DOCSIS® Today and Beyond …

Presented to the SCTE San Diego Chapter

Society of Cable Telecommunications Engineers
San Diego Chapter

DOCSIS® What’s Next – An Overview

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Cisco Systems

Agenda

- **DOCSIS Today Review**
- DOCSIS 3.1 Drivers – The need for more speed
- DOCSIS 3.1 High Level Overview
- DOCSIS 3.1 Channel Anatomy
- DOCSIS 3.1 Spectrum Options and Deployment Examples

Do you remember when….

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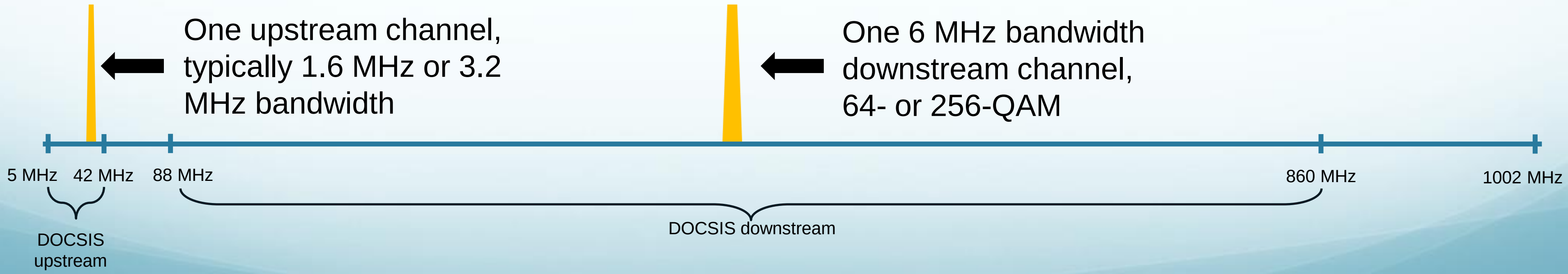
DOCSIS Background

Data-Over-Cable Service Interface Specifications

- **DOCSIS 1.0** gave us standards-based interoperability, which means “certified” cable modems from multiple vendors work with “qualified” cable modem termination systems (CMTSs) from multiple vendors.

- **DOCSIS 1.1** added a number of features, including quality of service (QoS), more robust scheduling, packet classification and other enhancements that facilitate voice services.



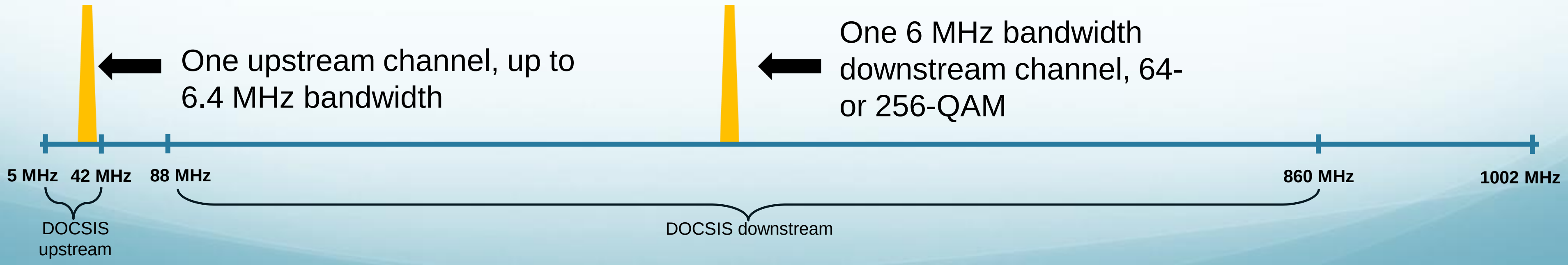
DOCSIS Background

- DOCSIS 1.x supported several upstream data rates, ranging from a low of 320 kbps to a high of 10.24 Mbps. It also supported two modulation formats – quadrature phase shift keying (QPSK) and 16-QAM – as well as five upstream RF channel bandwidths.
- DOCSIS 1.1 added some enhancement to upstream transmission robustness, using 8-tap adaptive pre-equalization.

Channel bandwidth, MHz	Symbol rate, ksym/sec	QPSK raw data rate, Mbps	QPSK nominal data rate, Mbps	16-QAM raw data rate, Mbps	16-QAM nominal data rate, Mbps
0.200	160	0.32	~0.3	0.64	~0.6
0.400	320	0.64	~0.6	1.28	~1.2
0.800	640	1.28	~1.2	2.56	~2.4
1.60	1,280	2.56	~2.3	5.12	~4.8
3.20	2,560	5.12	~4.6	10.24	~9.0

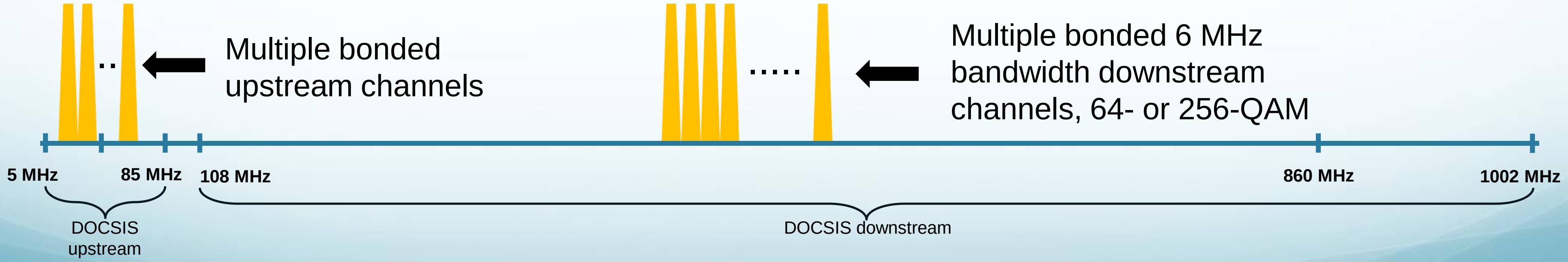
DOCSIS Background

- **DOCSIS 2.0**: Higher upstream data throughput per RF channel, up to 30.72 Mbps
- DOCSIS 2.0 supported 64-QAM in the upstream – plus 8-QAM and 32-QAM – and optionally supported 128-QAM trellis coded modulation (TCM) encoded modulations for S-CDMA channels – and up to 6.4 MHz channel bandwidth.
  - To facilitate more robust upstream data transmission, DOCSIS 2.0 introduced advanced PHY (24-tap pre-equalizer, improved FEC, ingress cancellation, direct sampled RF in burst receiver, etc.)



DOCSIS Background

- **DOCSIS 3.0** introduced channel bonding
  - Logically bond multiple channels to increase data throughput
- RF spectrum changes – Downstream increased to **1 GHz** and upstream increased from 5 MHz to as high as **85 MHz** (optional)
- Includes support for IPv6 and IP Multicast enhancements
  - Prepare for video
- DOCSIS 1.x / 2.0 cable modems can reside on same system



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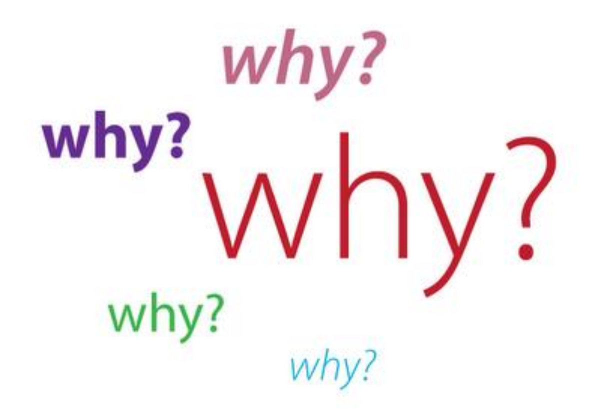
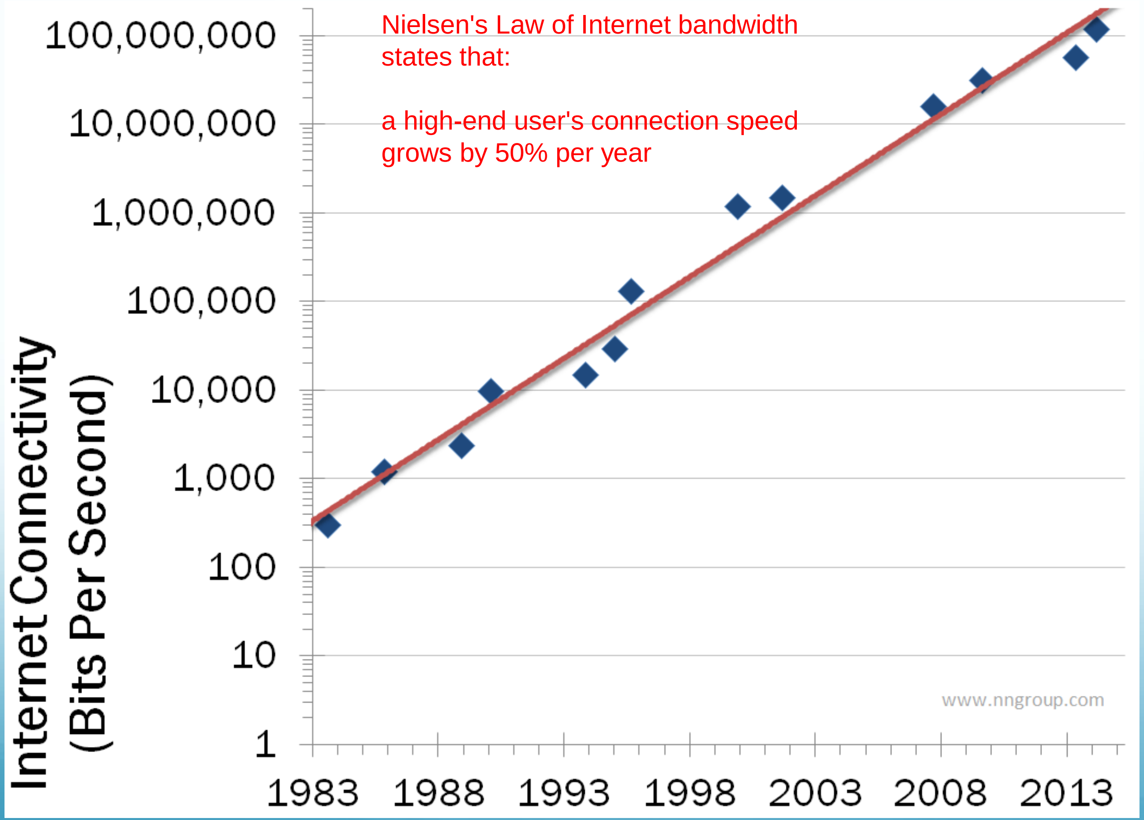
Why DOCSIS 3.1?



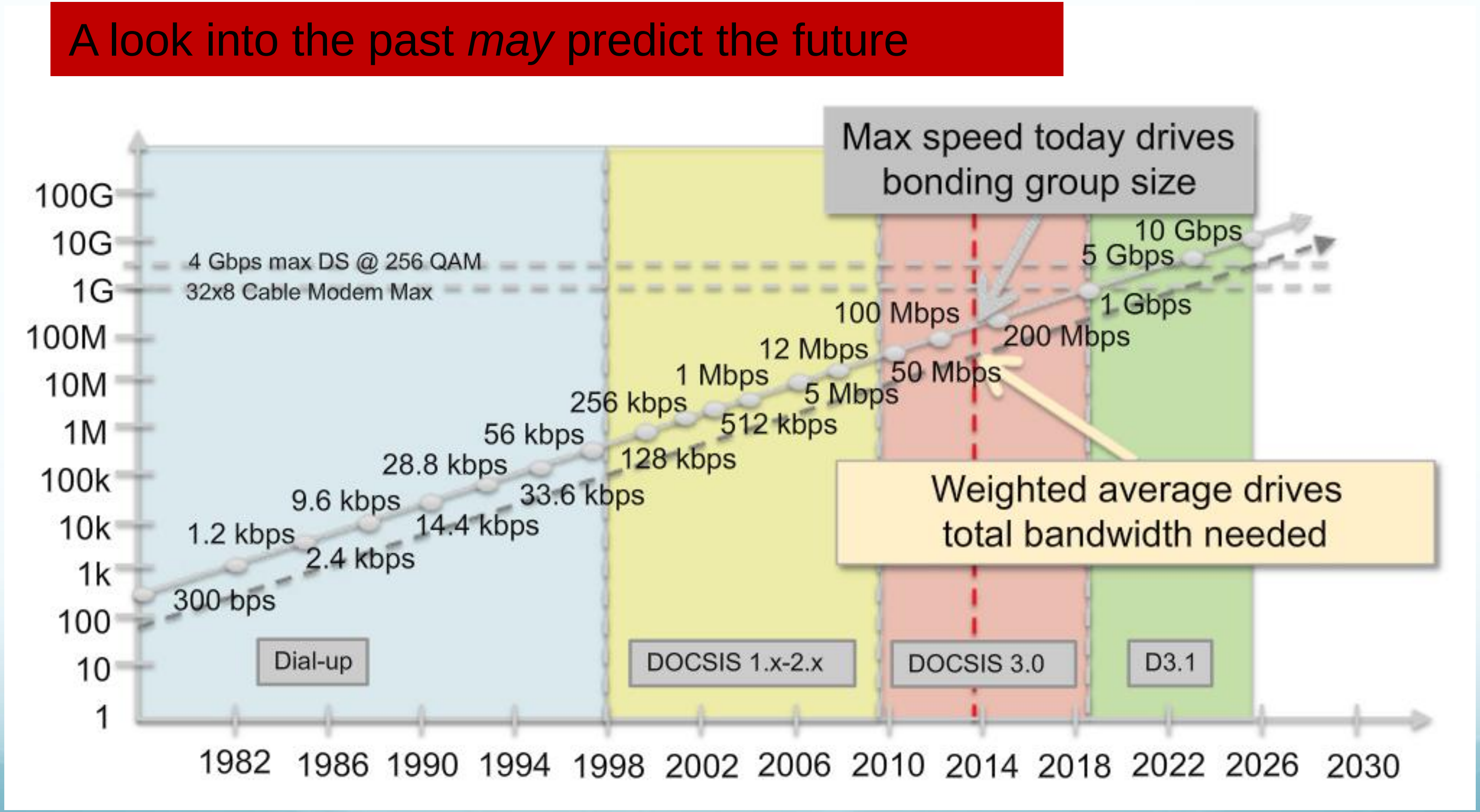
- Why not just continue with DOCSIS 3.0?
  - DOCSIS 3.0 could scale to gigabit-class speeds
  - DOCSIS 3.1 will scale better, and is more spectrally efficient than today's single carrier quadrature amplitude modulation (SC-QAM) technology
- According to CableLabs:
  - *"DOCSIS 3.1 technology will enable a new generation of cable services and help operators continue to meet consumer demand for high speed connections and sophisticated applications, positioning them to be the providers of choice in their markets."*

Nielsens law of Internet Bandwidth

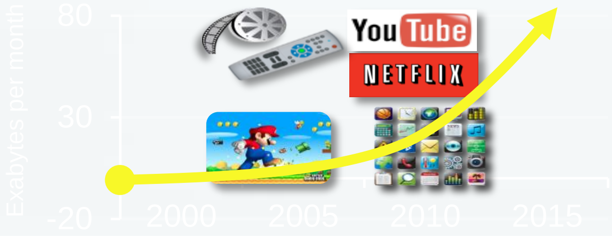


The dots in the diagram show the various speeds with which Nielsen has connected to the Net, from an early acoustic 300 bps modem in 1984 to an ISDN line when he first wrote this article (and updated to show the 120 Mbps upgrade he got in 2014). It is amazing how closely the empirical data fits the exponential growth curve for the 50% annualized growth stated by Nielsen's Law. (The y-axis has a logarithmic scale: thus, a straight line in the diagram represents exponential growth by a constant percentage every year

Ever Increasing Speed Requirements



Consumer Needs Driving New Services



High Bandwidth for Next-gen Services

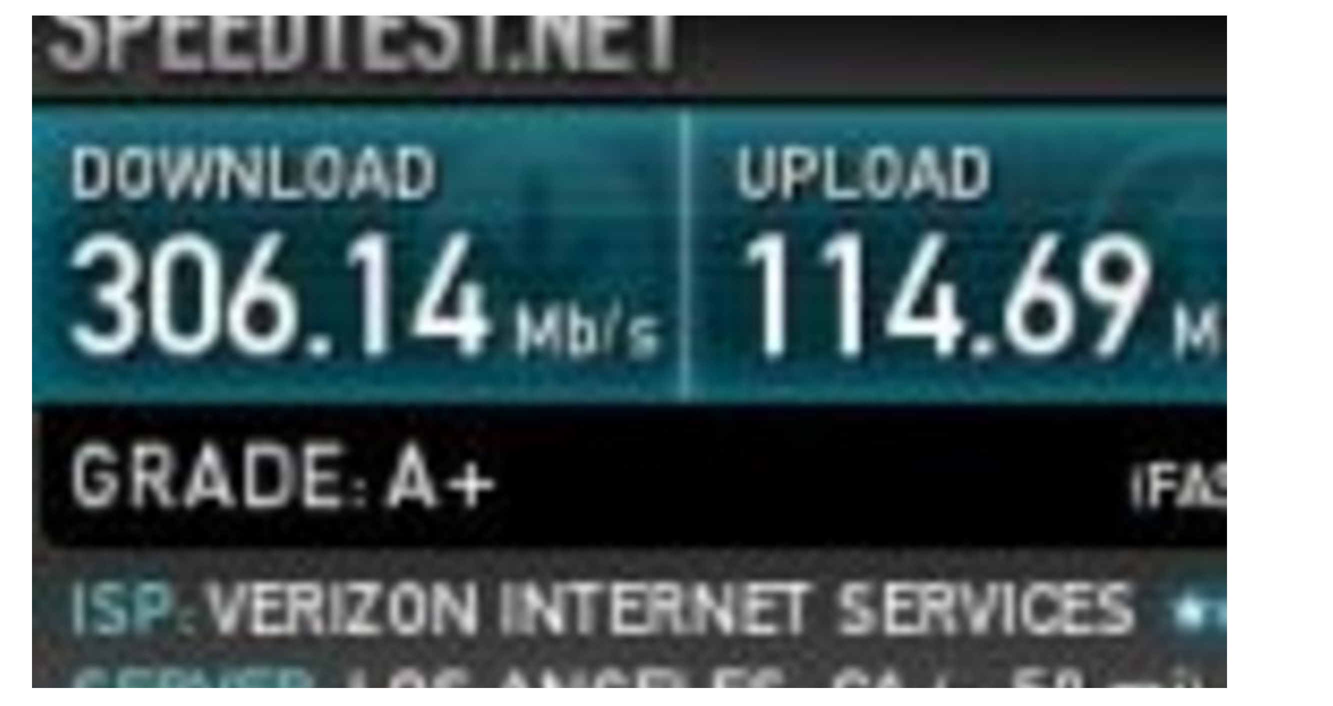
Social TV and Companion Services

A Multi-screen Video Experience

Managed and Unmanaged Devices

Support an Increasing Variety of Services and Common Experiences – At Any Time, Anywhere and on Any Device

Billboard Wars



IoE and IoT is driving Web 3.0

Click on image to view YouTube Video

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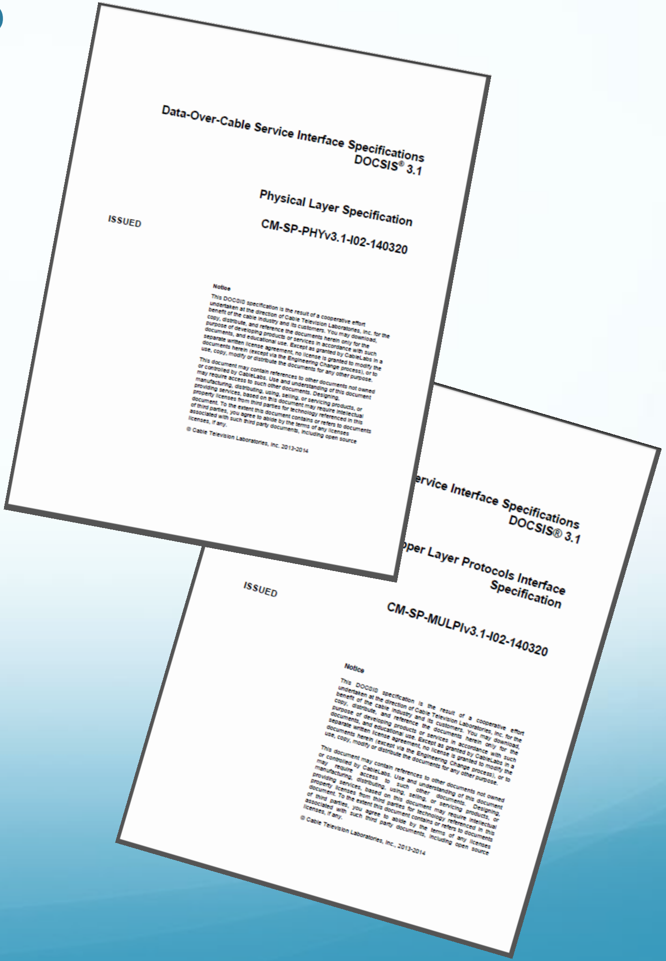
- DOCSIS 3.1 Spectrum Options and Deployment Examples

What is DOCSIS 3.1?

Answer: The latest *Data Over Cable Service Interface Specifications*

CableLabs® released version I01 of the new spec in late October, 2013, version I02 in March, 2014, and version I03 in June, 2014.

(available for download at http://www.cablelabs.com/specs/specification-search/?cat=docsis)



DOCSIS 3.1 Background

- Goals
  - Backwards compatibility with DOCSIS 3.0, 2.0, & 1.1
  - Better spectral efficiency (more bits/Hz)
  - Higher Capacity than D3.0
  - Deployable in today’s networks
- Technology
  - OFDM, OFDMA, LDPC
  - Expanded downstream and upstream spectrum
  - Improved energy efficiency
- This will allow DOCSIS 3.1 to support services competitive with FTTH.

Deployable in today’s HFC networks!

Backwards compatibility

- DOCSIS 3.1 devices will simultaneously support legacy SC-QAM channels and OFDM channels
- Devices will support bonding between OFDM and SC-QAM in order to aggregate that capacity and provide an incremental and orderly migration
- The time division nature of the existing DOCSIS upstream allows for legacy and OFDMA to be time multiplexed
- Allows a gradual and evolutionary introduction of DOCSIS 3.1

D3.1 Improved performance

- New physical layer (PHY) technology: OFDM (orthogonal frequency division multiplex) and OFDMA (orthogonal frequency division multiple access)
  - Better spectral efficiency than SC-QAM
    - Multiple subcarriers per ch
    - Each subcarrier is a QAM signal
- Better forward error correction (FEC): low density parity check (LDPC)
  - More robust than the Viterbi/Reed-Solomon FEC used in earlier versions of DOCSIS
  - 5-6dB SNR Gain

D3.1 Improved performance

- Expanded downstream and upstream RF spectrum usage
  - Downstream: 258 MHz to 1218 MHz, optional to 1794 MHz (and 108 MHz on lower end)
  - Upstream: 5 MHz to 204 MHz
- DOCSIS 3.1 supports larger blocks of spectrum
  - Downstream supports at least 2x192MHz blocks
    - Plus support for SC QAMs
  - US Supports at least 2x96MHz blocks

D3.1 Improved performance

Spectral Efficiency – The amount of bits that fit into a given RF channel bandwidth

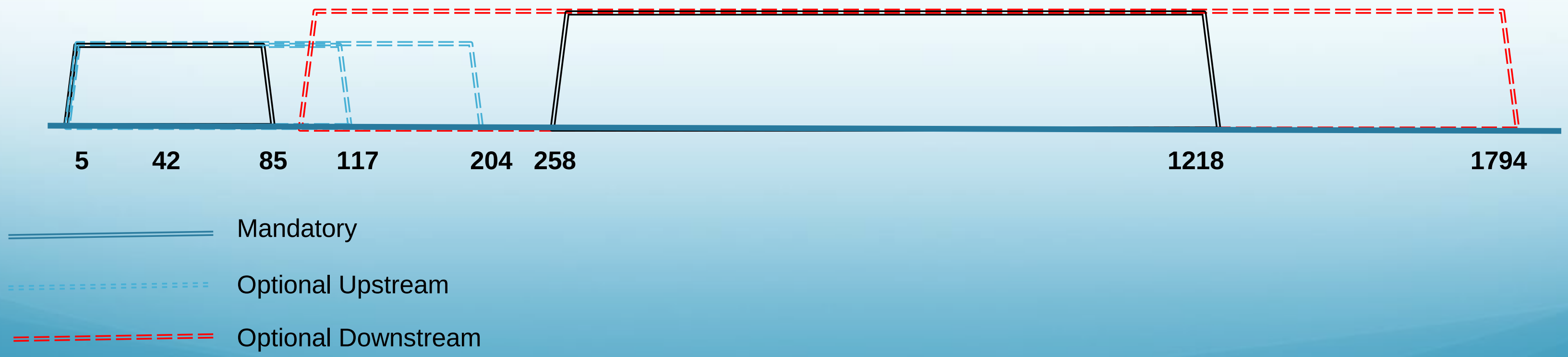
Example DOCSIS 3.1 SNR/MER requirements		Bits per Hz
Modulation order	MER/SNR	
256-QAM	29~30 dB	8
512-QAM	31~33 dB	9
1024-QAM	34~36 dB	10
2048-QAM	37~39 dB	11
4096-QAM	40~42 dB	12

- Assume minimum of 10 b/p/Hz, 192MHz block = ~ 1.9Gbps
- Compare to D3.0, 32 QAMs = 192MHz = ~1.5Gbps

DOCSIS 3.1 Frequency Plans

- **HFC Plant Expansion Options**

- **Extended Frequency Plans**
  - **Downstream**
    - **[108MHz] 258MHz - 1218MHz [1794MHz] [ ] = Optional**
  - **Upstream**
    - **5MHz-42MHz /65MHz /85MHz /108MHz /204MHz**

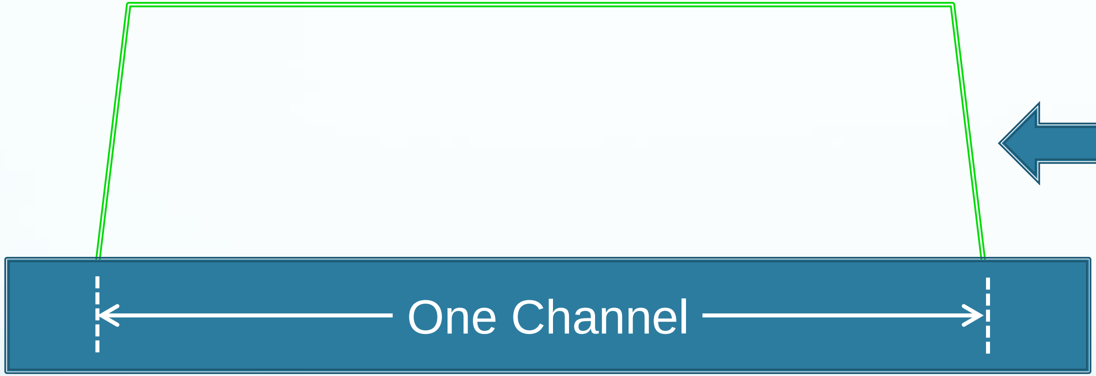


OFDM

- A D3.1 OFDM Channel is comprised of individual subcarriers
  - Spaced at either 25KHz or 50KHz
- Each subcarrier carries a small percentage of the total data payload at a very low data rate.
  - The aggregate of all of the subcarriers' data rates comprises the total data payload.
- This variation of FDM is known as orthogonal frequency division multiplexing, or OFDM, and is used in the DOCSIS 3.1 downstream
- The upstream counterpart is called OFDMA, or orthogonal frequency division multiple access.
  - Time division multiple access (TDMA) also is used, for a two-dimensional sharing of the upstream channel.

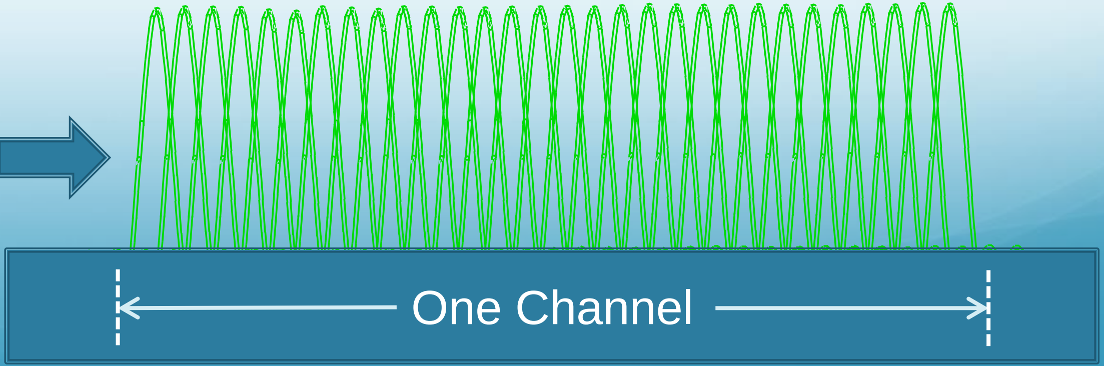
OFDM

One SC-QAM signal within one channel



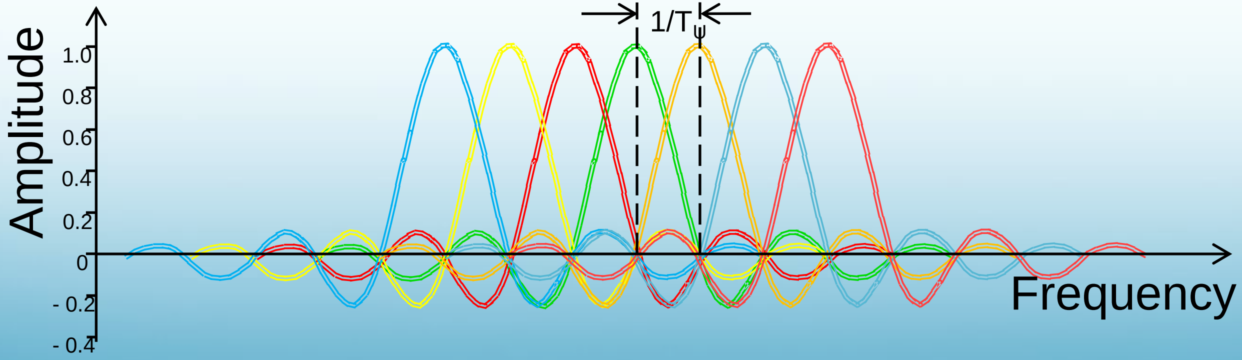
The 6 MHz-wide downstream channel slots defined by the North American CEA-542-D frequency plan can each accommodate one analog NTSC TV signal or one SC-QAM signal.

Multiple subcarriers within one channel



Imagine transmitting a large number of individual very narrow-bandwidth QAM signals – dozens, hundreds or even thousands – within a single channel. Each narrow-bandwidth QAM signal is called a subcarrier.

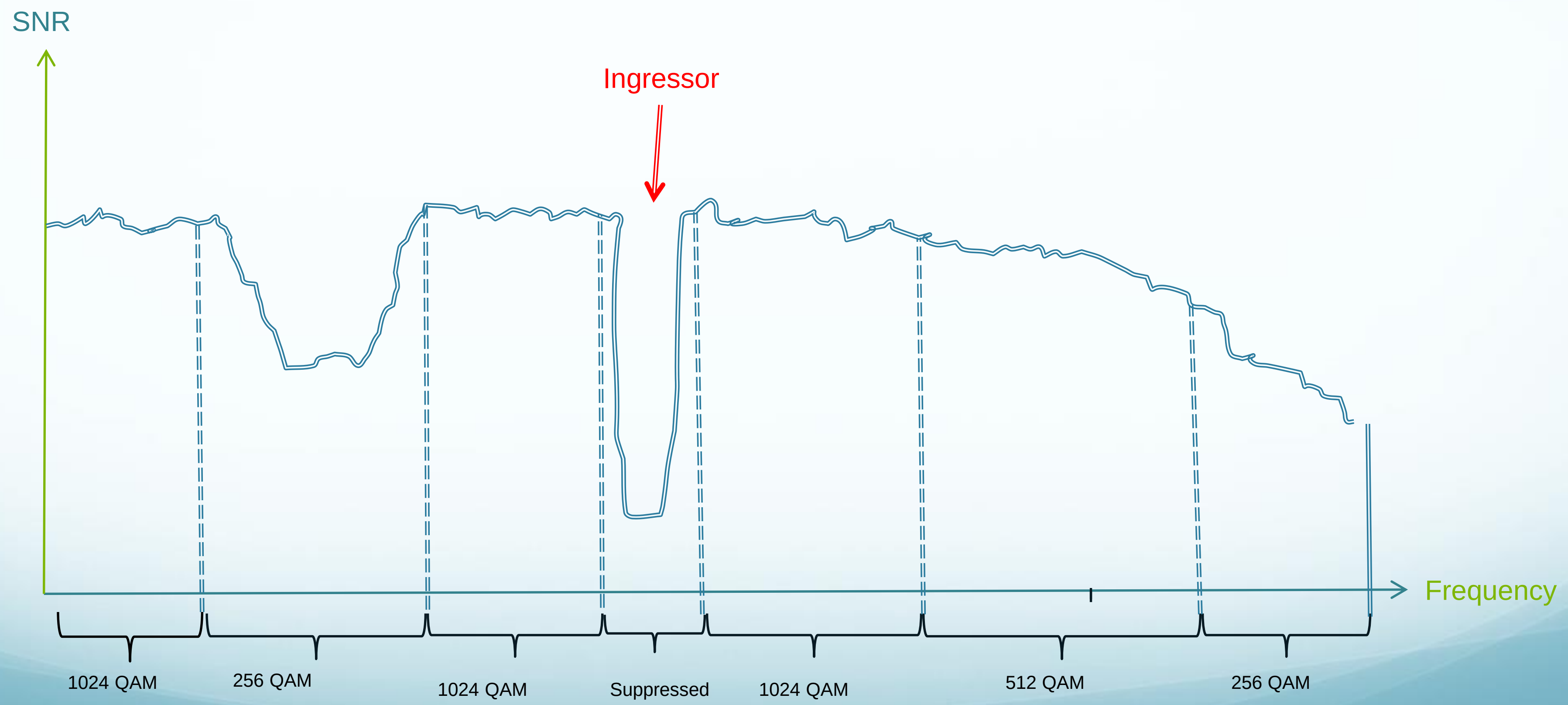
OFDM: Analogy



OFDM

- With OFDM, the concept of a 6 MHz or 8 MHz channel is no longer necessary.
- A DOCSIS 3.1 downstream OFDM channel's bandwidth is up to 192 MHz
- The upstream OFDMA channel bandwidth is up to 96 MHz
- Narrower OFDM and OFDMA channel bandwidths are possible by excluding or "nulling" subcarriers
  - Downstream channel bandwidths: 24 MHz to 192 MHz
  - Upstream channel bandwidths: 6.4 MHz (25 kHz subcarrier spacing) or 10 MHz (50 kHz subcarrier spacing) to 96 MHz

OFDM – Individual Sub-Carrier Management



OFDM

- Optimizes channel capacity
- Granular spectrum allocation
- Maximize cross industry investments
- Consistency with other standards

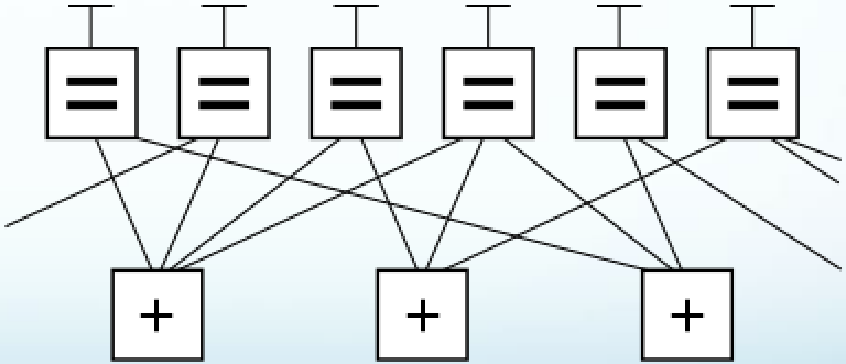
OFDM is a proven technology that enjoys widespread use:

LDPC FEC

- DOCSIS 3.1 uses a form of FEC known as LDPC

- LDPC = low density parity check
  - The concept of LDPC was introduced by Robert G. Gallager in his 1960 Sc.D. thesis at MIT. Because of encoder and decoder complexity, it wasn't practical to implement LDPC until relatively recently

- More robust than Viterbi/Reed-Solomon FEC
  - Provides up to 5~6 dB gain compared to Viterbi/RS FEC



D 3.1 Higher modulation orders: downstream

	CMTS downstream transmit	Cable modem downstream receive	Bits per symbol
MUST	16-QAM	16-QAM	4
MUST	64-QAM	64-QAM	6
MUST	128-QAM	128-QAM	7
MUST	256-QAM	256-QAM	8
MUST	512-QAM	512-QAM	9
MUST	1024-QAM	1024-QAM	10
MUST	2048-QAM	2048-QAM	11
MUST	4096-QAM	4096-QAM	12
MAY	8192-QAM	8192-QAM	13
MAY	16384-QAM	16384-QAM	14

D3.1 Approximate downstream speeds

Single 192 MHz OFDM channel (full channel, no exclusions)

Modulation order	25 kHz subcarrier spacing	50 kHz subcarrier spacing
256-QAM	1.26 Gbps	1.20 Gbps
512-QAM	1.42 Gbps	1.35 Gbps
1024-QAM	1.58 Gbps	1.50 Gbps
2048-QAM	1.73 Gbps	1.65 Gbps
4096-QAM	1.89 Gbps	1.80 Gbps
8192-QAM	2.05 Gbps	1.96 Gbps
16384-QAM	2.21 Gbps	2.11 Gbps

8192-QAM and 16384-QAM are optional, and may not be practical in most of today's plants

D3.1 Higher modulation orders: upstream

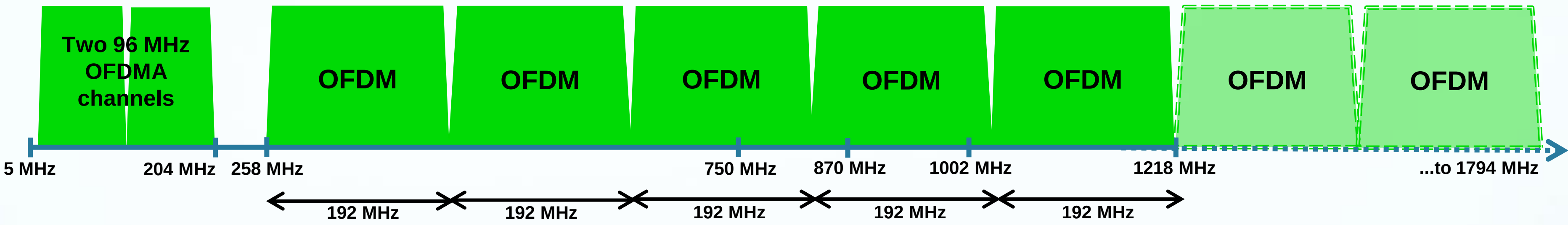
	Cable modem upstream transmit	CMTS upstream receive	Bits per symbol
MUST	QPSK	QPSK	2
MUST	8-QAM	8-QAM	3
MUST	16-QAM	16-QAM	4
MUST	32-QAM	32-QAM	5
MUST	64-QAM	64-QAM	6
MUST	128-QAM	128-QAM	7
MUST	256-QAM	256-QAM	8
MUST	512-QAM	512-QAM	9
MUST	1024-QAM	1024-QAM	10
MUST	2048-QAM	—	11
MUST	4096-QAM	—	12
SHOULD	—	2048-QAM	11
SHOULD	—	4096-QAM	12

D 3.1 Approximate upstream speeds

Single 96 MHz OFDMA channel (full channel, no exclusions)

Modulation order	25 kHz subcarrier spacing	50 kHz subcarrier spacing
64-QAM	0.47 Gbps	0.46 Gbps
128-QAM	0.55 Gbps	0.53 Gbps
256-QAM	0.63 Gbps	0.61 Gbps
512-QAM	0.71 Gbps	0.69 Gbps
1024-QAM	0.78 Gbps	0.76 Gbps
2048-QAM	0.86 Gbps	0.84 Gbps
4096-QAM	0.94 Gbps	0.91 Gbps

Full spectrum DOCSIS 3.1 BW Potential

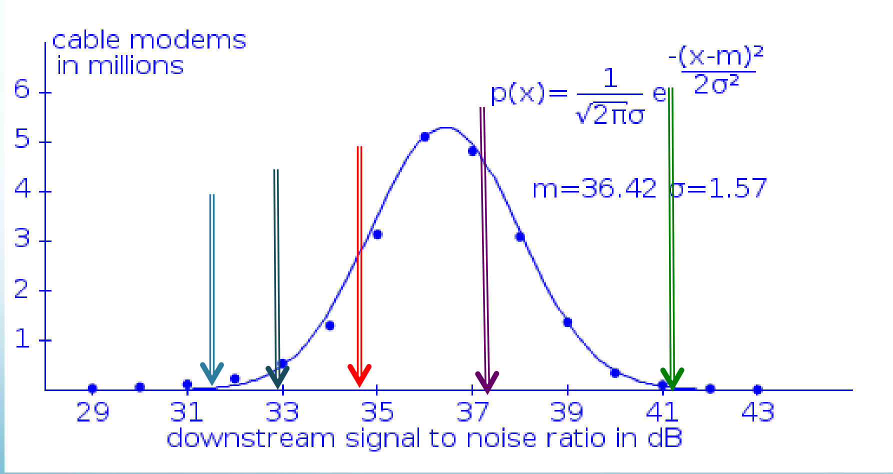


QAM	BW Gbps
64	.94
256	1.26
512	1.42
1024	1.56
2048	1.72
4096	1.88

QAM	BW Gbps
256	6.3
512	7.1
1024	7.8
2048	8.6
4096	9.4

Plant performance?

One cable operator's analysis showed at least 8 dB variation in downstream SNR (MER) among millions of modems:



Example DOCSIS 3.1 SNR/MER requirements	
Modulation order	MER/SNR
256-QAM	29~30 dB
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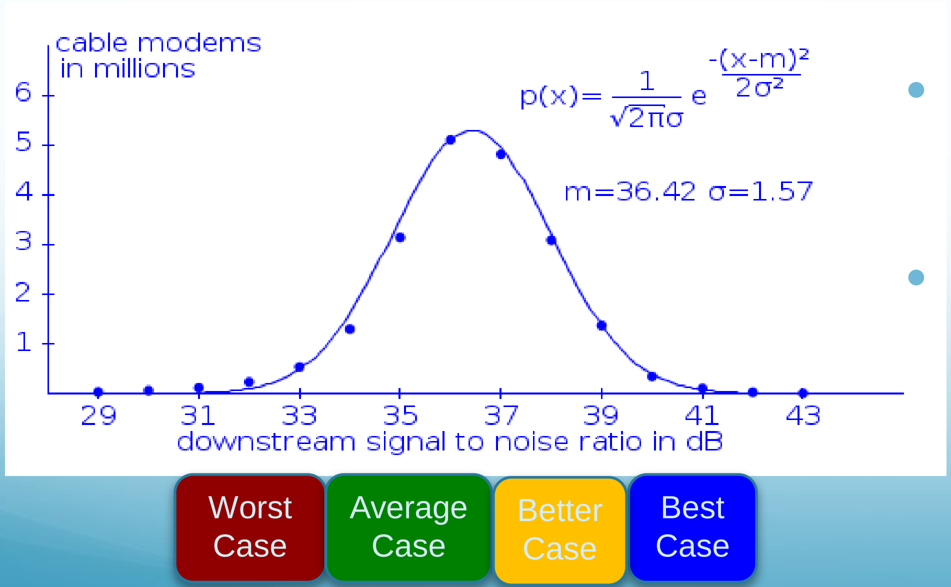
4096-QAM	40~42 dB

Downstream profiles



- Downstream profiles support the transmission of different modulation orders to different modems
- The downstream profiles feature is always used, even if the feature is configured for just one profile
- Multiple downstream profiles could enable operators to leverage SNR/MER variation to improve system capacity
- Example with four profiles:
  - A: Worst (say, mostly 256-QAM)
  - B: Average (say, mostly 1024-QAM)
  - C: Better (say, mostly 2048-QAM)
  - D: Best (say, mostly 4096-QAM)

Profile Management

- Single-profile system works by providing *worst* service to all CMs
- Multi-profile system works by providing *best* overall service to all CMs
- Profile defines bit loading for each subcarrier
- CM reports MER/SNR and RX power of each subcarrier
- CM can test its ability to receive unused profiles and report result
- CMTS updates and publishes profiles
- CMTS assigns CMs to profiles

Upstream Profiles

- Efficient profiles are assigned to CMs with good SNR, robust profiles to CMs with lower SNR
- No energy is transmitted in excluded subcarriers or zero value subcarriers
- Excluded subcarriers skip over narrowband interferers, very noisy spectrum, and legacy carriers
- CM required to support 2 profiles per OFDMA channel at a time; CMTS required to support 4 profiles at one time

DOCSIS 3.1 Key Takeaways

- Introduces a new FEC to DOCSIS (LDPC)
  - Better SNR performance
  - More Bits per Hz
- More overall capacity than D3.0
  - Larger blocks of frequency Spectrum
- Introduces a New Modulation to DOCSIS (OFDM)
- Multiple Modulation Profiles
- Backwards Compatible

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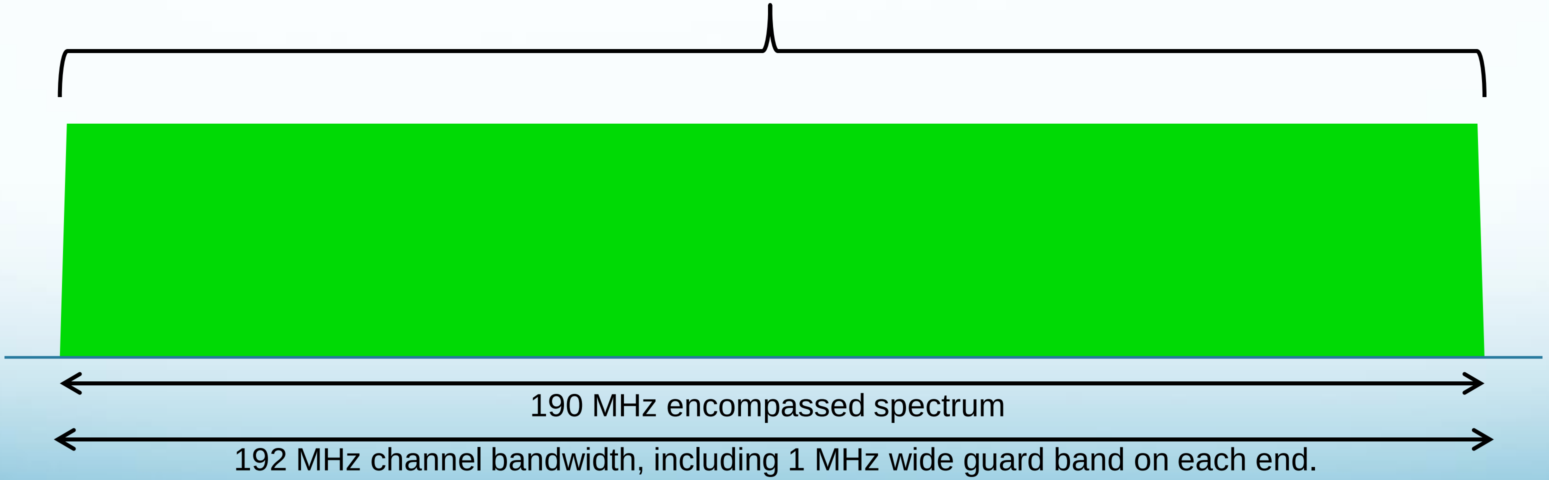
Anatomy of a downstream OFDM channel

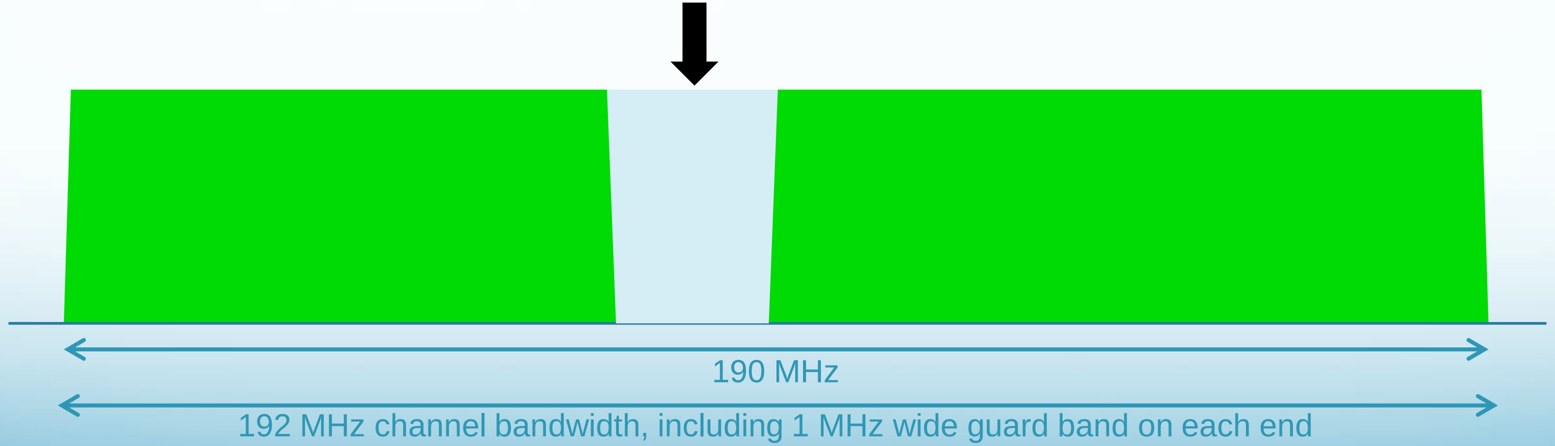
25 kHz subcarrier spacing: 7600 subcarriers (8K FFT)
50 kHz subcarrier spacing: 3800 subcarriers (4K FFT)



Since the guard bands in this example total 2 MHz out of 192 MHz, the equivalent excess bandwidth or “alpha” is (2/192) x 100 ≈ 1%, compared to 12% for DOCSIS 3.0 and earlier 256-QAM SC-QAM.

Anatomy of a downstream OFDM channel

Exclusion bands may be created within an OFDM channel for problems such as strong ingress (e.g., LTE interference), or for the carriage of legacy SC-QAM signals.



An exclusion band is a set of contiguous subcarriers within the OFDM channel bandwidth that are set to zero-value by the transmitter to avoid interference or to accommodate co-existing transmissions such as legacy SC-QAM signals.

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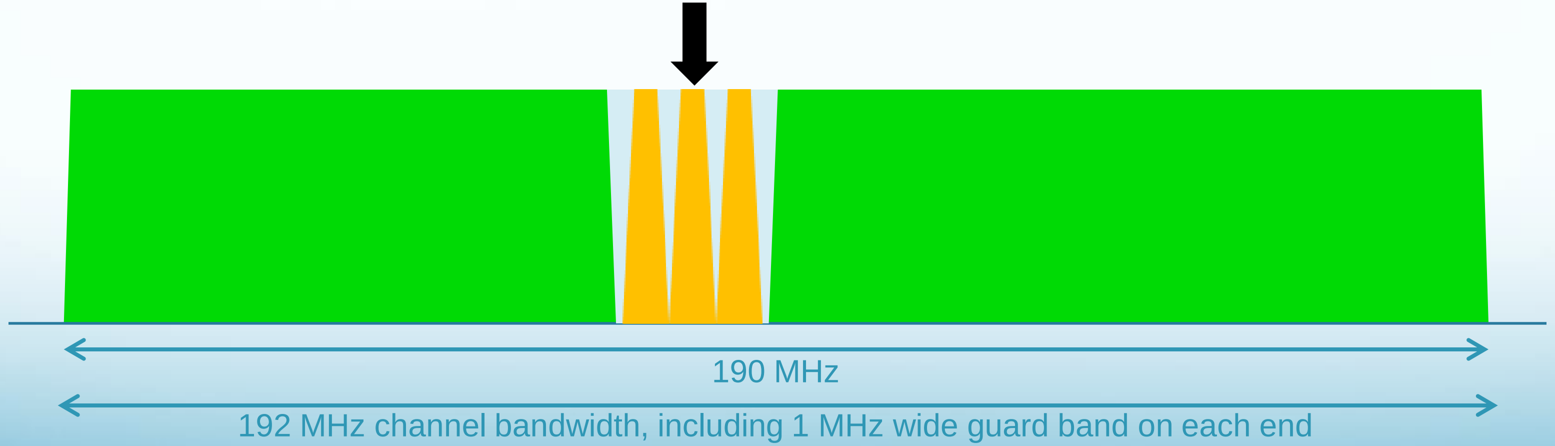

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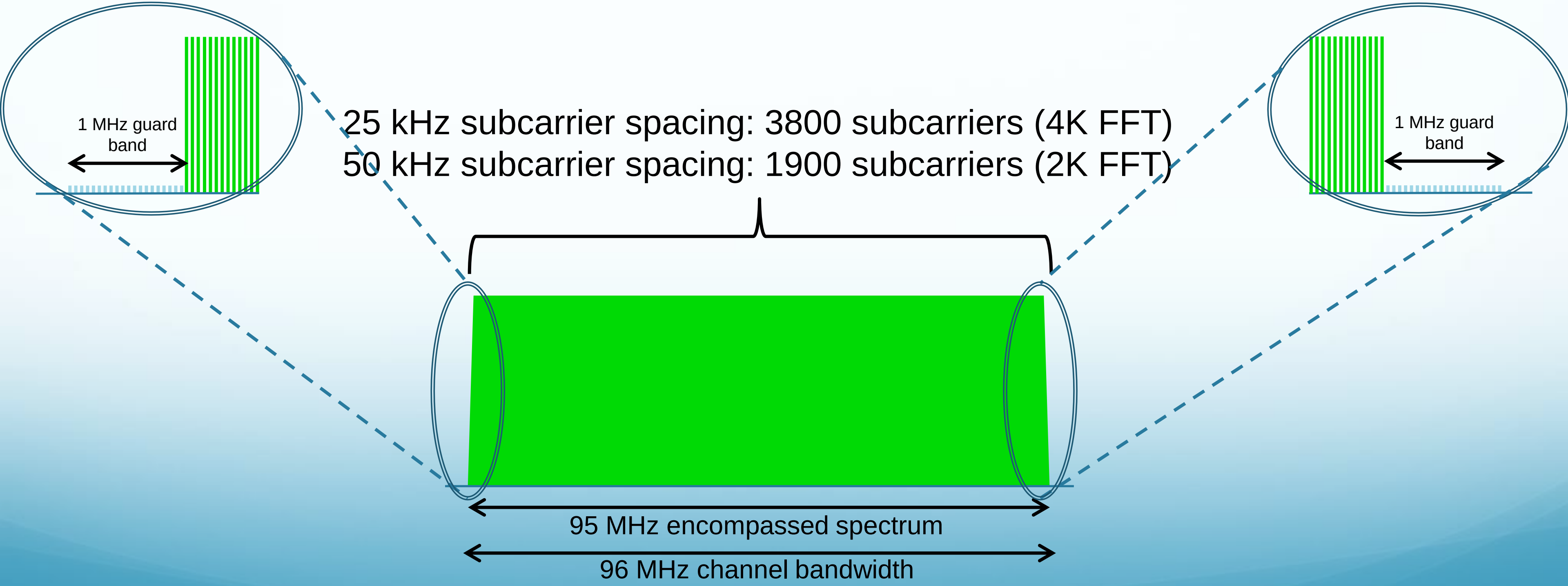
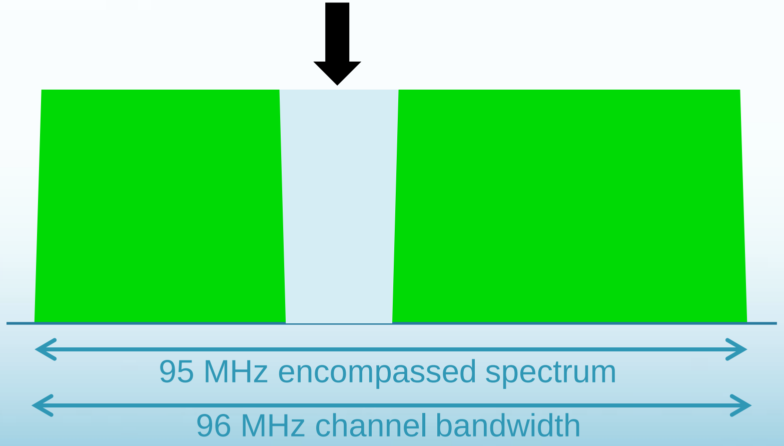
Anatomy of an upstream OFDMA channel



Anatomy of an upstream OFDMA channel

Exclusion bands may be created within an OFDMA channel for problems such as strong ingress (e.g., shortwave, CB radio), or for the carriage of legacy SC-QAM signals.



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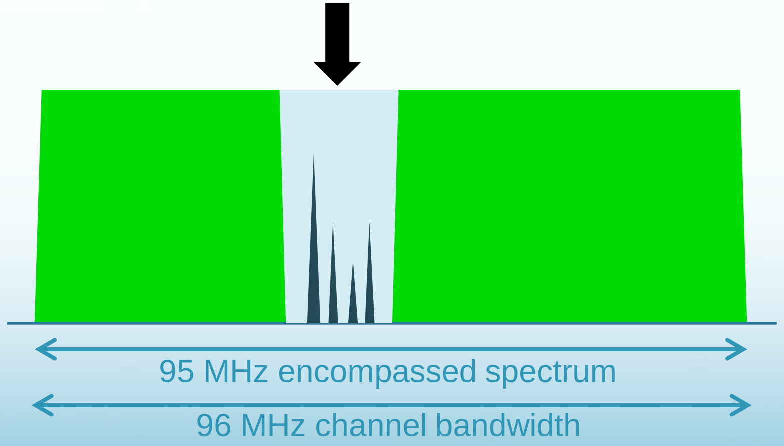

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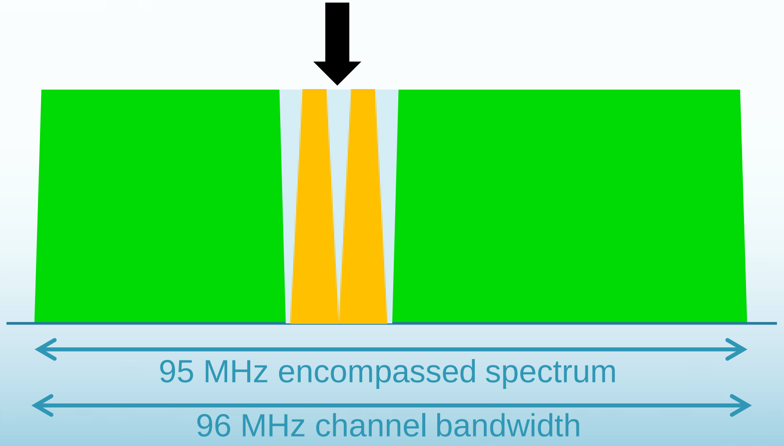
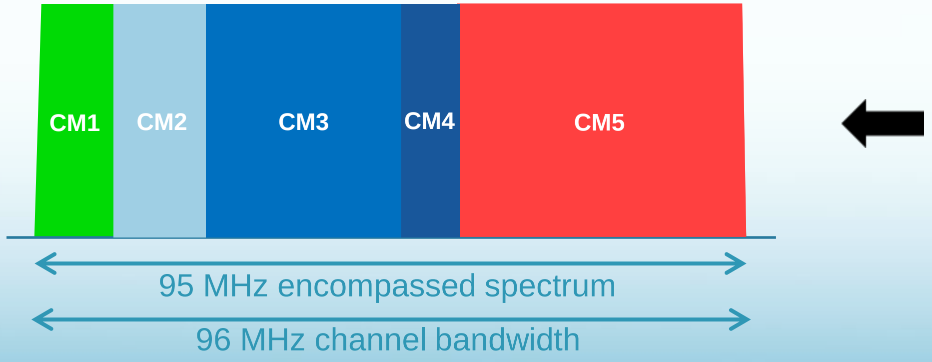


An exclusion band is a set of contiguous subcarriers within the OFDMA channel bandwidth that are set to zero-value by the transmitter to avoid interference or to accommodate co-existing transmissions such as legacy SC-QAM signals.

Anatomy of an upstream OFDMA channel

OFDMA is a multi-user version of OFDM, and assigns subsets of subcarriers to individual CMs.



In this example, five modems are transmitting simultaneously within the same 96 MHz bandwidth OFDMA channel. The different colors represent subsets of the channel's subcarriers assigned to each modem.

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Additional example spectrum options

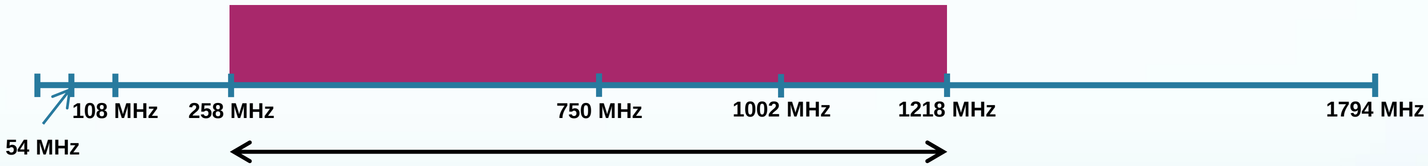
Downstream spectrum options:

1. Initially use 750/862/1002 MHz plant (6 Gbps)
2. Next step is 1218 MHz (7+ Gbps, amp upgrade)
3. Long-term is 1794 MHz (10+ Gbps, tap upgrade)

Upstream spectrum options:

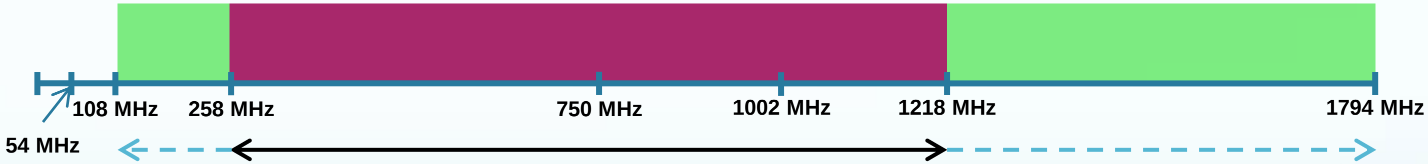
1. Initially use sub-split (42/65 MHz, 200 Mbps)
2. Next step is mid-split (85 MHz, 400 Mbps)

DOCSIS 3.1 downstream frequency usage



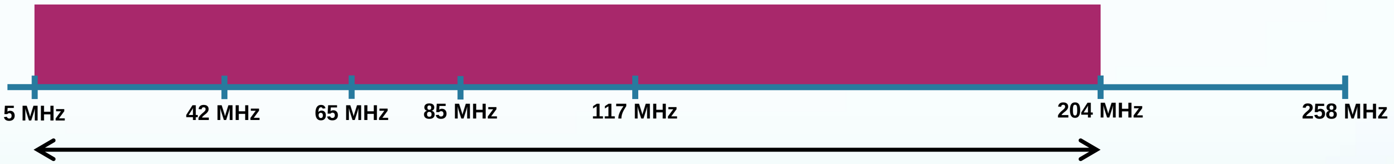
- DOCSIS 3.1 downstream: 258 MHz to 1218 MHz

DOCSIS 3.1 downstream frequency usage



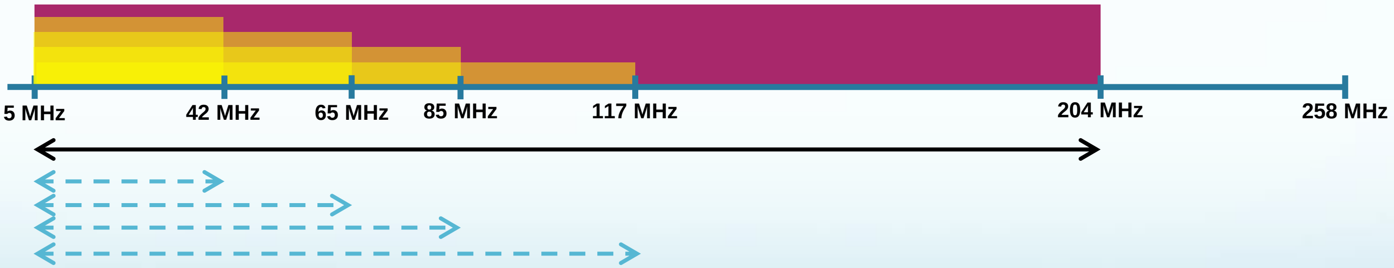
- DOCSIS 3.1 downstream: 258 MHz to 1218 MHz
  - Optional 108 MHz lower end
  - Optional 1794 MHz upper end
- Must support a minimum of two 192 MHz-wide OFDM channels in the downstream

DOCSIS 3.1 upstream frequency usage



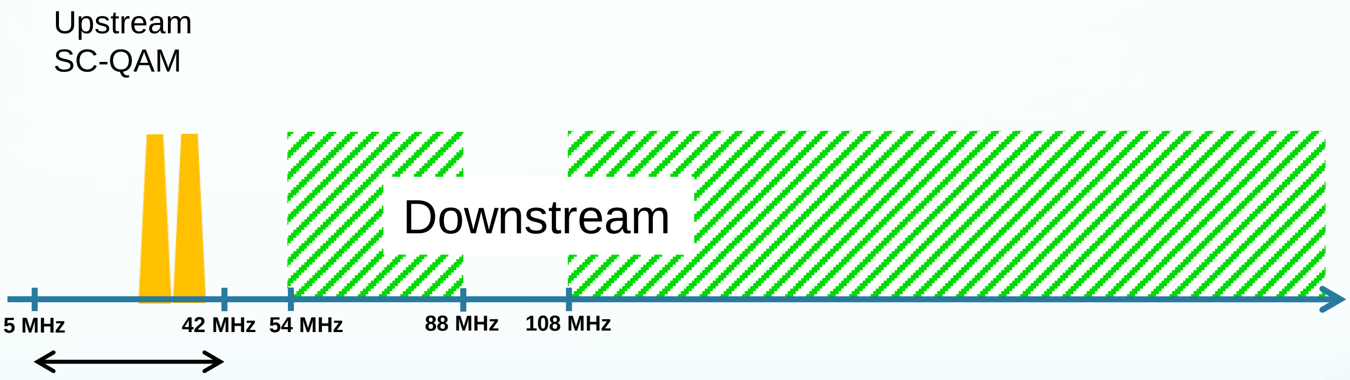
- DOCSIS 3.1 upstream: 5 MHz to 204 MHz

DOCSIS 3.1 upstream frequency usage



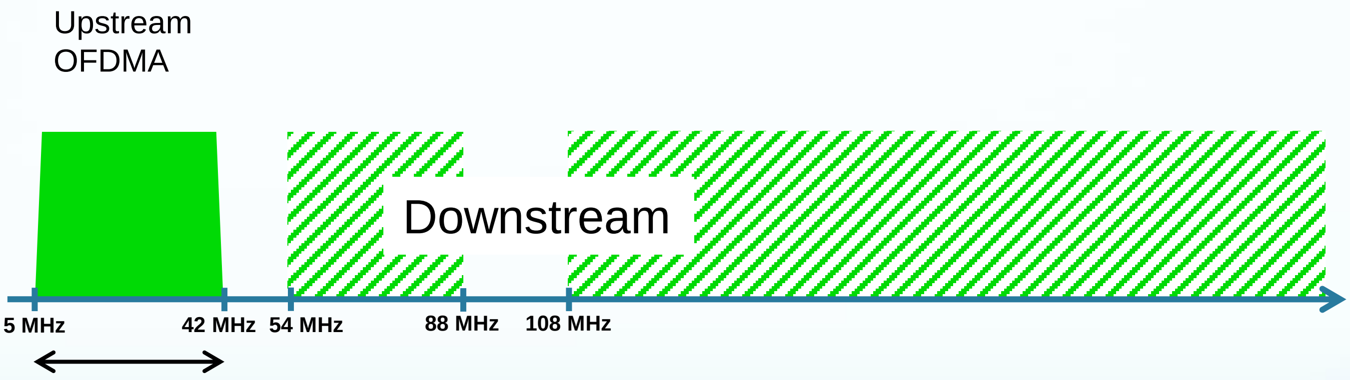
- DOCSIS 3.1 upstream: 5 MHz to 204 MHz
  - Also must support 5 MHz to 42 MHz, 5 MHz to 65 MHz, 5 MHz to 85 MHz, and 5 MHz to 117 MHz
- Must support a minimum of two 96 MHz-wide OFDMA channels in the upstream

DOCSIS 3.1 upstream frequency usage



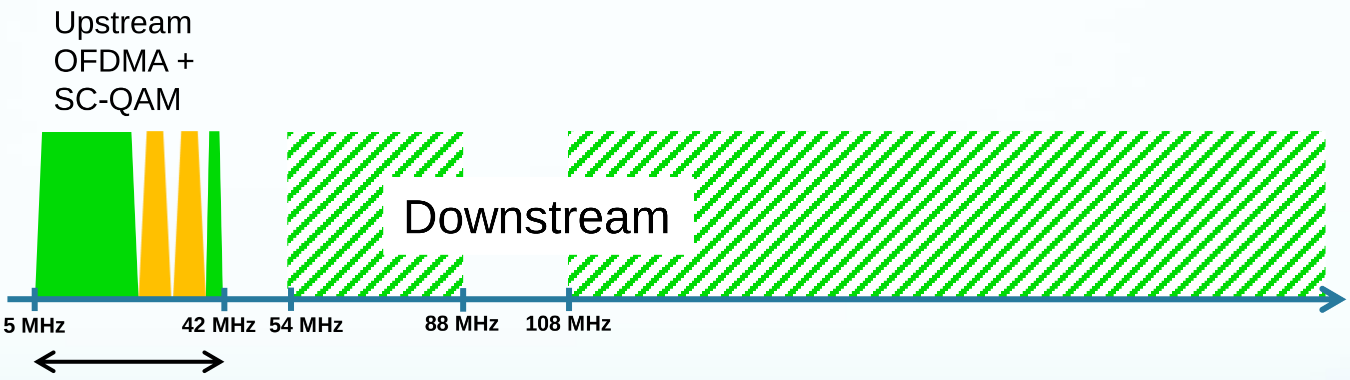
- Using time division duplexing, legacy upstream SC-QAM signals can share the return spectrum with full-bandwidth OFDMA.
  - A DOCSIS 3.0 (or earlier) modem transmits when DOCSIS 3.1 modems are not transmitting

DOCSIS 3.1 upstream frequency usage



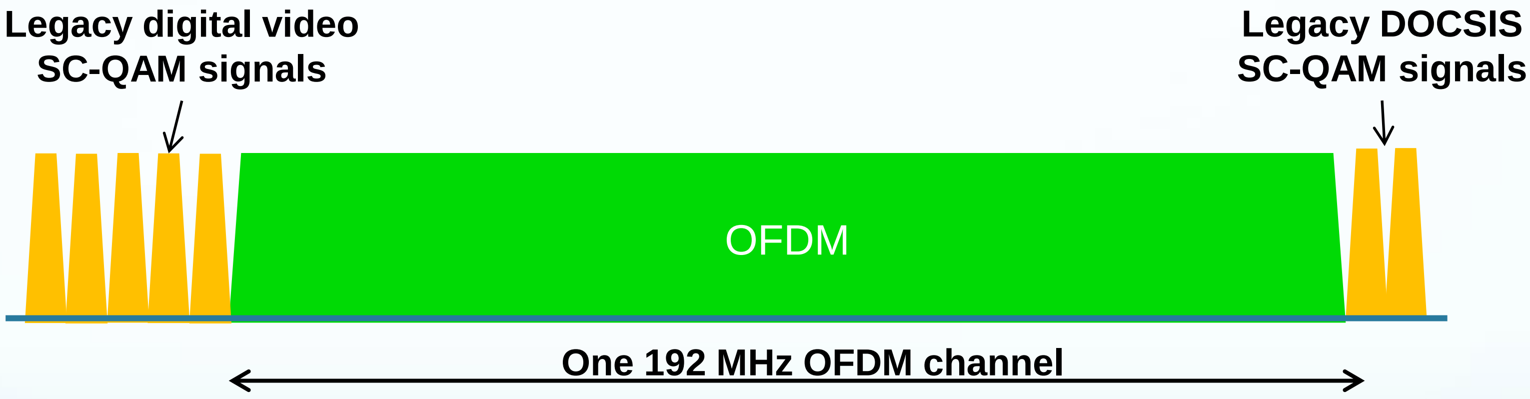
- Using time division duplexing, legacy upstream SC-QAM signals can share the return spectrum with full-bandwidth OFDMA.
  - A DOCSIS 3.1 modem transmits when legacy modems are not transmitting

DOCSIS 3.1 upstream frequency usage



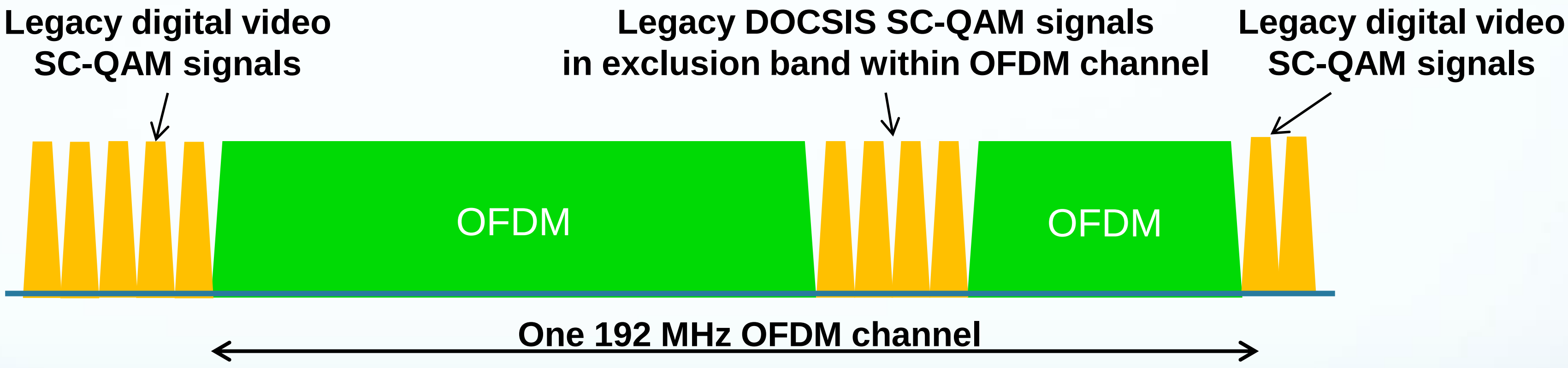
- Alternatively, the OFDMA channel can be configured with an exclusion band to accommodate legacy SC-QAM channels, while the OFDMA signal occupies the rest of the spectrum.
  - This would allow legacy and DOCSIS 3.1 modems to use the spectrum simultaneously

DOCSIS 3.1 deployment example



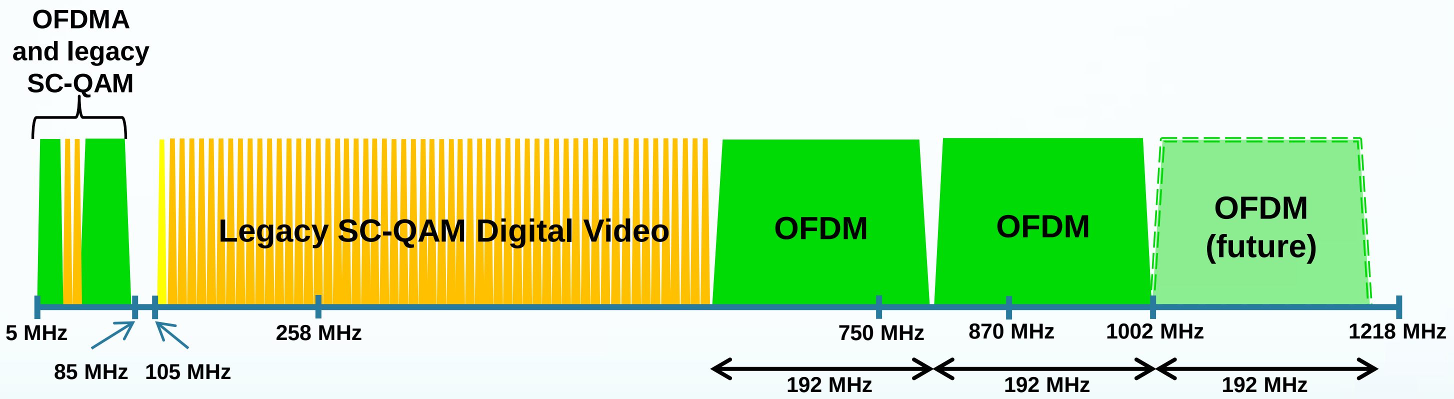
- The OFDM channel can be located in available spectrum
- Windowing can be used to sharpen the spectral edges of the OFDM signal
- Legacy DOCSIS SC-QAM and DOCSIS 3.1 OFDM can be bonded

DOCSIS 3.1 deployment example



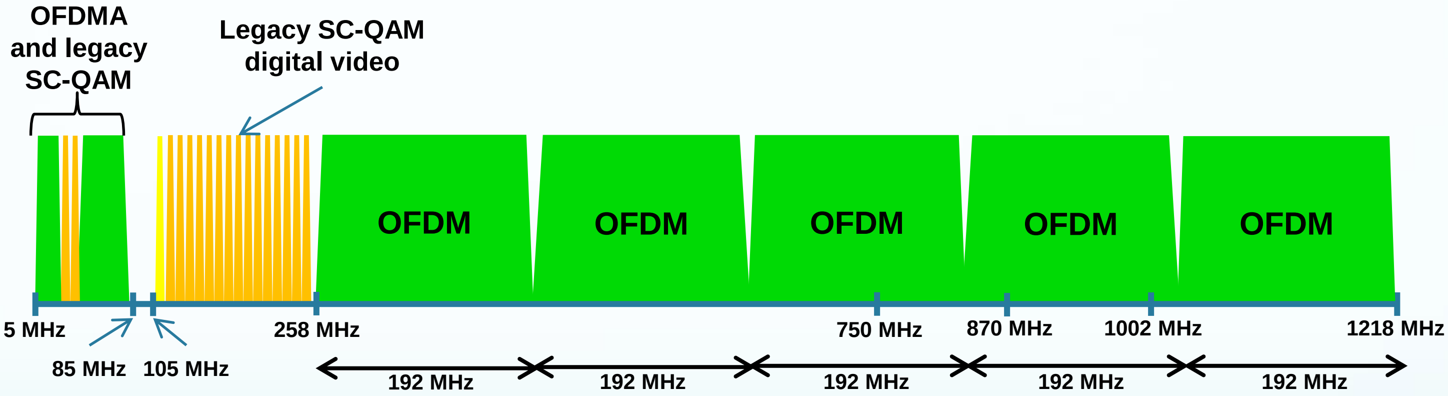
- Excluded subcarriers ("nulling") can be used to facilitate coexistence of an OFDM channel with legacy SC-QAM signals
- The OFDM subcarriers can be located in available spectrum
- As before, legacy DOCSIS SC-QAM and DOCSIS 3.1 OFDM can be bonded

DOCSIS 3.1 deployment example



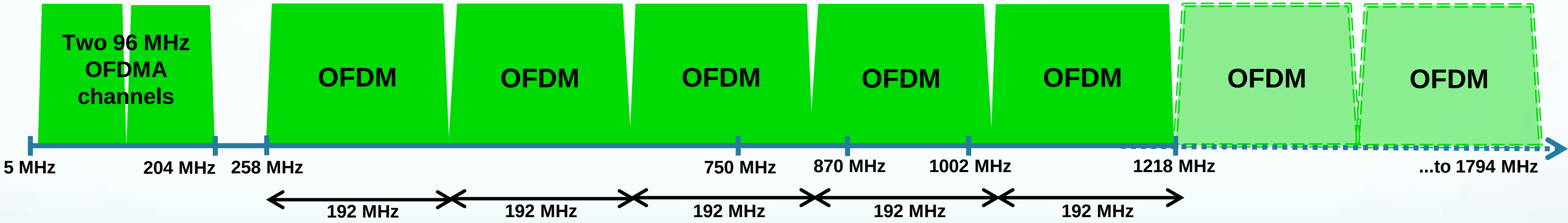
- Upgrade split to 5-85 MHz upstream, 105 MHz to 1002 MHz (or 1218 MHz) downstream
  - Legacy SC-QAM digital video in the 108 MHz to ~600 MHz spectrum
  - Two 192 MHz wide OFDM signals from 618 MHz to 1002 MHz (optional third OFDM >1 GHz)
  - Mix of OFDMA and legacy SC-QAM in upstream
  - Downstream out-of-band for set-tops in the 105~108 MHz range (avoid local FM), although it could be anywhere in the 105 MHz to 130 MHz range, assuming available spectrum.

DOCSIS 3.1 deployment example



- Upgrade split to 5-85 MHz upstream, 105 MHz to 1218 MHz downstream
  - Legacy SC-QAM digital video in the 108 MHz to 258 MHz spectrum
  - Five 192 MHz wide OFDM signals from 258 MHz to 1218 MHz
  - Mix of OFDMA and legacy SC-QAM in upstream
  - Downstream out-of-band for set-tops in the 105~108 MHz range (avoid local FM), although it could be anywhere in the 105 MHz to 130 MHz range, assuming available spectrum.

Full spectrum DOCSIS 3.1 deployment example



- Upgrade split to 5-204 MHz upstream, 258 MHz to 1218 MHz downstream (optionally to 1794 MHz)
  - Five 192 MHz wide OFDM signals from 258 MHz to 1218 MHz
  - Optionally another three 192 MHz wide OFDM signals between 1218 MHz and 1794 MHz
  - Two 96 MHz wide OFDMA signals in the 5 MHz to 204 MHz spectrum

Summary

- New PHY layer: OFDM, OFDMA, and LDPC
- Higher modulation orders
- New spectrum usage options
- Takes DOCSIS to full-spectrum capability
- Cost-effectively scales to 10+ Gbps in the downstream, 2+ Gbps in the upstream
- FTTH equivalent at lower price point on an existing HFC plant
- Deployable in today's HFC networks

Thank You