**DOCSIS® 3.0 Upstream Channel Bonding
in the “Real World”**

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This article will focus on the potential issues associated with upstream (US) deployments. DOCSIS 2.0 is here to help curtail the “*speed hunger*” for a while, so we’ll tackle D2.0, and then move to 3.0 US issues.

The business objective for many operators today is to provide faster speeds to compete with FiOS. These speeds are for DS and US. DOCSIS 2.0 can provide approximately 37 Mbps on the DS and 27 Mbps on the US, aggregate speed. Some per-CM speeds are approaching these peak rates and exceeding them. The only way to offer higher rates than what DOCSIS 2.0 can offer is to upgrade to DOCSIS 3.0. Instead of reducing node sizes, which can exceed $10,000 per node split, it may be more economical to add more frequencies and logically bond traffic across multiple channels. This will require new CMTS equipment and cable modems. This allows more aggregate speed for higher tier services to share and/or offer per-CM peak rates in excess of what a single channel can offer. At the expense of more spectrum allocation, a DOCSIS 3.0 CM can offer 150 Mbps on the DS and 100 Mbps on the US. This may be necessary for 100x25 Mbps service or to allow many modems at 20x5 Mbps service to share the bigger “pipe”. This is the premise behind statistical multiplexing (stat muxing) and our oversubscription calculations.

**Potential Pitfalls**

Any new technology will have some trade-offs and potential pitfalls that must be understood and planned for in advance. The following will discuss some of these issues:

1. Why it’s Needed – This can range from competitive pressure, to higher tiers of service, to more customers signing up.
2. Frequency Stacking Levels & Placement – What is the modem maximum US output with four channels stacked and do the channels have to be contiguous?
3. Isolation Concerns – Whenever applications have different service groups, we have overlaid networks. Signals destined for one node could “bleed” over to another.
4. US Frequency Expansion to 85 MHz – Amplifier upgrades are occurring now. It’s best to make the truck roll once. Think about diplex filters, line EQs, step attenuators, taps, etc.

**Note**: DOCSIS 3.0 CMs support a minimum of 4 US and 4 DS channels even though it could be more. Keep in mind that more USs in a mac domain requires more maps and “eats” into the DS throughput. Approximately every US port uses .25 Mbps of DS capacity or more for maps.

**Upstream Speed Required to Support DS Bonded TCP Traffic**

Typically DS TCP flows have a 50:1 ratio in regards to US acknowledgements (acks). This means, supplying a 100 Mbps tier of service for DS could require 2 Mbps of US speed just for acks. Many newer CMs support ack suppression, so the acks could end up taking less BW, but it’s not guaranteed.

Looking at the typical US scheduler and DS maps sent every 2 msec, most modems use every other map. If looking at an example of single modem speeds, one CM would use every other map and another modem could use the maps between those. So, you have maps every 2 msec that will have some modems. Example: If I had 1 modem in the first map and using every other map to get 1/.004 = 250 PPS, I could have another in the next map for 250 PPS.

Since maps are every 2 msec, it cannot grant more than 2 msec of US in terms of minislots. If using 16-QAM at 3.2 MHz, 2-tick minislot, that would be 12.5 usec per minislot and 16 B. The math for 20 concatenated TCP acks is approximately 104 minislots. Two msec will be 160 minislots, but 2 are usually reserved for a contention request. So, that one CM doing DS TCP of 100 Mbps using about 2 Mbps US would use 104 minislots and about 54 leftover. Another CM could be on the next map using 104 minislots and 54 left over. This would be enough for a CM to do 50 Mbps DS and support 1 Mbps of US for acks every other map and another CM at 50 Mbps by 1 Mbps.

This would lead to about 300 Mbps on DS and only 6 Mbps of US to support 4 modems. It’s interesting that only 6 Mbps would deplete the 10 Mbps US pipe, but that can be expected when using such small frames. There's a lot of overhead when using small frames, even if concatenated. The point here is, three customers with 100 Mbps DS speed could deplete the entire US pipe, which is more reason to the make the pipe bigger with ATDMA.

**DOCSIS 2.0 – ATDMA**

It would be good to understand how to exploit the upstream (US) capabilities we have with DOCSIS 2.0 and its corresponding issues before moving into DOCSIS 3.0 US issues. A quick way to increase upstream data rates is to deploy DOCSIS 2.0 in a DOCSIS 1.x system. A 6.4 MHz wide channel using 64-QAM will provide up to 27 Mbps vs. the 9 Mbps available with a DOCSIS 1.x system.

**DOCSIS 2.0 US Considerations**

There are a few considerations that need to be addressed when utilizing ATDMA:

1. 64-QAM at 6.4 MHz – What levels are supported, how do modulation profiles affect levels and modulation error ratio (MER). What about frequency allocation?

**Note** – MER is the same as signal-to-noise ratio (SNR) as reported from a Cable Modem Termination System (CMTS).

1. Linear Impairments – How do group delay & micro-reflections affect per-CM MER and US port average MER, how to use pre-equalization to your advantage?
2. Laser Clipping – More channels means more power and potential laser clipping. Do you have FP or DFB lasers deployed in your return path? If you don’t know, you should do some research.
3. Monitoring, Testing, & Troubleshooting – Proactive vs. reactive and testing with a signal that is realistic.

**Linear Impairment Effect**

Many times doubling the US channel width will indicate more issues with the plant than actually increasing the modulation to 64-QAM. Linear impairments like group delay and micro- reflections will not be apparent with a spectrum analyzer, but will severely degrade US MER.

After increasing the channel width to 6.4 MHz, it’s imperative to measure and document unequalized US MER at multiple test points in the plant. Unequalized means per-CM US MER without pre-equalization activated. Some tools that can be used include: JDSU PathTrak Return Path Monitoring System or the Sunrise Telecom Upstream Characterization toolkit. The new RPM-3000 linecard from JDSU supports demodulation of live CM signals along with US constellations and also demodulates a continuously 16-QAM to 64-QAM signal generated from the JDSU DSAM meter. The new version can also demod in-band packets from the DSAM with the 2.5 release, not just out-of-band continuous carrier. This provides invaluable insight into monitoring and troubleshooting of non-linear impairments. Keep in mind that the CMTS US chip also has equalization that is complementary to CM pre-eq. It’s best to get US MER readings with no equalization whatsoever.

The recommended unequalized MER is 25 dB or higher. Less than 25 dB reduces operating margin. Be sure to check US MER as well as per-CM MER. The Cisco CMTS command, “show cable modem phy”, can be used to display per-CM MER (SNR). If diplex filter group delay is suspect in addition to long amplifier cascades, it may be necessary to pick a frequency below 30 MHz, away from the diplex filter band edge. If group delay is causing per-CM low MER issues and a lower frequency is not an option, it may be possible to activate pre-equalization, “cable upstream n equalization-coefficient”.

**Note**: Be sure the latest IOS version is running on the CMTS with proper modulation profiles.

**Tip**: US interleaving has been added in DOCSIS 2.0 and can be applied to the D2.0 A-long burst in the mod profiles for added protection to impulse noise events. An example is below where the RS US interleave has been changed from 1 (off) to 0 (dynamic):

cab modu 224 atdma a-long 9 232 0 22 64qam scram 152 no-diff 64 short qpsk1 **0** 2048

DOCSIS 2.0 has many benefits and one of those comes in the DOCSIS 2.0 CMTS linecards and is called pre-equalization. The CMTS first analyzes the signal coming from the CM and sends correction information back to it. The CM uses this information to pre-distort, or pre-equalize, its signal before transmission. Now the signal travels through the HFC network and is impaired by group delay and frequency response. The pre-distorted signal is distorted back and the CMTS actually receives a nearly ideal signal. Pre-equalization is very useful for supporting 6.4 MHz wide channels whether using 16-QAM or 64-QAM.

The divide-and-conquer troubleshooting method recommended is to exclude the MAC address of a field meter (i.e. DSAM) from the CM pre-equalization process.

An example would be:

10K(config)#cab pre-equalization exclude ?

 modem Exclude single modem

 oui Exclude group of modems based on OUI

This will cause the DSAM to report MER without pre-eq, while the customer CMs are operating at a higher, pre-equalized MER. The objective is to then use the non pre-equalized DSAM to troubleshoot the HFC network until impairments are identified and resolved, such as bad connectors and taps. The goal is to have the non pre-equalized MER of the DSAM nearly as good as the pre-equalized MER of CMs on the same US leg.

**Note**: Increasing the channel width from 3.2 to 6.4 MHz keeps the same average power for a single carrier, for the Cisco implementation. This means the MER will drop by 3 dB, and possibly more because wider channels incur more group delay. If the CMTS kept the same power/Hz, it could cause maximum transmit levels from CMs and/or laser clipping or overload.

Understanding equalized vs. unequalized MER readings is paramount to quantifying plant issues. Regardless if the CMs have pre-eq activated, the CMTS linecard will also have adaptive equalization. The end user must know if the CMTS US MER is reported before or after this adaptive EQ and preamble lengths in the modulation profile could affect this.

Modulation profile choices include QPSK for maintenance, 64-QAM for Data, and possibly 16-QAM for VoIP. Many options are possible and the station maintenance (SM) burst modulation could affect level reporting and subsequently MER. The level reported by the CM could be based on the long burst while the CMTS level is based on the SM burst. If Pre-EQ is activated in 1.1 & > CMs, it can greatly enhance the US per-CM MER readings, but could mask plant issues. DOCSIS 1.1 CMs have an 8-tap EQ and DOCSIS 2.0 CMs have a 24-tap EQ. In a simplified explanation, this can be thought of as 8 or 24 sampling points to get a “good” digital representation of the “haystack”.

**Monitoring the CMTS for Plant Health**

By monitoring US MER and FEC counters, a generalization can be made for the US health of the plant, but further investigation is needed. It is recommended to also monitor per-CM FEC and MER numbers. Another data point can be formulated with the Flap-list. This Cisco feature has been included in DOCSIS 3.0 as the Modem Diagnostics Log and can indicate US issues.

Table 1 below lists some recommended thresholds for alarms of different parameters.



Table 1 – FEC Thresholds

After deploying ATDMA, it will be necessary to monitor MER on a per US basis with the ability to drill-down for per-CM MER. Uncorrectable / Correctable FEC per US with ability to drill-down for per-CM counters will also be used. Use Return Path monitoring tools like Cisco Broadband Troubleshooter (CBT) or PathTrak to view 5-65 MHz for apparent laser clipping. It’s also needed to have an analyzer that can read < 5 MHz for AM radio or ham radio ingress. The new PathTrak card reads 0.5 MHz - 85 MHz and can also do “real” modem US constellations. Since the CBT tool is in the CMTS and understands minislot time assignments, it can be used to see the US with no modem bursts and also display specific modem bursts.

**Flap-List**

Cable Flap-List monitoring is used for CM issues caused by US noise impairments and timing issues. The following configurations are recommended as a best practice:

cable flap-list miss-threshold 5

Modems are polled every 20 seconds (15 when linecard redundancy is configured) and correlates with a “hit” when the 3-way maintenance “handshake” is successful. If a poll is missed, the CMTS will go into a fast mode and poll every second. If there are five consecutive polls missed, the flap count increments by one and the miss count would increment by five. “Misses” can be correlated with T3 timeouts from the CM log.

cable flap-list power-adjust threshold 2

If the CM has power adjustments of 2 dB or higher during one station maintenance interval, the flap count and power adjust count increment by one. Having modems maxed out in power, but allowed to stay online via the power-adjust continue command, will be listed in the flap list and could also cause excessive flap entries.

cable flap-list insertion-time 120

If the CM sends initial ranging two or more times within two minutes, the flap count increments by one. This does not necessarily mean a modem going offline and online. It could be a modem that goes through “init” states many times.

Some recommendations for flap-list monitoring include:

1. Periodically poll the flap-list at an appropriate interval of every 30 minutes or so.
2. Perform trend analysis to identify CMs that are consistently in the flap-list.
3. Clear the flap-list periodically (daily?) to “re-calibrate”.
4. Query the billing and administrative database for CM MAC address-to-street address translation and generate appropriate reports and work orders. CMs in a specific area with lots of flaps can indicate a faulty amplifier or feeder lines.

**Note**: The bottom line is uncorrectable FEC (dropped packets) and not relying on just one parameter to quantify the health of the plant.

Table 2 below correlates types of US impairments with CMTS reporting. For example; if uncorrectable is incrementing much faster than corr and/or SNR seems good, then it could be an impulse event like laser clipping, impulse noise, or sweep interference.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| (Increasing Impairments) | CNR | MER(SNR) | Corr FEC | Uncorr FEC |
| AWGN | Bad | Bad | Bad | Eventually Bad |
| CW Carrier | Bad | Ok | Ok | Ok |
| Impulse Noise / Laser Clipping | Bad | Ok | Ok | Bad |
| Group Delay / Micro-Reflections | Ok | Bad | Bad | Eventually Bad |

Table 2 – Impairments vs Reporting

The reason a CW interferer can cause bad CNR, but ok MER is because the CMTS typically has ingress cancellation implemented to “digitally erase” narrow, relatively steady, interference.

**DOCSIS 3.0 US Considerations**

When DOCSIS 2.0 US speed is exhausted, then DOCSIS 3.0 US can be implemented. Some considerations include:

1. Frequency Stacking Levels – What is the maximum output with multiple channels stacked, is it pwr/Hz, could it cause laser clipping?
2. Diplex Filter Expansion to 85 MHz – If amplifier upgrades are planned for 1 GHz, then pluggable diplex filters may be warranted to expand to 85 MHz in the US. We still must address existing CPE equipment in the field and potential overload.
3. Monitoring, Testing, & Troubleshooting – Just like DOCSIS 2.0, now test equipment needs to have D3.0 capabilities.

**DOCSIS 3.0 US Issues**

As with DS issues, there are also US issues that need to be addressed. US bonding has not been pursued at this point because most people haven’t even exploited D2.0 US capabilities. This does not mean we should avoid the potential issues that will arise. Eventually, we will want to offer US speeds greater than what a single channel modem can offer of ~ 25 Mbps. This will require more US spectrum, D3.0 CMs, and CMTS linecards with US bonding capability. Some of the potential issues are:

1. Levels – (max, periodic ranging, min)
2. Upstream Passband
3. Channel Placement
4. Total Power Loading
5. New Architectures
6. Isolation Issues
7. Shrinking CM Transmit “Bell Curve”

**Levels**

The CMTS US channel uses the equivalent of a bandpass filter that is tuned to the configured frequency for the US port. So it is measuring occupied channel power of the 3.2 MHz signal. If the upstream receiver is tuned to 30 MHz in the CMTS config with a 3.2 MHz channel-width, then it would only be looking at 28.4 MHz through 31.6 MHz. The adjacent channels energy is not a factor in the measurement.

The HFC plant should be designed, so that in normal DOCSIS operation, modems transmit between 40 and 50 dBmV. This gives enough headroom for customer induced losses, modulation changes, temperature related issues, and age factors. By designing a lower bound of 40 dBmV, it helps alleviate noise induced from low value taps (4, 8, 11 dB). Special equalized taps and feeder EQs with return frequency pads are available to achieve this.

Levels to keep a CM online are done during station maintenance and each CM vendor may have implemented their preambles differently for QPSK versus 16-QAM. It is very possible that changing the station maintenance burst to 16-QAM could make the CM appear to transmit 3 dB higher. Keep in mind that while the maximum upstream transmission power required by DOCSIS is +58 dBmV for a cable modem using QPSK, a cable modem using 16-QAM only needs to transmit at a maximum power of +55 dBmV. This may have an impact in cable systems where the total upstream attenuation between the modem and the CMTS is higher than 55 dB. Excessive upstream attenuation is usually related to poor design, subscriber drop problems, and/ or network misalignment.

The reporting capability of CMs could be +/- a few dB.  Who knows how accurate they really are and it could be different accuracy when doing QPSK vs. 16-QAM.  Some modems report their transmit level based on the long burst even though they are leveled based on the station maintenance burst. Using a mixed modulation profile could lead to erroneous results.

One issue concerning the US is when changing channel bandwidth from 1.6 to 3.2 MHz. The CM is not told to increase its power to follow power/Hz calculations, but to keep a constant average power. This can have the negative result of 3 dB worse CNR since the noise BW has doubled, but the channel level has remained the same. If doubling the bandwidth automatically increased the expected return level at the CMTS by 3 dB to keep a constant CNR, then the modem could reach max transmit power in some situations. The work-around to this would be to ether increase the CMTS US configured Rx level to make CMs transmit higher or add more padding inline.

1. If you change the channel width from 1.6 MHz to 3.2 MHz, you may want the carrier to be 3 dB hotter. You can change the input level on the CMTS from 0 to +3 dBmV, which will make the modems transmit 3 dB more and you'll have the same CNR you had to begin with because of double the noise bandwidth also.

2. If you install 3 dB more padding in front of the CMTS US port, the modems will transmit 3 dB higher, but the total noise and interference on the front end of the CMTS US port will be 3 dB lower. This is the preferred method with a side benefit that configurations do not change. It’s advantageous to use the return path combining networks made by PCI technologies, QRF, ADC, Cisco, etc. They have plug-in pads that can be changed without disconnecting cables.

3. Another scenario is installing 3 dB padding in front of the US laser in the node. This provides less chance of laser clipping, less noise in the node, and the same overall affect at the CMTS. The pitfall is you'll be adjusting the node receive levels for that one service. What about Settop signals, telephony, etc.? It also takes more work!

Remember to observe the transmit levels from the modems to see if they are reaching their maximum transmit power, especially the ones off high value taps. You can do a **show cable modem remote-query** (if configured) to display the modems’ outputs and a **show cable modem** to see if there is a "!" displayed next to the receive column indicating the modem is at its maximum output power. **Show cable modem phy** is another command that will report per-CM Tx levels.

**Max Transmit Levels**

A modem’s max transmit is dictated by the modulation scheme used and the actual vendor implementation. Max output for D2.0 & D3.0 modems is listed in Table 3 below. If the CM has reached its maximum transmit power, a "**!**" will be displayed next to the receive level in the **Show Cable Modem** command. The modem will be permitted to stay online if it is within a certain range. This range has a default of 4 dB from nominal and can be changed with; "**cable upstream n** **power-adjust continue y**". The value of y can be increased up to 15 dB, but many systems have settled with the default of 4 or increased it to 6 dB.

**Note**: A max transmit modem will be commanded to change level every 20 seconds during its SM, optimally only once. Some modems have been observed to go into the fast polling mode for 5-10 times before moving on. This is a good reason to make sure < 10% of your CMs are in this state.

There is no special message sent by the modem when it reaches max transmit power. If the CMTS keeps telling the modem to increase its transmit power several times in a row, the CMTS concludes that the CM cannot increase its transmit power any higher and flags it with "**!**".

**Note:** There are some corner conditions where the flag may be erroneously set. For example, if the CMTS commands the modem to adjust its power by 1 dB and the modem only adjusts its transmit power if the request is above 1 dB, the CMTS may erroneously conclude that the CM is out of transmit power. Thus, besides looking at the "!", the customer should also look at the actual reported power level and see if it is outside the target power level. The real intent of the "!" is for troubleshooting and identification.

By increasing the “continue” command to 6 dB, the CM will be permitted to stay online if the CMTS receive level is between -6 dBmV and 0 dBmV. If the level is above -1, you won't see a "!". If the level is below -6 dBmV, the modem will go offline. For systems that still have high-value taps (29 & 26 dB), this helps keep the CM online, but will produce modems with different CNRs.

**DOCSIS 3.0 Level Issues**

Activating multiple frequencies per US connector on a D3.0 CM has different maximum power per channel vs. a D2.0 CM as shown in Table 3 below.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Modulation** | **Max Tx – D2.0 (dBmV)** | **Max Tx – D3.0 1 Ch (dBmV)** | **Max Tx - D3.0 2 Chs (dBmV)** | **Max Tx - D3.0** **3 or 4 Chs (dBmV)** |
| **QPSK** | 58 | 61 | 58 | 55 |
| **8-QAM** | 55 | 58 | 55 | 52 |
| **16-QAM** | 55 | 58 | 55 | 52 |
| **32-QAM** | 54 | 57 | 54 | 51 |
| **64-QAM** | 54 | 57 | 54 | 51 |
| **SCDMA** | 56 | 56 | 53 | 53 |

Table 3 – D2.0 & 3.0 CM Levels using Different Modulation Schemes

As explained above, it can be seen that the max power for one channel on the connector has been raised by 3 dB over a D2.0 CM, but max transmit per channel for four frequencies stacked using 64-QAM, ATDMA is only 51 dBmV & 53 dBmV for S-CDMA.

In existing plant (D2.0 and lower), modems range and the CMTS sends deltas, but never really knows the actual CM transmit power.  The Cisco CMTS has code that allows a CM to register and/or stay online if it is within the “power-adjust continue” window. This may not happen with D3.0 CMs.  The D3.0 spec says the CMTS will know the CM transmit level and if the CM hits max power, it will not register.  This was not taking into account the “power-adjust continue” window either, but newer code does.

D3.0 increased CM transmit by 3 dB, but when we stack 4 chs, it drops by 6. This is an overall affect of 3 dB less output for specific modulation schemes.  Hence, 54 dBmV for D2.0 using 64-QAM, equals 51 dBmV for 64-QAM, 4-ch D3.0.  When a D3.0 CM registers, it does so on a single channel, a reference channel, and relays its transmit power level back to the CMTS. The CMTS can determine if that level will be adequate for 4-channel bonding.  It may not be using the “power-adjust continue” range for that determination. If that level is not adequate, then the modem resets itself instead of just dropping to single-channel mode. Example: a CM ranges on US0 and reports 52 dBmV, the CMTS wants to do 4-ch bonding and determines that 64-QAM for 4-ch US bonding has a max output of 51 dBmV, in this case the modem may not register.

**Food-for Thought**: This may be a case for dynamic logical channels where logical 1 uses QPSK. This modulation scheme allows 4 dB more power over 64-QAM!  If modems don’t register on logical 0 at 64-QAM, then they could try logical 1 and possibly meet the requirements there.

**Note**: Newer code takes into account the power adjust continue window and will allow the CM to do single channel mode. Cisco is implementing a new feature to take this a step further and drop from 4 ch to 2 or 1 depending on if the level is supported, plus add in a new config for the calculations.

If the CM is fine with the reference channel, it still needs to finalize initial maintenance/ ranging with the other US channels. A 12 dB dynamic range is allowed to accommodate different losses at different frequencies, but that range cannot exceed the max allowed. Example; the power-adjust continue command is set to 6 and a CM ranges on US0 and reports 48 dBmV. The CMTS wants to do 4-ch bonding and determines that 64-QAM for 4-ch US bonding has a max output of 51 dBmV. The CM registers and the dynamic window is set for 42-54, but 54 is beyond max, so the window is reset to 39-51 dBmV dynamic window. The dynamic window could adjust multiple times. US1 needs 50 dBmV and succeeds with ranging. US2 needs 52 dBmV, which is outside 51. It will report 51 Tx and hit the CMTS at -1 dBmV. US3 needs 56 dBmV, it will max out at 51 and hit the CMTS at -5 dBmV, but within the continue window.

**Note**: Currently, the CM will report its max, but the CMTS could be receiving much lower than the reported 0 dBmV, regardless of “power-adjust continue”. It may be useful to observe “scm phy” for per-CM MER and “scm “mac-address” ver” for other information.

**D3.0 CMTS Receive Levels**

To address the potential issue where a CM today transmits near max power of 54 dBmV for 64-QAM, the specification has changed the CMTS US port level setting to allow it to be 6 dB lower as shown in figure 3 below.

 

Figure 3 – CMTS US Level Range Based on Channel Width

This means the CMTS can be set lower so modems can be placed on those high value taps without changing HE or plant losses. This is at the expense of lower MER/SNR readings. The lowest setting on the CMTS today is -1 dBmV for a 6.4 MHz wide channel. The range allowed on the CMTS is dictated by DOCSIS 2.0 and lower and says -1 to + 29 dBmV for 6.4 MHz and related to channel width, also known as symbol rate or baud.

**Note**: To activate this lower setting on the Cisco CMTS, global modulation schemes must be configured. Refer to Cisco for more information.

D3.0 identified this potential level issue and forced D3.0 CMTS vendors to support lower receive levels and D3.0 CM vendors to support a transmit level of 3 dB higher than the 2.0 spec. Therefore, 64-QAM has to transmit at least a max output of 57 dBmV with a single channel.

**Bottom Line:** To keep the CM inexpensive and act as a constant power device, the max output will be dictated by how many US frequencies are active on the port (known as TCS for transmit channel set) and the highest modulation used. Four channels stacked will be 57-6 = 51 dBmV per ch. So, the overall effect from 2.0 to 3.0 is really a 3 dB difference. The spec lowered the nominal setting allowed on the CMTS so cable operators didn’t need to lower tap faceplates or drop padding on every US port on the CMTS to keep D3.0 CMs online if they maxed out. Most systems will leave the default of 0 dBmV configured and adjust padding appropriately. Cisco has a command to keep CMs online that are maxed out, power-adjust continue 4 (default). Many customers set it to 6 dB to give more room to work with.

**D3.0 CM Periodic Maintenance, Partial US Bonding Mode, & T4 Multiplier**

If the modem does successfully register and the levels change slightly during normal periodic ranging, the “power-adjust continue” will be taken into account and the CM will stay online and be marked with “!”. Example: a CM ranges on US0 and reports 50 dBmV, the CMTS wants to do 4-ch bonding and determines that 64-QAM for 4-ch US bonding has a max output of 51 dBmV, so the modem registers correctly. The temperature goes up, which adds more attenuation to cable, and the CMTS reports -3 dBmV instead of the normal 0. The CMTS sends SM to the CM to change by 12 steps of .25 dB and the CM only has 1 dB more range left. The CM transmits 51 dBmV (its max); the CMTS reports -2 dBmV and goes into fast poll mode to change again. The CM cannot change and the CMTS determines that -2 is within the power-adjust continue of 4 and allows the CM to stay online and it is marked with “!”. If any of the US channels are outside the continue window, the modem with go into US partial mode and be marked with “p” instead of “UB”. Review “sh cab modem mac-address ver” for specifics about the CM in question.

Modems have a T4 timer that is 30 seconds. The CMTS typically sends a station maintenance message every 20 seconds per CM. If the CM does not get a station maintenance message within that time, it will go offline and start to re-scan DS. Now with multiple US channels for a D3.0 CM, it can become excessive to send every one of those channels a station maintenance burst every 20 seconds. This is where the T4 multiplier comes into play.

The T4 multiplier value is only applicable to modems operating in mtc-mode and sent in every RNG-RSP message. The T4 timer is for the CM, and not per US.

10k(config-if)#cable upstream ranging-poll interval 20000 ?

 t4-multiplier T4 multiplier ranged from 1 to 10, 0 as auto

The multiplier value default is 0 (auto), which is the sum of all channels assigned in the US transmit channel set. With no MTC-mode, it is one. With mtc-mode, the multiplier is the number of channels on the largest US bonding group for that MAC domain.

Example:

CM is doing 4 Ch US bonding (USs 0-3)

The CMTS uses a 4x multiplier by default. We tell the CM that its T4 is 30 \* 4 and internally we are scheduling at 4 x 20 sec intervals.

CM has 120 sec T4 timer (30\*4).

CMTS send SM burst to US0 every 4\*20 = 80 sec

CMTS send SM burst to US1 every 4\*20 = 80 sec

CMTS send SM burst to US2 every 4\*20 = 80 sec

CMTS send SM burst to US2 every 4\*20 = 80 sec

Impairment example: If US0 has noise issues, the CMTS goes into fast polling. The CMTS tries 16 times total and eventually quits sending grants and it reports the US channel down. The CM should go into US partial mode. Partial mode is a CMTS concept where the CMTS stops scheduling grants on the failed channel. You will see a lot of T3 timeouts from the CM perspective or misses in the CMTS flaplist. In this case, you are not going to see T4 timeouts, since there are SM opportunities on other operational channels.

The number of ranging misses before a channel is marked is now configurable by this:

10K(config-if)#cable upstream resiliency modem-offline-detect ?

 <4-16> Number of consecutive ranging misses

Modem-offline-detect 8 is the default. When the criteria is met, this is what triggers the fast polling on all channels, instead of waiting for the normal polling cycle. This means that after 8 consecutive misses, the CMTS will automatically do a quick poll on all channels. This will speed up marking modems offline instead of waiting for the normal polling cycle.

The action taken is configurable by this:

10K(config-if)#cable upstream resiliency on-failure ?

 disable-channel disable channel

 extended-ranging continue to range

 reset-modem take modem offline

The default is “extended-ranging” when a channel is down. In this mode, the CMTS will continue to schedule SM opportunities at the normal interval to give the CM a chance to recover the failed channel.

**Question**: What happens when there are 2, 2-Ch US BGs and there are multiple flow - some associated with one group and some with another? Does this only send fast poll for all channels for that group the flow is on? Or, does it poll all channels in all US BGs which the modem has admitted flows?

**Answer**: The spec requires the CMTS to mark the CM offline whenever all channels associated to the primary flow are down. Otherwise, the CM remains online in partial mode.

We mark a modem offline only when all USs that a modem's primary US SF is associated are down. Ranging does not care about individual flows in that sense. Ranging cares about ranging all the individual channels. Upon detection of channel going down, ranging informs the scheduler for any flows associated to the bonding groups, in which its channel membership has the same impacted (impaired) channel, to make sure that scheduler stops scheduling grants on that upstream for any of the flows.

**Potential Minimum Transmit Issue**

Minimum transmit has never been seen as a big issue. DOCSIS 3.0 has set the minimum level much higher than it used to be with D2.0, which was as low as 8 dBmV. This minimum CM transmit level is related to channel width and displayed in Table 4 below.

|  |  |  |
| --- | --- | --- |
| **Symbol** **Rate (kHz)** | **Minimum****Tx (dBmV)**  | **Applicability** |
| **160**  | 17  | CM MAY support |
| **320**  | 17  | CM MAY support |
| **640**  | 17  | CM MAY support |
| **1280** | 17 | CM MUST support |
| **2560**  | 20  | CM MUST support |
| **5120**  | 23  | CM MUST support |

Table 4 – D3.0 Minimum US Transmit Level based on US Channel Width

One potential issue can arise when using a CM in the headend as a test modem and not providing the proper attenuation. If this test modem ranges and comes online with a transmit level of 20 dBmV, which is legal, then it also has plenty of range left in its transmit. If it ever re-registers and ranges on the wrong upstream channel descriptor (UCD) it could cause packet collisions on other US ports. If this example were using 16-QAM with a max output of 55 dBmV, which means this modem could range all the way to 55 dBmV, which is 35 dB more than it needs.

Depending on the headend wiring and architecture, this signal could find a path to “bleed” across because of isolation issues or lack thereof. Because the CMTS can typically “see” a CM around -20 dBmV, this re-ranging modem could be detected on the wrong US port even with 35+20 = 55 dB of isolation design.

The latest issue pertains to lab setups and D3.0 and/or SCDMA. Many lab environments will not have attenuation to force modems to transmit in the 40-50 dBmV range. The minimum range when using a D3.0 CM at 6.4 MHz channel width is 23 dBmV. This is specific to mtc-mode being activated for US channel bonding. When testing with SCDMA, that minimum could be as high as 42 dBmV! According to the D3.0 RFI spec, Min Tx = max[17 - Gconst] + 10 log(number\_active\_codes / #\_of\_codes\_per\_minislot), where the maximum is over all burst profiles used by the CM in channel x. The bottom line is, modems may not register because of minimum transmit requirements not previously seen with D2.0. One example would be SCDMA using 6.4 MHz channel width using QPSK for Ranging and 64-QAM for Data. Depending on active codes & codes per minislot, the minimum could be as low as 24 dBmV or as high as 42 dBmV!

**Upstream Passband**

The US upper edge has changed in the D3.0 specification to 85 MHz, whereas it was previously 42 (annex B), 55 (Japan), & 65 MHz for Euro-DOCSIS. The option of going higher is good for future spectrum re-allocation and avoiding known bad frequencies on the US. Some things need to be considered and they include; diplex filters, line EQs, step attenuators, etc. If any of devices are incorporated, they may need to be replaced to support the new frequency split.

Also, can current customer premises equipment (CPE) like settops and TVs handle a potentially high level of “noise” from a modem at 40 MHz or higher? Television intermediate frequency (IF) in the United States is between 41 & 47 MHz. One user could overload their own TV as well as a few of their neighbors!

An extended upper frequency may be best suited for PON or RFoG architectures where the only diplex filter in the link would reside in the house. If this were the case, a high-split LAN like 5-200 MHz may be realized considering many US lasers are specified for that range today.

**Channel Placement**

Since each US channel used for bonding is an individual channel, frequencies can be anywhere in the US passband and do not need to be contiguous. Although, it may be wise to keep relatively close so plant problems like attenuation and tilt don’t cause issues. The CM should have some dynamic range to allow specific channels to be a few dB different vs. other channels. According to the spec, that range is 12 dB.

Since the transmitters (channels) are separate, they don't have to be contiguous and can have different physical layer attributes like; modulation, channel width, TDMA or S-CDMA, etc.

There are many ways that this spectrum is used. The upstream spectrum may be shared between:

* DOCSIS 1.0, 1.1, 2.0, and 3.0 CMs,
* Legacy set-top box (STB) out-of-band (OOB) signaling channel,
* Legacy TDM voice
* Telemetry (power supply monitoring, sweep,…..).

Table 5 below gives a sample layout of US spectrum allocation with an extended range for Euro-DOCSIS to 65 MHz. Keep in mind that analog TV IF resides within ch 7 below. SCDMA is better suited for regions of the spectrum prevalent with electrical impulse noise, which is typically below 20 MHz. This multiplexing scheme is for D2.0 and later CMs.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **#**  | **From**  | **To**  | **BW**  | **Modulation**  | **Style**  | **Primary****Usage**  |
| 10 | 61.4  | 64.6  | 3.2  | 64-QAM  | ATDMA  | D3.0  |
| 9  | 54.8  | 61.2  | 6.4  | 64-QAM | ATDMA  | D3.0  |
| 8  | 48.2  | 54.6  | 6.4  | 64-QAM | ATDMA  | D3.0 |
| 7  | 41.6  | 48  | 6.4  | 64-QAM | ATDMA  | D3.0 |
| 6  | 35  | 41.4  | 6.4 | 64-QAM | ATDMA  | D3.0 & 2.0  |
| 5  | 28.4  | 34.8  | 6.4 | 64-QAM | ATDMA  | D3.0 & 2.0  |
| 4  | 23.6  | 26.8  | 3.2 | 16-QAM  | TDMA  | D1.x  |
| 3  | 20.2  | 23.4  | 3.2  | QPSK  | TDMA  | D1.0 DSG  |
| 2  | 13.6  | 20  | 6.4 | 64-QAM | SCDMA  | D3.0  |
| 1  | 7  | 13.4  | 6.4 | 64-QAM | SCDMA  | D3.0  |

Table 5 - US Spectrum Allocation

**Total Power**

Significant consideration must be given to the total RF power loading that will now be realized with US channel bonding in DOCSIS 3.0 CMs. In previous DOCSIS standards, only one US channel was present. For DOCSIS 3.0, up to four (4) US channels will be transmitting at the same time, possibly with a 6.4 MHz bandwidth each, resulting in nearly 26 MHz of US channel loading. This is a lot of power hitting the return path fiber optic transmitter. The probability of laser clipping is increased, especially if one has legacy Fabry-Perot (FP) lasers in the fiber nodes. It’s a good idea to upgrade to Distributed Feedback (DFB) lasers, which have significantly more dynamic range. Another option is Baseband Digital Reverse (BDR) technology where the US analog signal is digitized and sent back on a pure digital link.

It’s wise to have a comprehensive plan to monitor US laser clipping. Using an US monitoring system capable of looking above 42 MHz, like PathTrak, will enable you to see second and third order harmonics. Remember, any burst noise above the diplex filter (i.e. 42 MHz) coming out of the US receiver in the HE is usually indicative of US laser clipping.

The blue trace in Figure 1 below shows the case of strong laser clipping, while the green line represents a flat noise floor from the US laser with no clipping. This US has 4 bonded chs.

Figure 1 – Apparent Laser Clipping

Using US monitoring tools like PathTrak or Cisco Broadband Troubleshooter (CBT) to view 5-65 MHz for apparent laser clipping as in the above figure is critical for ongoing preventative maintenance. Also needed is an analyzer that can read < 5 MHz for AM radio or ham radio ingress which can quickly leak into the network and contribute additional power to the US laser causing clipping, as well as cause problems at the input of the CMTS. The new PathTrak card (RPM-3000) further has the ability to demodulate and display live cable modem US constellations as seen in Figure 2 below.



Figure 2 – US 64-QAM Constellation

This monitoring system provides average, max, and min MER of D3.0 and < CMs on each node.

**New Architectures**

When fiber is run deeper into the network as in the case of RF over Glass (RFoG) or DOCSIS Passive Optical Networks (DPON), a new conundrum is raised. Many of these architectures will incorporate 32-way optical splitter/combiners. Having a laser Tx in your house combined with 32 other houses feeding 1 Rx in the HE is addressed with lasers timed with the actual traffic from the house; unlike how it is done today where the US laser is on all the time.

Having US bonding and/or load balancing presents a potential issue where an US laser could be transmitting the same time as another US laser. This may be addressed with the fact that even though multiple lasers are transmitting the same instant in time, if they are carrying different frequencies, then it may be acceptable. The other option is to make sure all modems in that domain are based on one scheduler. The next question is, will S-CDMA pose the same problems? This multiplexing scheme allows multiple CMs to transmit the same instant in time.

**Isolation Issues**

Figure 4 below depicts possible US isolation issues that can occur when an US frequency is narrowcast and another US frequency is introduced across multiple nodes. Creative placement of pads and filters and/or isolation amplifiers can be used to prevent the signal from back-feeding when architectures like these are implemented.



Figure 4 – Possible US Isolation Issues

Because of different combining schemes for different nodes as shown in figure 4 above, two USs which are at the same frequency, could interfere with each other. Upstream 2 is being fed from two nodes, while US0 is from one node and US1 is from the other, separate node. The 24 MHz signal for US0 will travel to the US2 combiner and back-feed to the fiber receiver number 2, then possibly back-feed to US1 of the CMTS. This 24 MHz signal will be about 40 dB lower than the expected signal if the isolation in each splitter is at least 20 dB.

Some ways to increase the isolation are: use amplifiers, add filters, or selectively move attenuation to different points in the network. This situation may also cause issues with load balancing since one port is shared across two other ports. Can US2 load balance with US0 and load balance with US1?

**Shrinking the CM Transmit “Bell Curve”**



Figure 5 – US System Plant Design Options

Figure 5 above illustrates system plant design variations; not the in-home wiring variations! This is the level that a home user device would need to transmit (if attached directly to the tap) to arrive at the associated amplifier at its recommended level. If step attenuators, EQ taps, or line equalizers with reverse padding are used to make end of line CMs transmit higher, it addresses two concerns. Since more attenuation is added where there was once less loss for ingress, it allows “ALL” CMs to have a better CNR and maybe a better MER/SNR. The loss from step attenuators and these other options attenuates the ingress from those low value taps and houses attached to those taps. These options also solve the potential issue of modems “ramping up” to max power when a power outage occurs. A typical CM with 55 dBmV output would overdrive the system if located at the end of the cable span and ranged on the wrong US.

**Frequency Expansion & Tap Change-outs**

If systems are looking to do 1 GHz amplifier upgrades, they should look into removable diplex filters in case we change to 5-85 MHz, which D3.0 supports. Also, the truck roll for this is expensive, so doing some tap change outs now would be optimum. The first tap off of the active used to be a 29 dB tap, then got dropped to 26, then dropped to 23 all because of CM US transmit levels, very close to 55 dBmV or so. Modems farther away on low value taps transmit much less, sometimes as low as 35 dBmV. To get this delta much closer (tighter bell curve of CM transmit levels) we need to either add loss (attenuation) to low value taps or maybe we could just change the first few taps off the actives to cable simulator taps. So the tap would look like a 32 dB tap at 1 GHz, but maybe 17 dB at 5 MHz. This solves two issues:

1. DS level and tilt hitting the house
2. US max transmit levels

Since these CMs would go from say 55 dBmV to 49 dBmV, we have room for 3.0 CMs with US bonding and/or we could add padding at the node to force all the CMs higher again and get better SNR. If CM transmit levels are still a concern, using a D3.0 CM in 2.0 mode would allow higher US Tx level because the use of a single frequency and a D3.0 CM offers 3 dB higher power. Running D3.0 in low modulation schemes allows higher power as well. Using SCDMA with more codes may also allow higher Tx power, but will depend on implementation.

**Reasons CM Does Not Bond on Intended USs**

* CM not in w-online mode or using 1.0 cm file
* Mtc-mode off
* Mtc-mode required-attribute & no attribute in cm file
* No BG configured or incorrect fiber node config
* CM not set for bonding or firmware issue
* All US chs not “sta”
	+ US(s) shut
	+ Max or Min Tx issues
	+ Poor MER, plant issues, mis-wired

CM US channel states for bonding:

* + IM = waiting for initial maintenance
	+ SM = waiting for station maintenance
	+ Cont = continuous ranging (ranging miss or adjustment is needed)
	+ STA = station maintenance
	+ DR = down & recovery with extended ranging opportunities
	+ DT = down due to timeout, and no recovery
	+ DI  = down due to interface shutdown
* Oversubscribed CIR
	+ Call signaling (nRTPS), min US guaranteed speed, ..
	+ Could have multiple single ch bonding groups

We can’t afford to oversubscribe bonding groups given the possibility of overlapped bonding group configured in the same MD.  So, when not enough bandwidth is returned from admission control to serve the SF, we will not grant the assignment to the multiple channel bonding group.  Instead, we will assign the SF to the default single channel bonding group.  The difference is that the default bonding group has the same behavior as the legacy mode upstream channel for oversubscription.

Suppose that statically configure 4-channel BG has no bandwidth left. Flow 1 could be admitted to default BG-x with channel 1 & BG-y with channel 2. Same for flow 2. Because of LB in the BG selection, flow 1 could be admitted to BG-x with channel 1. Flow 2 to BG-y with channel 2. Then, the modem has channel set of 1 and 2.

**Note**: US service flows like UGS & RTPS are assigned to a single channel bonding group.

**US Best Practices**

This example assumes one or more ATDMA chs and one TDMA ch. This provide a quarantine ch of TDMA for 1.x CMs and/or settop boxes and load balancing of D2.0 CMs on the ATDMA channels. Allowing D2.0 CMs to load balance on the TDMA ch complicates things and explained later. This may require DOCSIS restricted LBGs and/or CM steering.

* Keep US freqs relatively close & same phy parameters when freq stacking
* Bond US channels of similar parameters/speed
* Use caution with rate adapt – refer to rate adapt paper
* Logical channel 1 is intended for lower/more robust modulation
* Best to use 6.4 MHz ch width, if possible, instead of 2, 3.2 MHz wide channels
* Recommended not to bother with odd constellations like 8 or 32-QAM, MER requirements not much different than those for next higher modulation
* Spectrum allocation has many variables such as; group delay, known ingress freqs, etc.

**Summary**

Customers and competition are driving the need for increasingly faster speeds in our DOCSIS networks. DOCSIS 3.0 provides an effective migration path for customer satisfaction, exceeding competitive pressures and enabling the delivery of new services and penetration of new markets. With more than four (4) times the data throughput capacity of its predecessors, DOCSIS 3.0 is apt to be nearly an order of magnitude more complex to deploy in such a manner as to take full advantage of its capabilities. Careful planning, plant maintenance and a well developed continued preventative maintenance program from the onset will help pave the road to a speedy and fiscally fruitful deployment.

**Bottom Line**

As with DOCSIS3.0 DS planning, US planning is equally important. Implementing and exploiting DOCSIS 2.0 capabilities first will lead to a more successful D3.0 US deployment. Planning frequency placement, combining/splitting with isolation considerations, addressing level issues and potential laser clipping probability will go a long way to solidify a successful deployment. Thinking about plant upgrades and options now will help mitigate issues later.

Deploy long term D3.0 service planning and ensure optimized frequency allocation. This should enable a seamless upgrade to higher D3.0 tiers with a “wire once” mentality. Keep-in-mind phy connectivity and not just channel capacity planning. It’s not advantageous to combine noise to satisfy connectivity. Fix max transmit issues now and design for a tight “bell-curve” (43-48 dBmV), if possible. The good news is, there’s a CableLabs ECR to increase the D3.0 US transmit levels to 61 dBmV max, with a 3 dB typical increase.