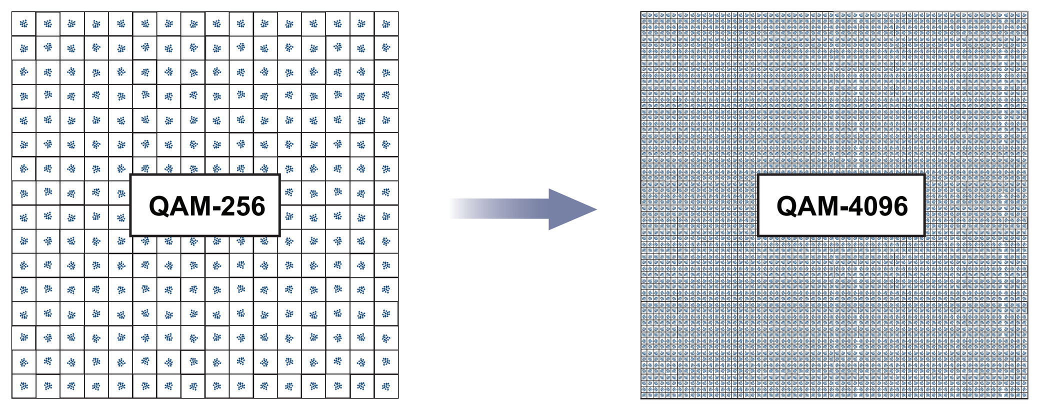
	Parameter	Value	
DOWNSTREAM	Frequency range	54 MHz to 1002 MHz. Extended ranges include lower downstream edges of (108 and 258 MHz) and upper downstream edges of 1218 and 1794 MHz	
	RF channel spacing (design bandwidth)	24 to 192 MHz	
	One way transit delay from headend to most distant customer	≤ 0.400 ms (typically much less)	
	Signal-to-Composite Noise Ratio	≥ 35 dB	
	Carrier-to-Composite triple beat distortion ratio	Not less than 41 dB	
	Carrier-to-Composite second order distortion ratio	Not less than 41 dB	
	Carrier-to-Cross modulation ratio	Not less than 41 dB	
	Carrier-to-any other discrete interference (ingress)	Not less than 41 dB	
	Maximum amplitude variation across the 6 MHz channel (digital channels)	≤ 1.74 dB pk-pk / 6 MHz	
	Group Delay Variation*	≤ 113 ns over 24 MHz	
	Micro-reflections bound for dominant single echo	-20 dBc for echos ≤ 0.5 µs -25 dBc for echos ≤ 1.0 µs -30 dBc for echos ≤ 1.5 µs -35 dBc for echos > 2.0 µs	-40 dBc for echos > 3.0 µs -45 dBc for echos > 4.5 µs -50 dBc for echos > 5.0 µs
	Carrier hum modulation	Not greater than -30 dBc (3%)	
	Maximum analog video carrier level at the CM input	17 dBmV	
	Maximum number of analog carriers	121	
UPSTREAM	Frequency range	From a lower band-edge of 5 MHz to upper band-edge of 42 and 65 MHz. Extended ranges include upper upstream band-edges of 85, 117, and 204 MHz	
	One way transit delay from most distant customer to headend	≤ 0.400 ms (typically much less)	
	Carrier-to-interference plus ingress ratio	Not less than 25 dB	
	Carrier hum modulation	Not greater than -26 dBc (5.0%)	
	Maximum amplitude variation across the 6 MHz channel (digital channels)	≤ 2.78 dB pk-pk / 6 MHz	
	Group Delay Variation*	≤ 163 ns over 24 MHz	
	Micro-reflections bound for dominant single echo	-16 dBc for echos ≤ 0.5 µs -22 dBc for echos ≤ 1.0 µs -29 dBc for echos ≤ 1.5 µs	-35 dBc for echos > 2.0 µs -42 dBc for echos > 3.0 µs -51 dBc for echos > 4.5 µs
	Seasonal and diurnal reverse gain (loss) variation	Not greater than 14 dB min to max	

** Cascaded group delay could exceed the ns value (within 30 MHz above the downstream spectrum's lower band edge and within 10 MHz of the upstream spectrum's lower and upper band edges), depending on cascade depth, diplex filter design, and actual band split.*

HIGHER ORDER QAM

Higher Order QAM Modulation with Dynamic Adaptation

- D3.1 supports multiple modulation profiles: base modulation and higher modulation profiles
- Different profiles can be used depending on customer line quality
- Higher quality lines can utilize higher modulation profiles
- Dynamic adaptation to line conditions. When an impairment appears, the affected OFDM Sub-carrier can downshift to a lower order modulation to help ensure robust, error free transmission



- LDPC FEC can yield a nearly 2 bit gain from Reed Solomon FEC
- Current D3.0 networks that support QAM-256 can support QAM-1024 with D3.1

Modulation Capability

Modulation	SNR Min	SNR Max	bps/Hz
QAM-256	26	29	8
QAM-512	29	32	9
QAM-1024	32	35	10
QAM-2048	35	38	11
QAM-4096	38	41	12

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D99-00-009P Rev.A00 | Source: CableLabs® Data-Over-Cable Service Interface Specifications DOCSIS® 3.1 Physical Layer Specification CM-SP-PHYv3.1-I03-140610