SCTE · ISBE

An Overview of DOCSIS® 4.0 FDD "Extended Spectrum" and the OSP

June 23 2020

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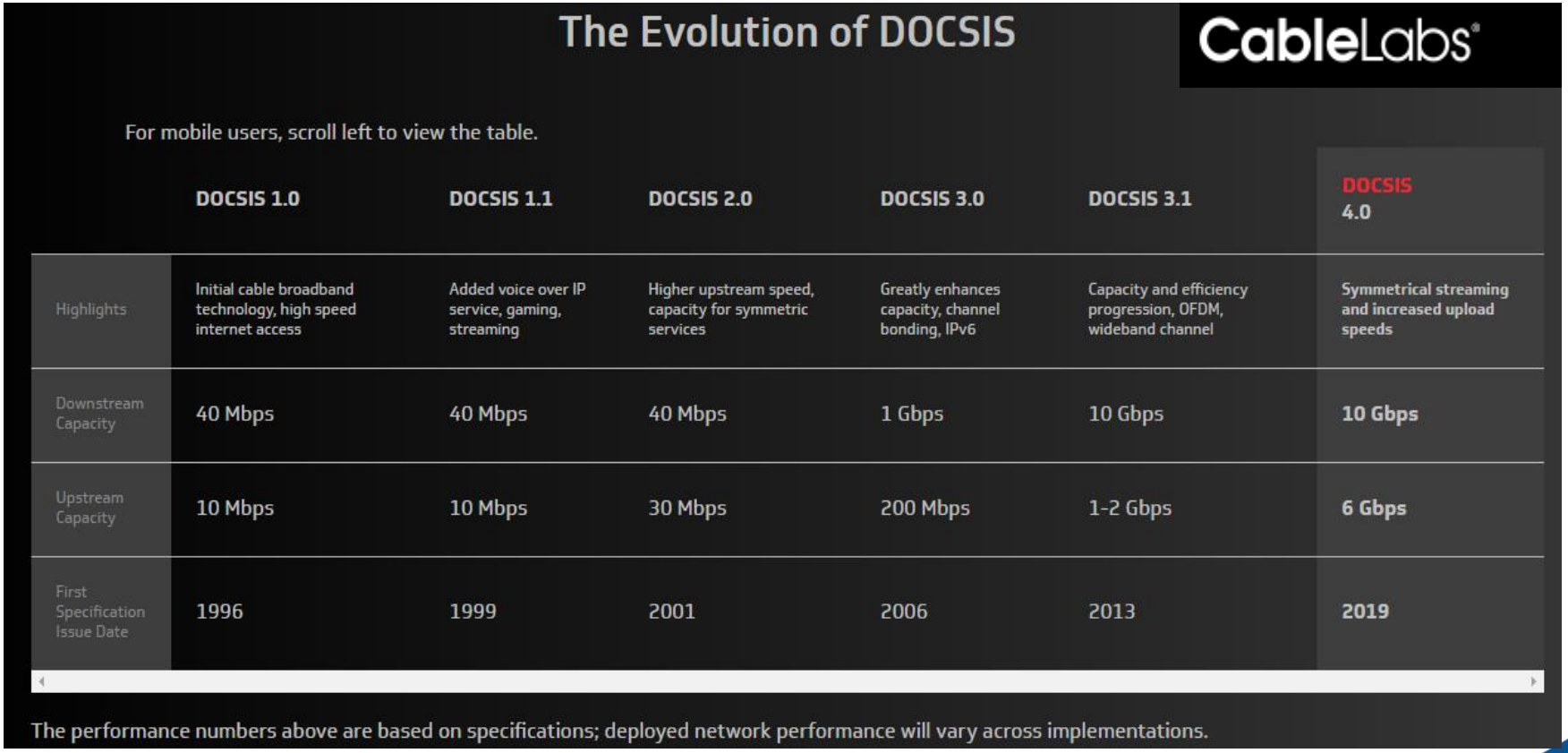
Agenda

- The Evolution of DOCSIS
- The DOCSIS 4.0 Story
- OFDM and OFDMA Overview
- A Quick Look at D4.0 FDX
- D4.0 FDD Overview
- D4.0 FDD OSP Architecture and Equipment Considerations

The DOCSIS ® Evolution



The Evolution of DOCSIS

CableLabs

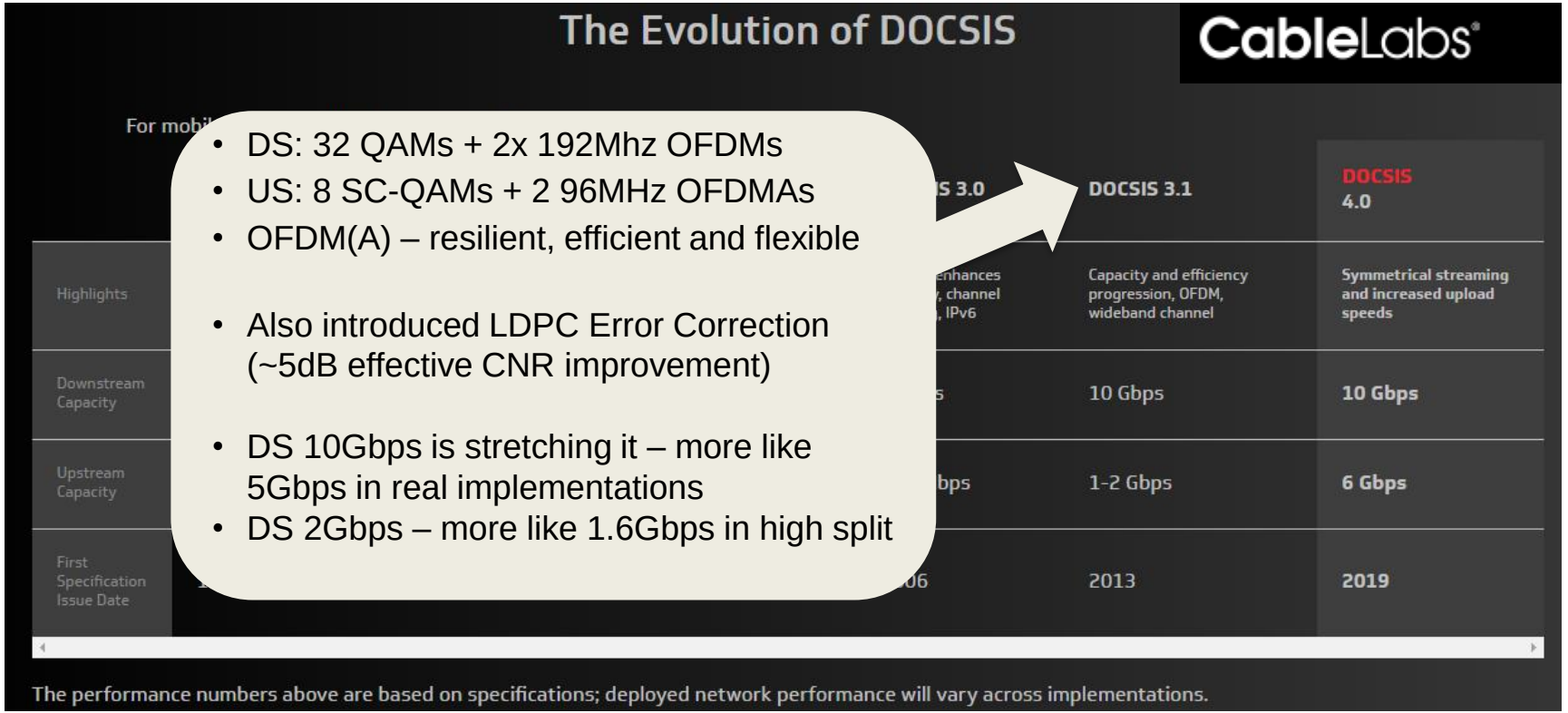
For mobile users, scroll left to view the table.

	DOCSIS 1.0	DOCSIS 1.1	DOCSIS 2.0	DOCSIS 3.0	DOCSIS 3.1	DOCSIS 4.0
Highlights	Initial cable broadband technology, high speed internet access	Added voice over IP service, gaming, streaming	Higher upstream speed, capacity for symmetric services	Greatly enhances capacity, channel bonding, IPv6	Capacity and efficiency progression, OFDM, wideband channel	Symmetrical streaming and increased upload speeds
Downstream Capacity	40 Mbps	40 Mbps	40 Mbps	1 Gbps	10 Gbps	10 Gbps
Upstream Capacity	10 Mbps	10 Mbps	30 Mbps	200 Mbps	1-2 Gbps	6 Gbps
First Specification Issue Date	1996	1999	2001	2006	2013	2019

The performance numbers above are based on specifications; deployed network performance will vary across implementations.

Continuing to leverage the HFC Network

The DOCSIS ® Evolution



- DS: 32 QAMs + 2x 192Mhz OFDMs
- US: 8 SC-QAMs + 2 96MHz OFDMAs
- OFDM(A) – resilient, efficient and flexible

- Also introduced LDPC Error Correction (~5dB effective CNR improvement)

- DS 10Gbps is stretching it – more like 5Gbps in real implementations
- DS 2Gbps – more like 1.6Gbps in high split

The DOCSIS ® 4.0 Story

- Today DOCSIS 3.1 is ROCKING!!
  - Significant deployment in NA and EMEA
  - Today, after a few false starts/iterations with Fiber Deep and FDX (talk about this more) vast majority of MSOs plan to exploit it further with mid split or high split upgrades
  - D3.1 return path is still rather anemic – 204Mhz high split yields approx. 1.6GB/s translating to ~ 1GB/s billboard rates – spectrum limited

LightReading

Most Larger NA MSOs Have Rolled Out DOCSIS 3.1

MSOs	Deployments
Comcast	Now offers DOCSIS 3.1 to virtually whole footprint after completing rollout in Oct. 2018
Charter Communications	Now offers D3.1 to about 95% of its footprint; aimed to wrap up rollout by end of 2018
Cox Communications	Now offers D3.1 to over 50% of its footprint; plans to reach 99% coverage by end of 2019
Altice USA	Despite plans to build FTTH networks, now quietly rolling out D3.1 in New York area
Mediacom Communications	One of the first MSOs to deploy D3.1, it now offers service to virtually all its footprint
Shaw Communications	Now offers D3.1 service to virtually all its Canadian homes, using Comcast's Xb6 modems
Midco	Another early D3.1 adopter, it now offers service to over 90% of its footprint
WOW	Has now rolled out D3.1 to at least 95% of its footprint
Rogers Communications	Now offers D3.1 service to virtually all its Canadian homes, using Comcast's Xb6 modems
Cable One	Now offers 1-Gig service to 95% of footprint; but relying solely on D3.0, not D3.1
RCN	Offers D3.1 in all legacy markets; now upgrading former Wave Broadband markets
Atlantic Broadband	Has rolled out DOCSIS 3.1 to 90% of its footprint
BCI	Now offers D3.1 to 99.9% of homes in footprint
Videotron	Has broadly deployed DOCSIS 3.1 throughout its Quebec markets
Cogeco Connexion	Now offers D3.1 service Has to 60% of its Ontario and Quebec homes

LightReading

While DOCSIS 3.1 Era Also Underway in Europe

MSO	Deployments
Liberty Global	Plans to offer DOCSIS 3.1 service to its nearly 15 million UK homes by the end of 2021, after starting with Southampton and Manchester launches this fall
Vodafone	Launched D3.1 in four Bavarian cities in fall 2018, covering 400,000 homes; aims to offer service to 13 million German homes by the end of 2020
Com Hem (Tele2)	Has upgraded most of its HFC network in Sweden for D3.1, with many small sites left
Stofa	Has now deployed D3.1 and DAA to 60% to 65% of its 400,000-home network in Denmark, with plans to reach 90% to 95% coverage by spring 2021
TDC	Planned to complete rollout of D3.1 in Denmark by the end of 2018
NOS	Has completed full network upgrade to D3.1 in Portugal and developed D3.1 routers
Telenet	Started rolling out D3.1 service in Belgium in Sept. 2019
Eltrona	Launched D3.1 service in Luxembourg in September 2018
Melita	Completed upgrading its Malta network to D3.1 in April 2019

The DOCSIS ® 4.0 Story

- The industry wants more!!
  - Upstream Capacity increase of particular interest – trend towards symmetrical services (compete vs. FTTH/PON)
  - CLs 10G symmetrical is group of technologies to be developed with the goal of getting to 10G symmetrical target (DOCSIS 4.0 is one of those)
  - To meet these demands and before anything above 1.2GHz was contemplated ….
    - MSOs were aligning with the concept of pushing fiber deep (Revolution not a Evolution) / D3.1 was added in
    - Full Duplex DOCSIS (a fiber deep technology) was being developed as the next DOCSIS technology

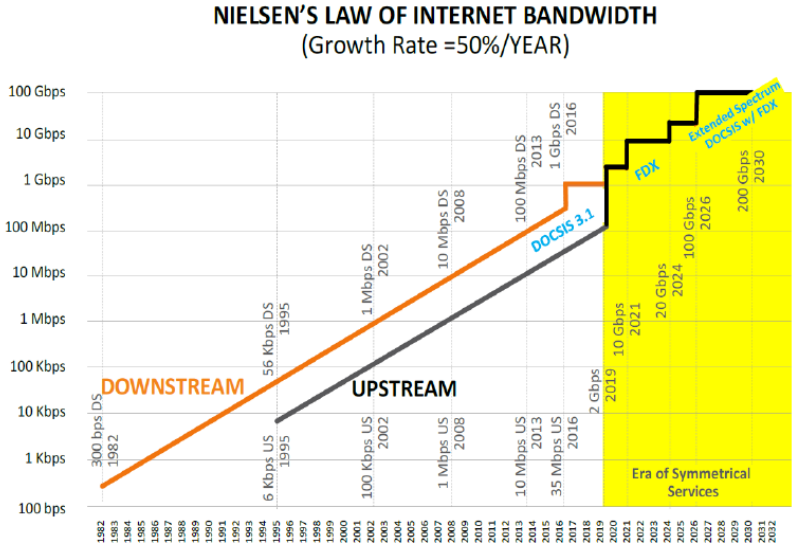


Figure 1 – Nielsen's Law of Internet Bandwidth – Tom Cloonan (Arris)

Why do we need the 10G platform?

10G
The Next Great Leap for Broadband

Our digital future will stall without a platform that can meet our needs. While we don't know what the next trend will be, we do know the internet will be central to it. By advancing device and network performance to stay ahead of consumer demand, 10G will provide a myriad of new immersive digital experiences and other emerging technologies that will revolutionize the way we live, work, learn and play. Like the saffron in paella, or the milk in a latte, our industry's networks and innovations are the crucial ingredients in creating a better future for humanity.

Watch our Near Future videos.

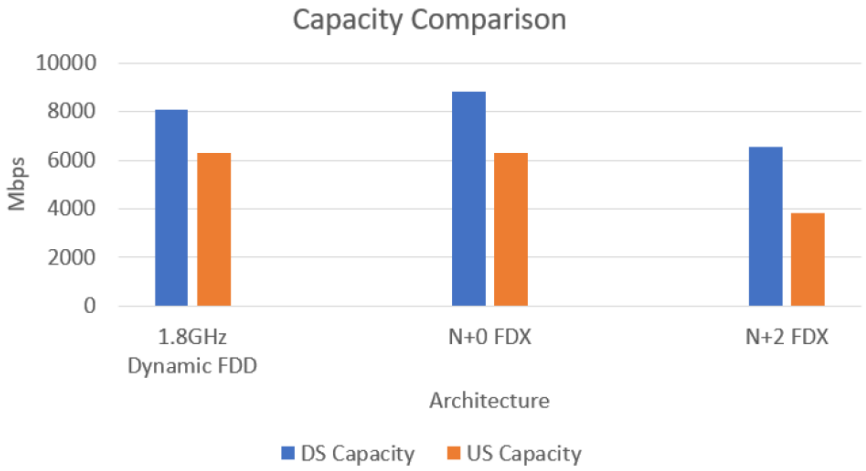
CableLabs

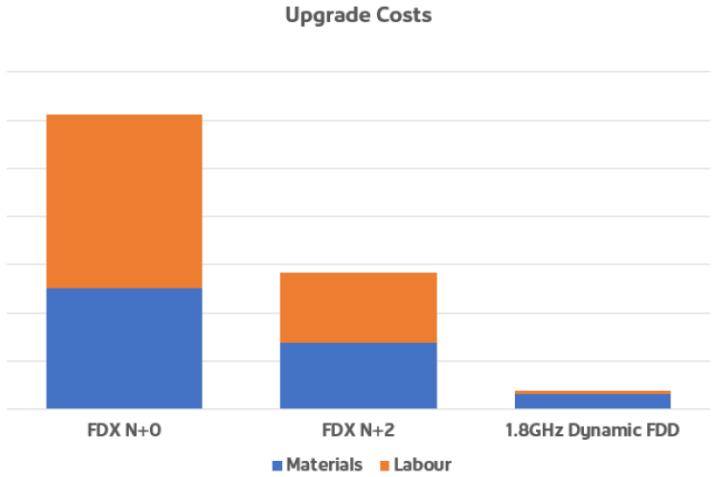
The DOCSIS® 4.0 Story

- But alignment with Fiber Deep and as such, Fiber Deep based technologies started to fade
  - Very costly
  - Difficult to implement
- There must be another way! Hey, what about increasing the upper frequency limit of the HFC plant?
- Cable Labs hosts an RFI in Jan 2019 regarding getting to 1.8GHz
  - Coax -> should be fine to support 1.8GHz, albeit at higher RF losses
  - Taps -> technology is available to pass 1.8GHz, but wont be faceplate upgrade, higher RF losses
  - Amps -> will need more gain, can support the bandwidth but have limited Total Composite Power (TCP)/output capability – likely compromises will have to be made above legacy frequency plans (ie. the slope can't continue as is to 1.8GHz)
  - Chip set vendors-> indicate end points (RPD/RMDs and Cable Modems) can be created
- Preliminary data collection, technical and cost analysis
  - Aug 2019: data collection aimed at characterizing the passive plant out to ~3Ghz– swapped the Taps out on MSO existing plant
  - Modelling with this data in conjunction with assumed amp gains and limited amplifier TCP limitations validated ability to "drop in" upgrade appropriate nodes/amps and support delivery of signals with adequate performance
  - Cost modelling suggested ESD was far more cost effective then fiber deep technologies

The DOCSIS® 4.0 Story

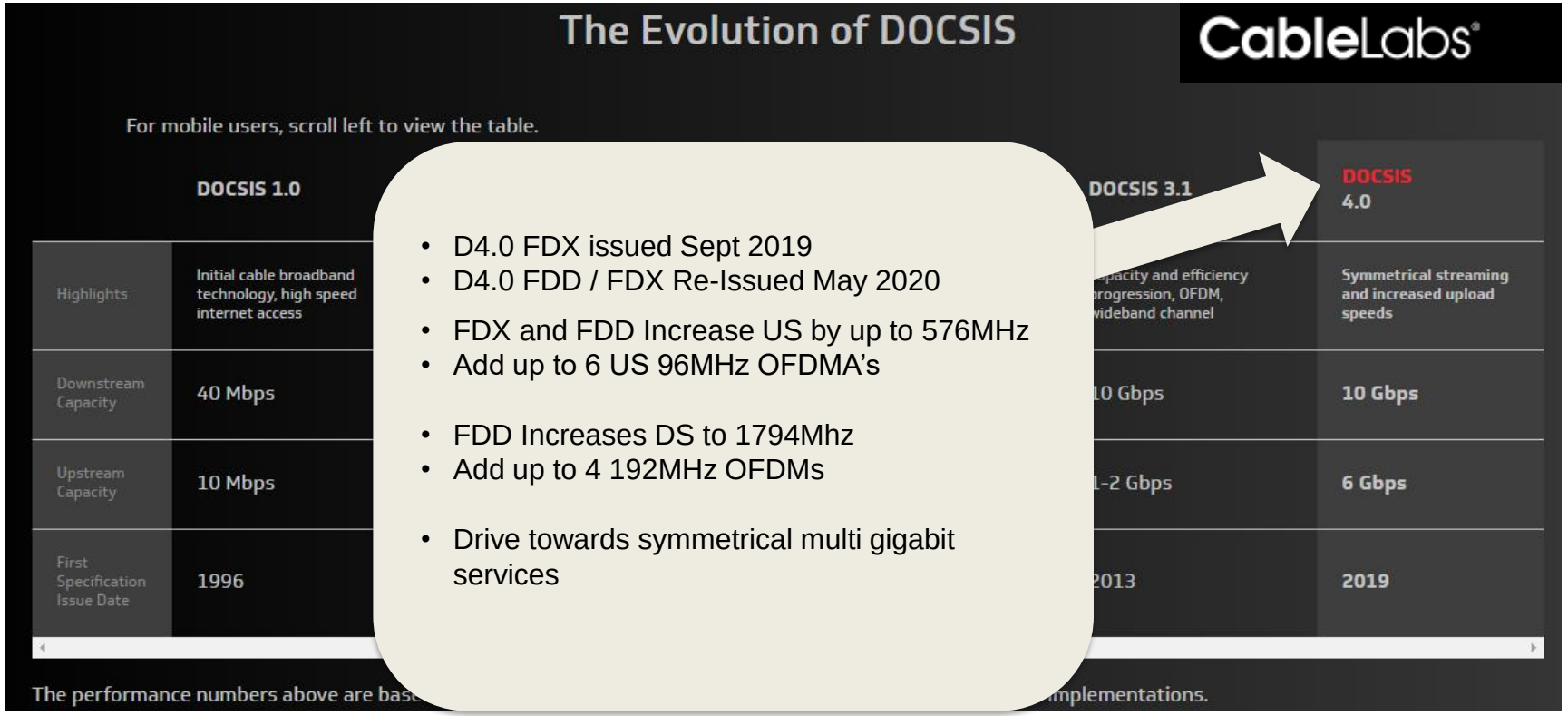
The HFC plant can be cost effectively upgraded to support 1.8GHz and similar data capacities as FDX at lower cost





Source: Upgrading the Plan to Satisfy Traffic Demands, The One Touch Approach, Nadar Foroughi, Sr. Network Architect, Shaw Communications, SCTE·ISBE Cable-Tec Expo 2019

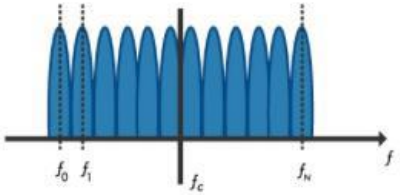
The DOCSIS ® 4.0 Story



- D4.0 FDX issued Sept 2019
- D4.0 FDD / FDX Re-Issued May 2020
- FDX and FDD Increase US by up to 576MHz
- Add up to 6 US 96MHz OFDMA's
- FDD Increases DS to 1794Mhz
- Add up to 4 192MHz OFDMs
- Drive towards symmetrical multi gigabit services

DOCSIS 4.0 is a two technology specification – FDD and FDX

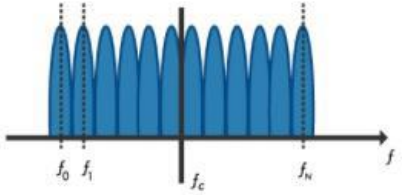
OFDM and OFDMA: Foundational to DOCSIS 4.0



- Digital Modulation Schemes
  - Orthogonal Frequency Division Multiplexing - DS
  - Orthogonal Frequency Division Multiple Access – “OFDM in the US”
- OFDM(A) is comprised of QAM subcarriers (low data rate QAMs)
  - Subcarriers spaced at 25kHz or 50kHz spacing
  - For a 192MHz OFDM -> 4K subcarriers or 8K subcarriers
- OFDM(A) is a proven more efficient, resilient and flexible signal then SC-QAM

OFDM and OFDMA: Foundational to DOCSIS 4.0

- The QAM modulation rate a subcarrier can support is based on the CNR/MER that the RF channel (Node->Modem / Modem -> Node) supports
  - CNR/MER degradation is a result of cascaded noise and distortions impacts from node, amps and cable modem
- The higher the QAM modulation that can be supported, the higher the payload (bit rate)
- QAM subcarrier modulation rates can be adapted to RF channel characteristics – modems seeing poorer CNR still get data, just at lower data rates



QAM Order	Modulation Efficiency (bits/subc)	Spectral Efficiency (bits/subc)	FEC SNR Threshold (dB)	CNR Threshold (dB)	Channel Capacity (bits/subc)
0	0.0	0.00	-100.0	-100.0	0.00
QPSK	2.0	1.76	7.5	9.0	2.73
16-QAM	4.0	3.51	13.0	15.0	4.39
64-QAM	6.0	5.27	18.6	21.0	6.20
64/128-QAM	6.5	5.71	20.4	22.5	6.79
128-QAM	7.0	6.15	21.4	24.0	7.12
128/256-QAM	7.5	6.59	23.3	25.5	7.75
256-QAM	8.0	7.03	24.2	27.0	8.04
256/512-QAM	8.5	7.47	26.0	28.7	8.64
512-QAM	9.0	7.91	26.9	30.5	8.94
512/1024-QAM	9.5	8.35	28.7	32.2	9.54
1024-QAM	10.0	8.79	29.7	34.0	9.87
1024/2048-QAM	10.5	9.22	31.6	35.5	10.50
2048-QAM	11.0	9.66	32.4	37.0	10.76
2048/4096-QAM	11.5	10.10	34.2	39.0	11.36
4096-QAM	12.0	10.54	35.2	41.0	11.69

DOCSIS 4.0 Full Duplex Technology

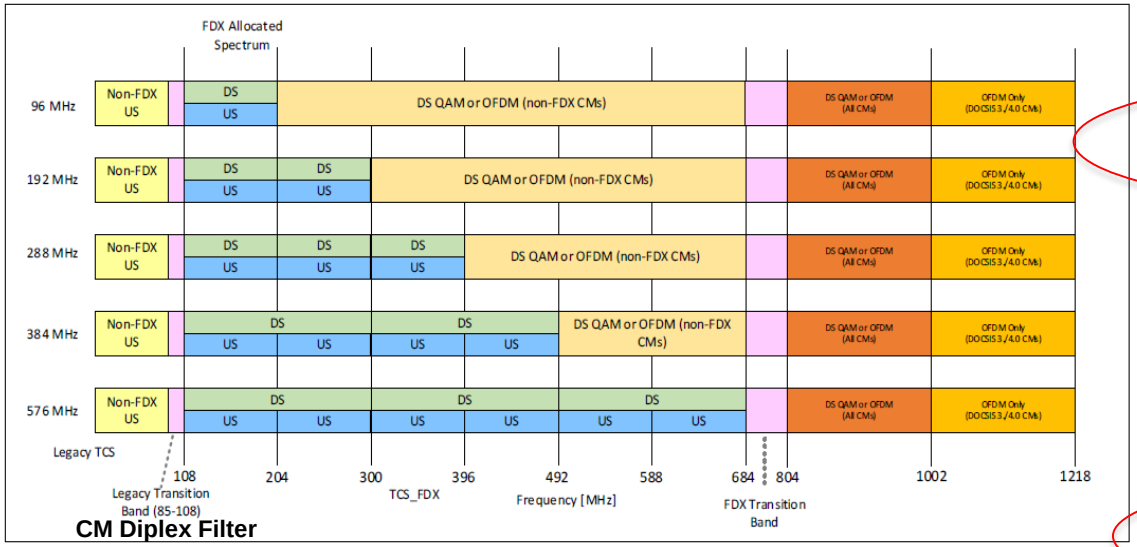


Figure 5 - Configurable FDX Allocated Spectrum Bandwidths

Source: Data-Over-Cable Service Interface Specifications
DOCSIS 4.0 Physical Layer Specification, CM-SP-PHYv4.0-I02-200429

- Preserves legacy DOCSIS US up to 85MHz as well as the OOB for legacy set top
- Utilizes simultaneous US and DS transmissions across the 108-684MHz band (DS 96/192MHz OFDM / US 96MHz OFMDAs)
- Preserves spectrum for legacy SC-QAM (video, DOCSIS 3.1 and lower)
- Spectrum above 1Ghz for D3.0/4.0 Modems (OFDM only)
- Increases US/DS capacity as well as dynamic US/DS allocation
- Requires Echo and Self Interference Cancellation at the RPD Node and the Cable Modem – FDX specific deices
- N+0 architecture - maybe N+1 with special FDX Amp

DOCSIS 4.0 FDD Technology

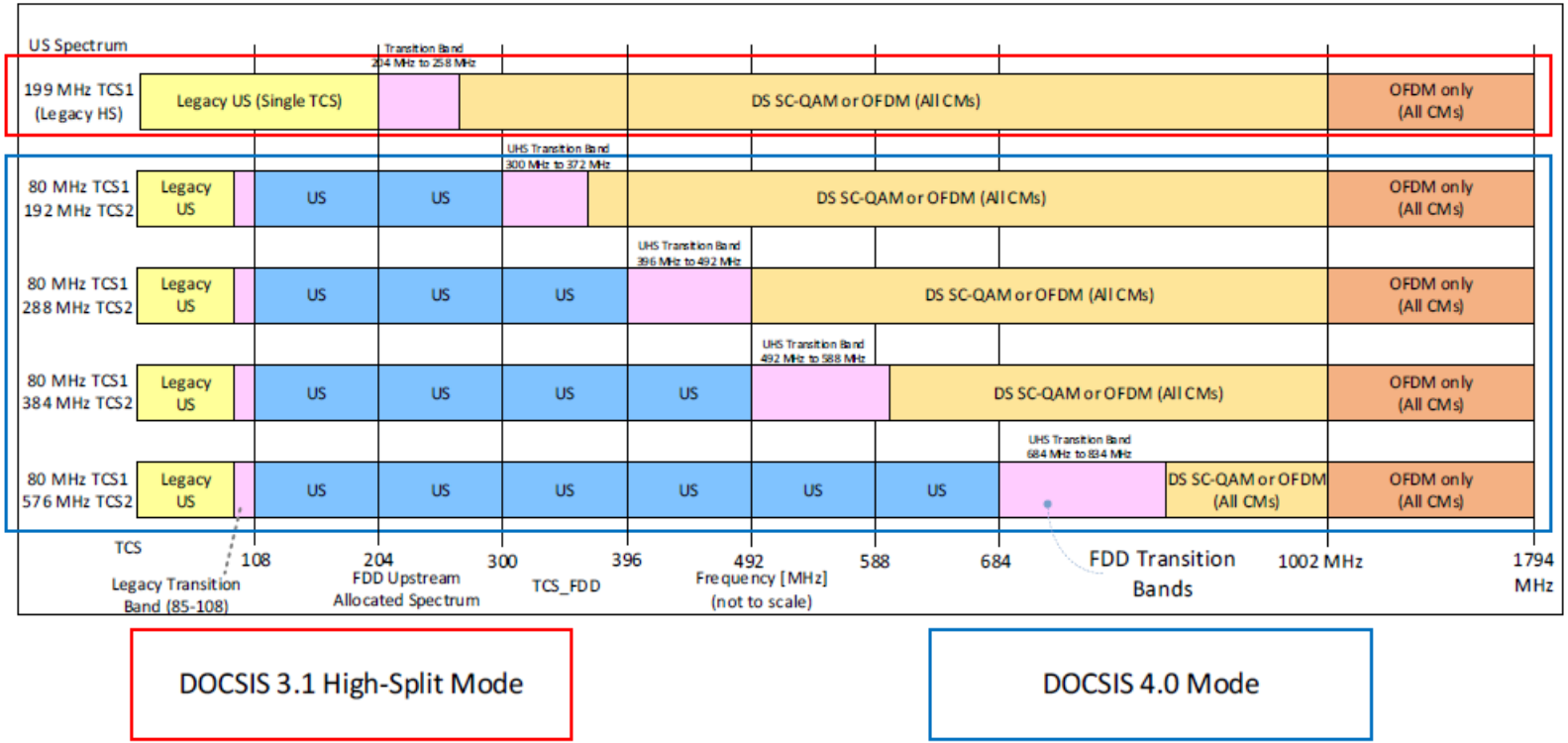


Figure 25 - Configurable FDD Upstream Allocated Spectrum Bandwidths

Source: Data-Over-Cable Service Interface Specifications
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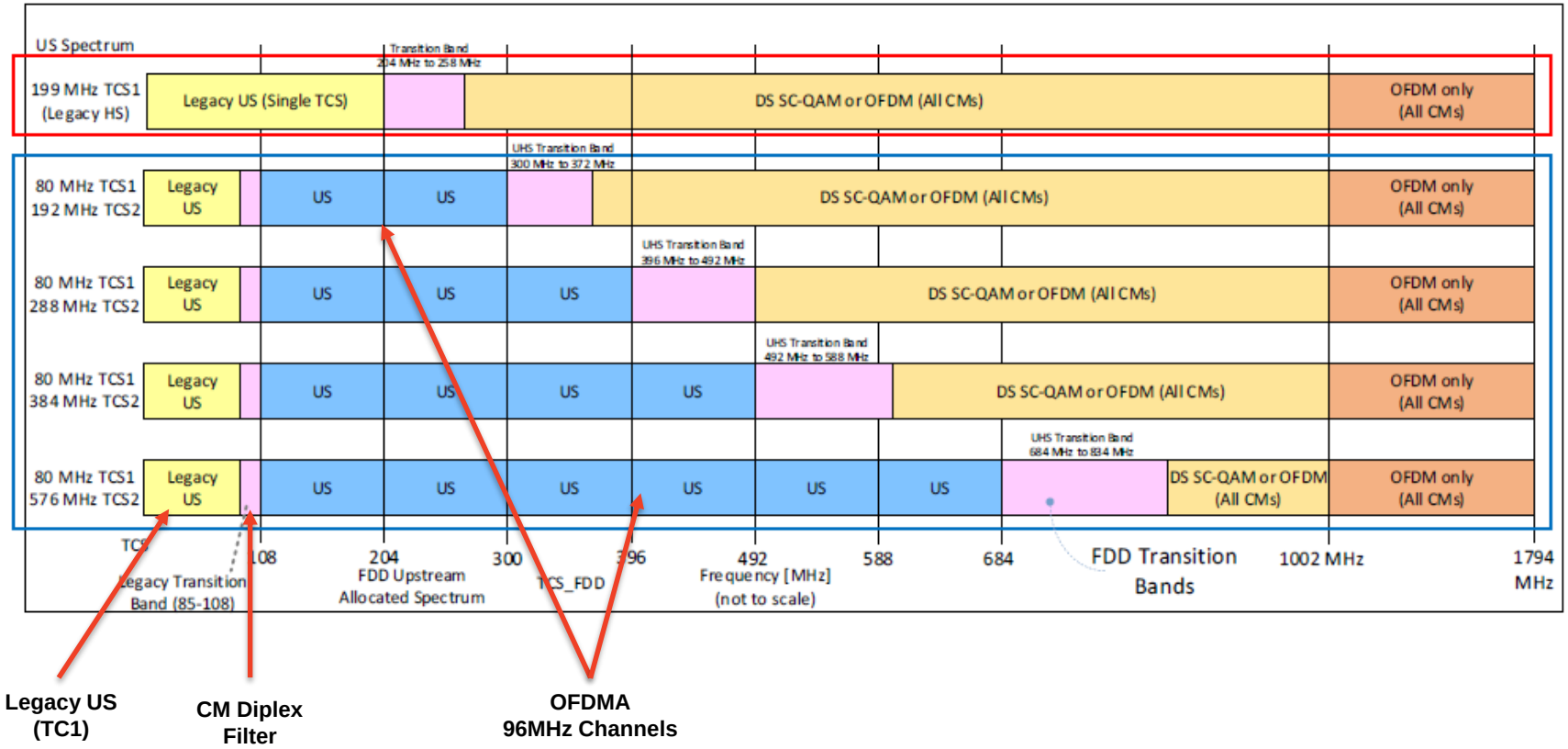
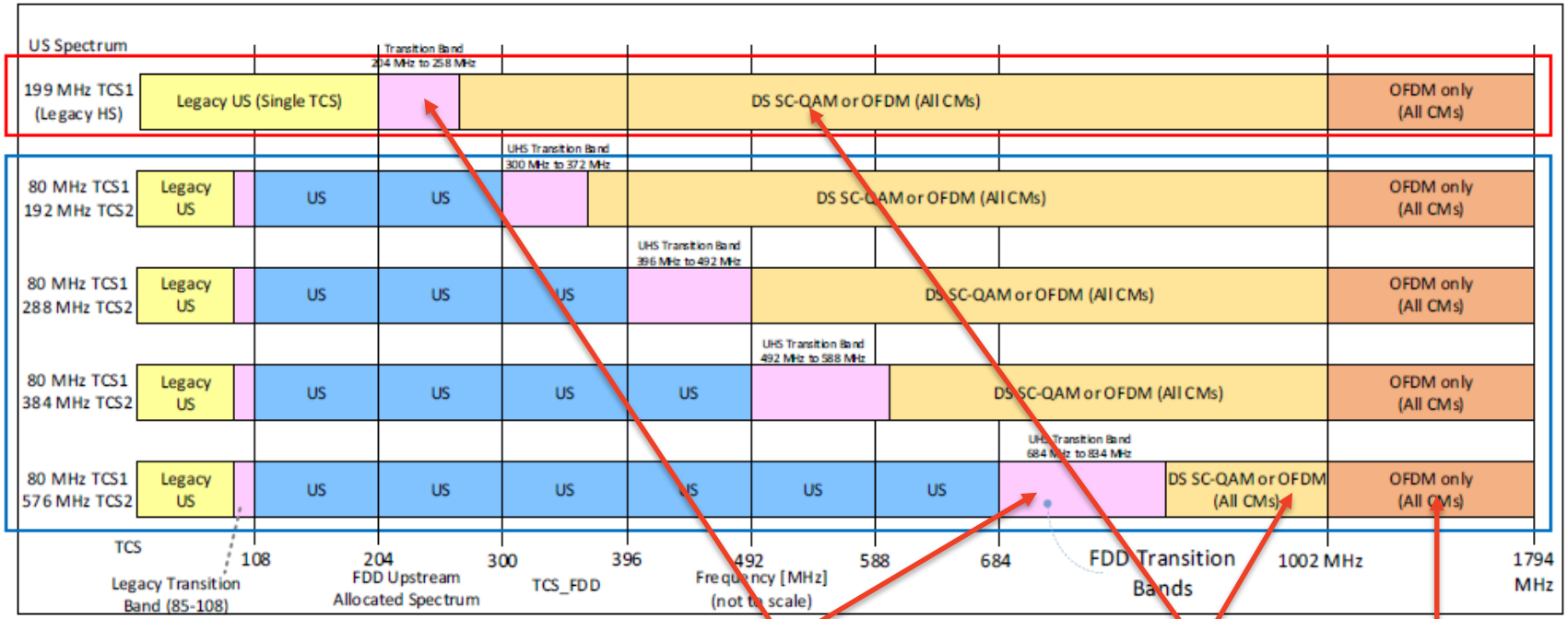
DOCSIS 4.0 FDD Technology



D4.0 FDD CMs Support Transmit of 7 configurable 96MHz OFDMAs + 4 (up to 8) SC-QAMs in 5-85MHz

DOCSIS 4.0 FDD Technology



Diplex Filters

CMs –> 2min. Supported

OSP Equipment

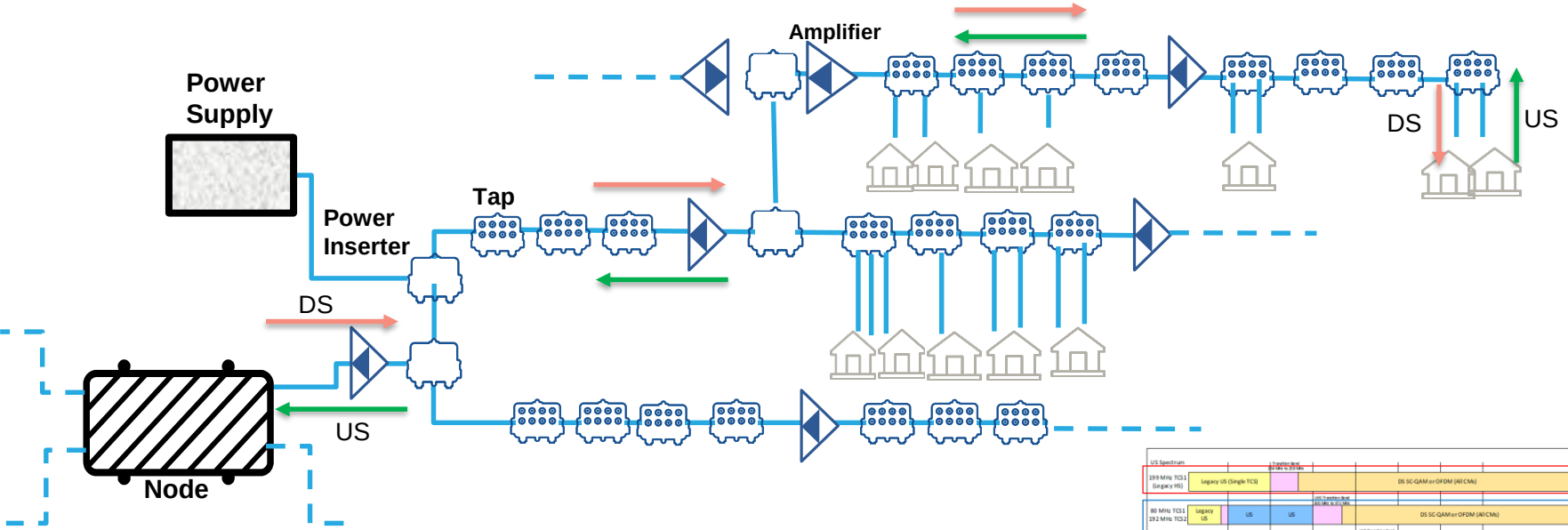
Legacy Video / DOCSIS

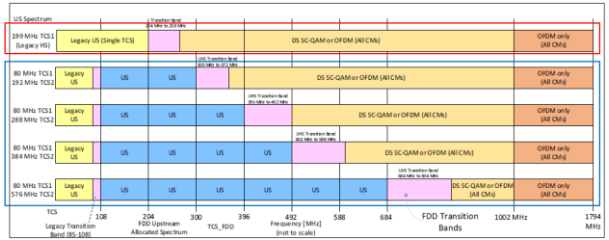
DOCSIS 4.0

Legacy DOCSIS / D4.0 (OFDM only)

D4.0 FDD Nodes (RPD/RMD) Support Transmit 6 configurable 192MHz OFDM + 32 SC-QAMs for DOCSIS – also need to support legacy (video etc.)

DOCSIS 4.0 FDD Technology – Supporting OSP Architecture





Fundamentally the OSP Architecture to support DOCSIS 4.0 FDD needs to…

- Support a passband of 5-XMHz in the US and Y-1794MHz in the DS (X/Y US/DS/Diplex dependent)
- DS Signal Transmissions from Y to 1794MHz from Node to the Premise D4.0 CM (Gateway) with best possible level/integrity; maintain “legacy” DS slopes and levels
- Support US Transmissions of 5-XMHz from US devices (CMs, Set Tops) to Nodes with best possible level/integrity

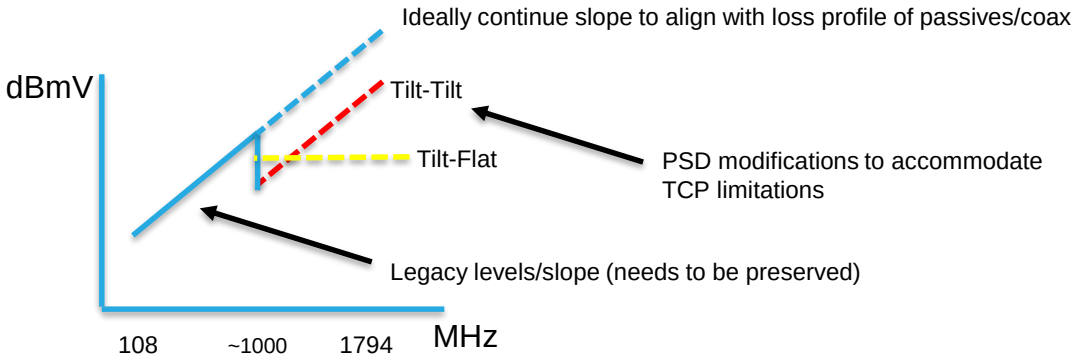
DOCSIS 4.0 FDD Technology – Supporting OSP Architecture

- Modelling on MSOs' existing plants have shown that D4.0 FDD can be supported in existing HFC OSP
  - Via Drop-in Upgrades
  - Across a range of Cascade's (N+0 -> N+8)

- However, every CM is not going to see 4096-QAM on the DS or deliver 2048-QAM on the US

    - Cascading of amplifiers inherently deteriorates DS and US CNR

    - DS PSD (Level vs Frequency) likely not linear – higher frequencies will have lower levels and CNR



DOCSIS 4.0 FDD Technology – Supporting OSP Architecture

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16-QAM	4.0	3.51	13.0	15.0	4.39
64-QAM	6.0	5.27	18.6	21.0	6.20
64/128-QAM	6.5	5.71	20.4	22.5	6.79
128-QAM	7.0	6.15	21.4	24.0	7.12
128/256-QAM	7.5	6.59	23.3	25.5	7.75
256-QAM	8.0	7.03	24.2	27.0	8.04
256/512-QAM	8.5	7.47	26.0	28.7	8.64
512-QAM	9.0	7.91	26.9	30.5	8.94
512/1024-QAM	9.5	8.35	28.7	32.2	9.54
1024-QAM	10.0	8.79	29.7	34.0	9.87
1024/2048-QAM	10.5	9.22	31.6	35.5	10.50
2048-QAM	11.0	9.66	32.4	37.0	10.76
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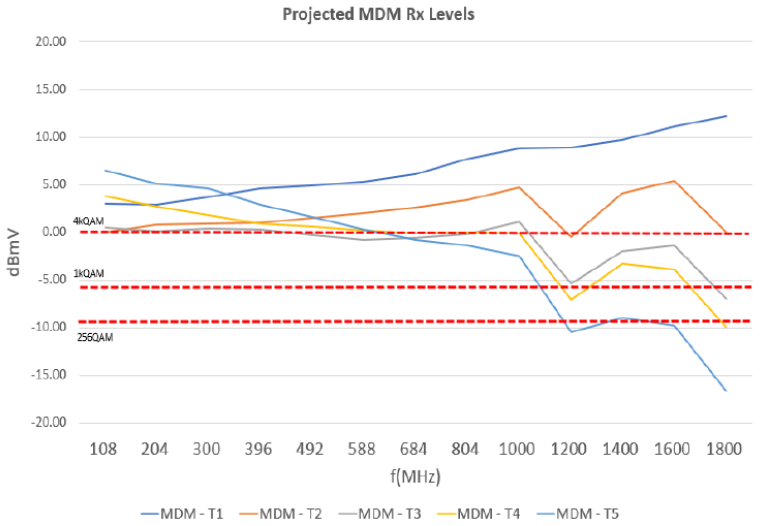

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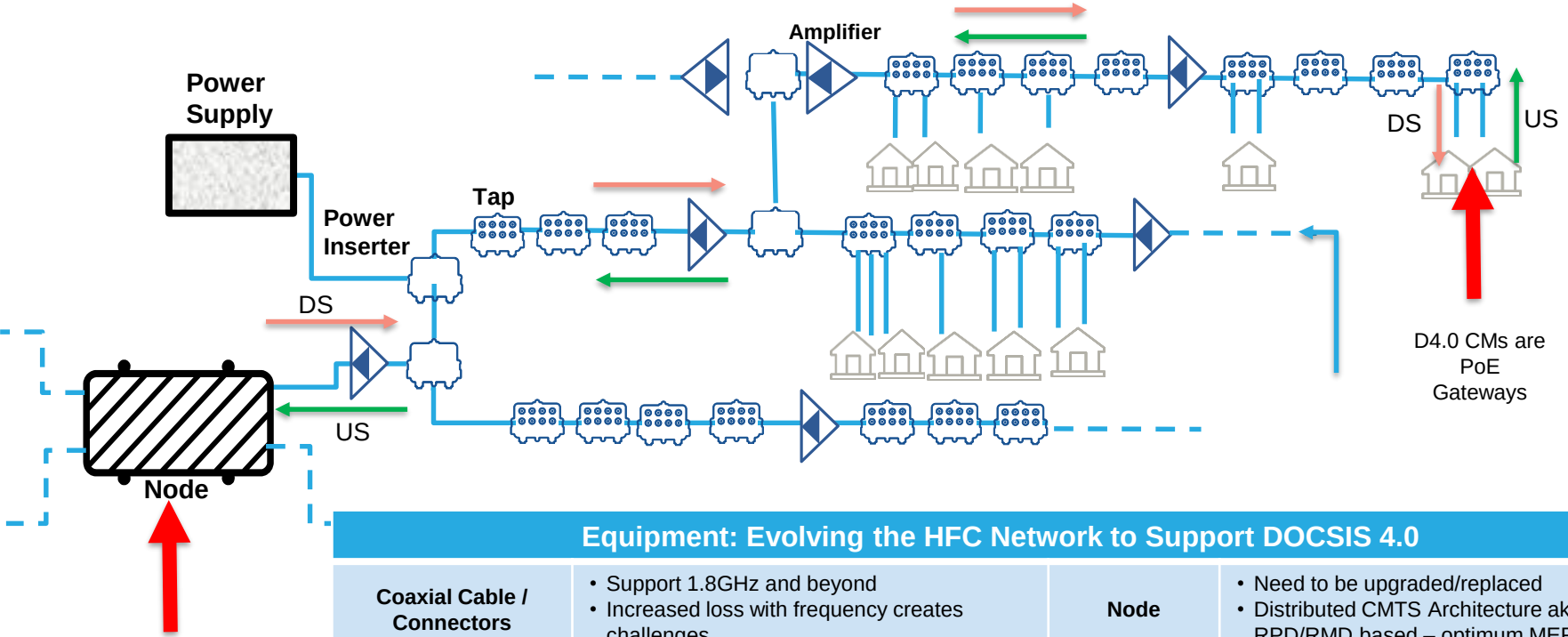
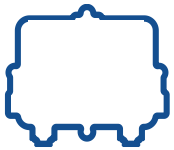
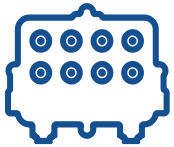


Equipment: Evolving the HFC Network to Support DOCSIS 4.0			
Coaxial Cable / Connectors	• Support 1.8GHz and beyond • Increased loss with frequency creates challenges	**Node**	• Need to be upgraded/replaced • Distributed CMTS Architecture aka DAA / RPD/RMD based – optimum MER
Taps & Passives	• Need to replace; faceplate upgrade NOT possible • Increased loss with frequency	**D4.0 CMs**	• Become PoE device – save 8-10dB RF
Amplifier	• Need to be upgraded/replaced • TCP limitations will impact PSD allocation	**Power Supply**	• TBD – power envelope recognized as important!! (Hence TCP limit on amps)

Taps, Passives and Power Inserters for D4.0 FDD





- Legacy Devices limited to ~ 1.5-1.7GHz – no faceplate upgrades
- D4.0 Support requires these devices being replaced
- New devices available now – 2GHz faceplate and 3+GHz performance inherent in the design
- SCTE IPS WG 2 “3Ghz Task Force” - Specs for 3GHz Taps
- Installing these devices now makes complete sense

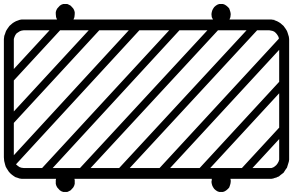
Amplifiers for D4.0 FDD

- Upgrade / replacement required
- Limited (if any) legacy housings could support tray upgrades (BW /Thermal limits)
- Look for new housings to have 3GHz BW support
- Increased operation gain required in DS (up to 1794MHz) and US (up to 684Mhz)
  - Based on one MSO's network
  - LE's: from 34dB @ 1GHz to 48dB @ 1.8GHz
    - Lower gain models (37dB) will also work in good portion (~50%) of plant
    - 2 versions of LE likely (HG and LG)
  - Multiport's: from 42dB @1GHz to 60dB @ 1.8GHz!!
    - Lower gain models (49dB) will also work in good portion of plant
    - 60dB gain amps – stability issues and CNR issues – may need a mid span amplifier instead (distribute the required gain up along the loss path)

Amplifiers for D4.0 FDD

- TCP limitations ~ 72dBmV (vendors working on this)
- Diplex Filters – how to support the US migration path D4.0 FDD offers?
  - Fixed diplex (D4.0 spec designed to support this)
  - Switchable diplex
  - Programmable diplex based on EC/FDX technology

DOCSIS 4.0 FDD Technology Support – Node



- Nodes will have to be replaced
- Look for RF bases to have 3GHz BW support / migration path to D4.0 RPDs
  - Start DAA now
- DAA based prerequisite - and contain a RPD/RMD module
  - D4.0 FDD RPD/RMD – Development Pending – FPGA or ASIC - TBD
- Amplifier TCP limitations -> RPD/RMD will need to support configurable PSD profiles (tilt-tilt, tilt-flat) so MSOs can configure accordingly
- Diplex Filters – how to support the US migration path?
- SCTE IPS WG1 - GAP Node Standard being developed

DOCSIS 4.0 FDD Technology Support – Modem

- PoE Device – WiFi or other distribution through home?
- Common Silicon for FDX and FDD (configuration changes)
- Modem builds for FDX and FDD will be different
- Development / Availability Pending

DOCSIS 4.0 FDD Technology Support – Test Equipment, Standards and Craft

- Test Equipment
  - Obviously will be critical for supporting the ecosystem
  - Likely pending further development progress on RPD and Modem

- SCTE IPS – 1.8 (3.0) GHz Actives and Passives – update/develop standards
  - Cable performance
  - Connector performance
  - Shielding effectiveness
  - Feeder and drop passives and actives
  - Measurement methods and test procedures
  - Hardline passives (couplers, splitters, and power inserters)
  - Hardline taps

- Craftsmanship – training will be critical

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