Testing and turn-up of DOCSIS 3.1 services in the HFC network from a field and maintenance technician perspective

An Operational Practice prepared for SCTE/ISBE by

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Table of Contents

Title **Page Number**

List of Figures

Title **Page Number**

List of Tables

Introduction

With the deployment of DOCSIS 3.1, field and maintenance technicians will be faced with new challenges due to the use of the new technology. In particular, DOCSIS 3.1 introduces new technologies including OFDM (Orthogonal Frequency Division Multiplexing) and modulation profiles that provide unprecedented flexibility and capability. Operators can use DOCSIS 3.1 to utilize portions of the plant that previously could not carry traditional QAM's. Operators can also leverage DOCSIS 3.1 to gain additional capacity and efficiency to maximize their utilization of the existing plant. Knowing what to look for and how to evaluate DOCSIS 3.1 is critical for the field technician.
This paper will examine some of the best practices for measuring and analyzing DOCSIS 3.1 performance. It will discuss using a combination of techniques to help validate network and DOCSIS performance.

The metrics and measurements of DOCSIS are covered in a building block fashion regarding OFDM carriers including how to properly setup and measure OFDM power levels, how to look at the multiple layers of DOCSIS 3.1 including PLC (Physical Link Channel), NCP (Next Codeword Pointer), OFDM physical layer characteristics including Level, MER, and Codeword Errors, as well as looking at advanced modulation profiles. Service layer testing of bonding and throughput performance are discussed as a critical tool to ensure proper RF and service performance.

Troubleshooting techniques for optimizing OFDM will also be explored throughout and will include examples from live field and lab testing where the testing methodologies were used to identify and fix problems affecting the DOCSIS and network performance.

Downstream Metrics and Measurements

1. Testing the basic building blocks of OFDM

1.1. OFDM Building Block Overview

OFDM is quite complex and may seem overwhelming to technicians. But when broken down to its basic components and how they affect the service, a simple approach with straight forward metrics can be applied so a technician can understand and troubleshoot an OFDM carrier. Figure 1 shows how each layer of OFDM is reliant on the previous layer. We will start with a bottoms up approach on OFDM. The core building blocks of the DOCSIS 3.1 OFDM carrier are

- The Phy Link Channel (PLC) contains the critical information on how to decode the OFDM signal
- The Next Codeword Pointer (NCP) tells the modem which Code Words (CW) are present, and which profile and frequencies to use on each CW.
- Profile A is the Boot profile. ALL 3.1 modems must be able to use profile A
- The OFDM avg. power needs to be within range. Good MER and lack of noise enable higher modulations
- Profiles B,C,D… enable higher modulations for greater efficiency

An effective test routine of these building blocks will assure the proper functioning of a DOCSIS 3.1 network.

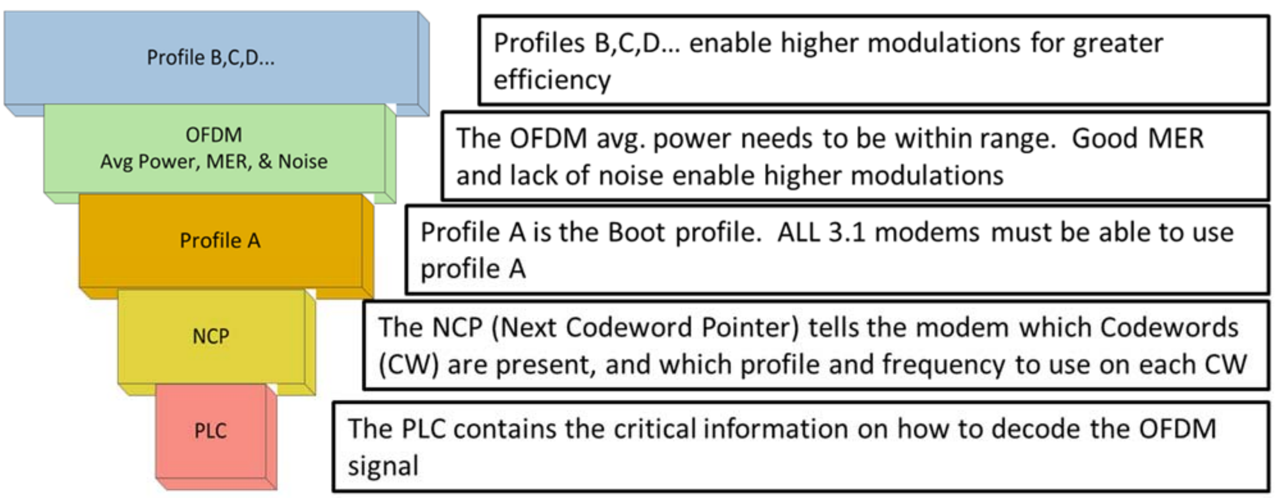


Figure 1 - Building Blocks of OFDM

1.1. PLC – Phy Link Channel

Let's start with the base layer, the PLC . The PLC contains the critical information on how to decode the OFDM signal. Without the PLC, the modem cannot find the OFDM carrier or understand how to decode it. In essence the PLC is the telemetry signal to the modem with the mapping to subcarriers and data decoding. Critital items to look at for the PLC

- Make sure that the PLC is locked
- Make sure that NO UNCORRECTABLE Codeword errors are occurring.
- Check that the PLC level and MER aren't on the verge of not being able to be demodulated.

Fortunately, the PLC is relatively robust since it uses BPSK and 16-QAM. Therefore it needs to have a minimum MER of 15dB and a minumum power level of -15dBmV

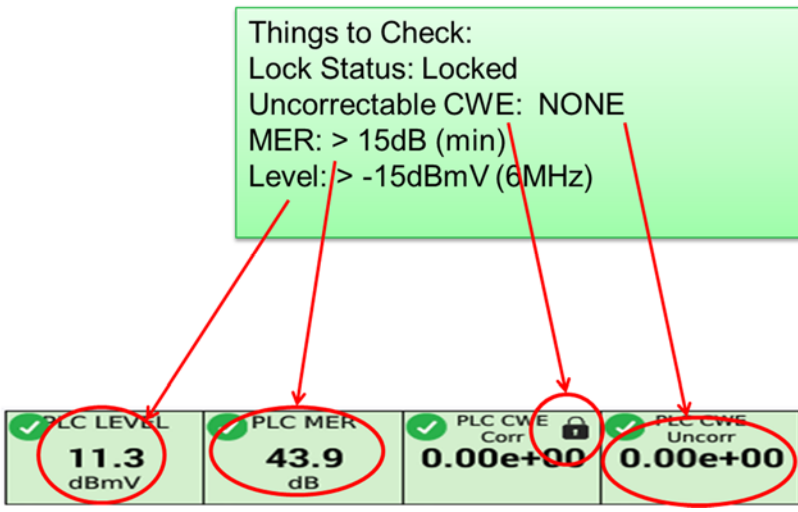


Figure 2 - PLC Measurements

1.1. NCP – Next Codeword Pointer

Next in importance is the NCP. The NCP tells the modem which Codewords (CW) are present, which frequency the CW's are carried on, and on which profile each codeword uses. Like the PLC it is vital to have near perfect performance of the NCP. Key items to look at for the NCP are

- Proper LOCK of the NCP
- NO Uncorrectable Codeword errors.

Lost NCP messages means retries at best (e.g. for TCP), and potentially no communications at worst.

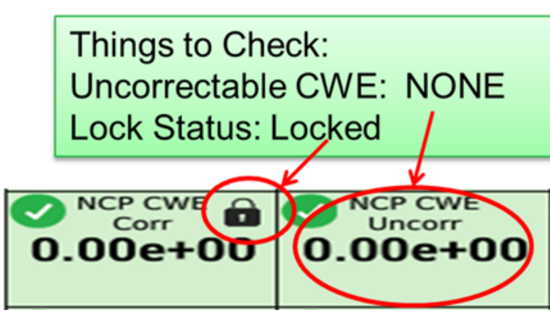


Figure 3 - NCP Measurements

Similar to the PLC, the NCP's also use lower modulations QPSK, 16-QAM or 64-QAM max which are relatively robust.

Since NCP frequencies vary on a symbol by symbol basis, measuring the MER and power level for the NCP isn't as relevant. Looking at the OFDM power metrics that they are above the minimum lock range should suffice for NCP power levels.Figure 4 shows a graphical representation of how the NCP and Codewords fill up the frequency allocation on a symbol by symbol basis. This build up is done prior to the frequency interleaving. Therefore, on the cable plant, it isn't viable to track impacting noise on a particular frequency by looking at the data, profiles or NCP.

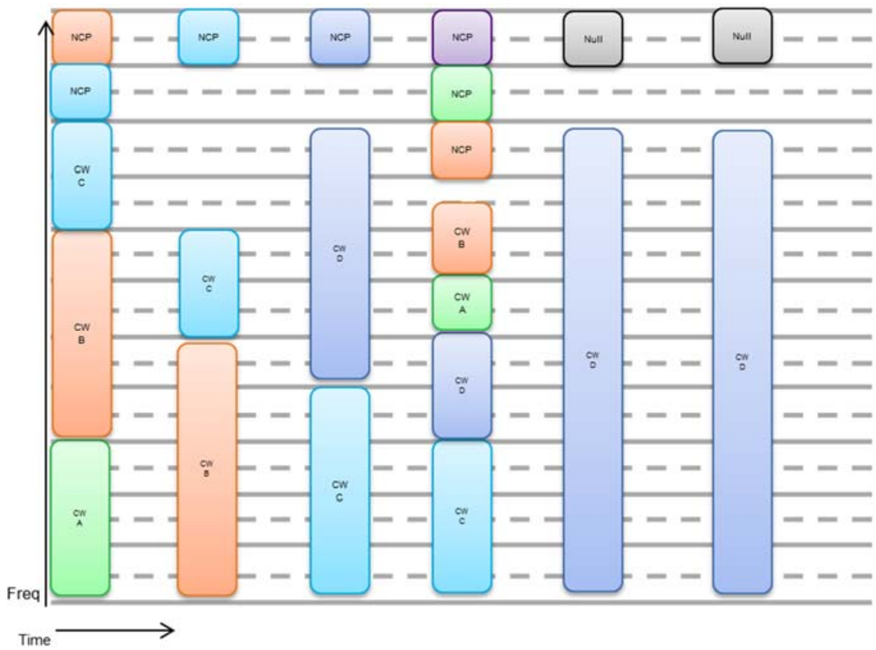


Figure 4 - NCP and Codeword Population by Symbol

1.2. Profile A Measurements

After validating the two basic building blocks of PLC and NCP are operating satisfactorily, next in importance is Profile A. Profile A is the cornerstone for a D3.1 modem to actually operate on the OFDM carrier. This is where the command and control, range and registration occurs. Profile A is the boot profile and EVERY 3.1 modem must be able to receive Profile A in order to utilize the OFDM carrier and operate in 3.1 mode.

In practice Profile A may be assigned lower modulations like 64-QAM or even 16-QAM so every 3.1 modem can communicate. Lower modulation profiles can operate at lower MER/CNR and power levels.

Like the NCP, it is critical to check that the Profile A can be locked on and that there aren't any UNCORRECTABLE errors.

If Profile A is using a higher modulation, it may be normal to have CORRECTABLE codeword errors. This can be OKAY as long as the UNCORRECTABLE's are still not happening.

Since the profiles use different frequencies on a symbol-by-symbol basis, and MER/SNR measurements are not dependent on the specific modulation, simply measuring the MER and power levels of the OFDM carrier across the frequency band satisfies the physical layer measurements for Profile A.

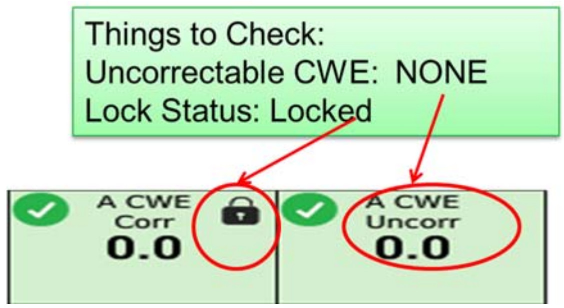


Figure 5 - Profile A measurements

1.3. Profile Analysis

Now that the basics of DOCSIS 3.1 are covered it is time to look into how the data layers that help provide greater efficiency are performing. We'll do this by looking at the performance of each of the profiles.

Things to look for: Profile A should have NO uncorrectables.

Ideally the higher profiles that you want the modems to operate on have very little to no Uncorrectables.

Some CWE may occur on higher profiles but need to be less than a level that causes poor QOE.

In reality if you aren't pushing your higher profiles to the level that you have correctable errors and an acceptable level of uncorrectable errors, you aren't getting the maximum effectiveness and efficiency that OFDM with LDPC can provide. You should expect to see the higher profiles continually operating with Correctable CWE's. This is OKAY.

You don't want to have too many Uncorrected CWE's that cause retries that exceed the efficiency gains of being on a higher profile.

Profile	Locked?	CWE Correctable	CWE Uncorrected
A	YES	0.0e+00	0.0e+00
B	YES	2.0e-01	0.0e+00
C	YES	01.6e-09	1.7e-05
D	NO	N/A	N/A

Figure 6 - Profile measurements and analysis

Table 1 – Codeword error expectations and impacts

Component	Importance	Code Word Error expectations and impact
PLC	**Critical**	Should have **0 Uncorrectable CWE** otherwise OFDM may not work
NCP	**Critical**	Should have **0 Uncorrectable CWE** otherwise OFDM may not work
Profile A	**Critical**	Uncorrectable CWE will cause poor QOE and possibly make the OFDM carrier unusable forcing data to regular QAM carriers instead of OFDM
Profile B,C,D	High	Uncorrectable CWE will affect bandwidth and overall QOE

1.4. RF General Physical Layer Measurements and Metrics

Once you have validated that the critical building blocks are working and within specification, the next step is to look at the overall OFDM carrier health and performance. Since there are 4k or 8k subcarriers it makes sense to look at the aggregate performance and not the individual subcarrier performance.

Things to look at are:

- Average power level relative to 6MHz carrier
- Minimum power level relative to 6MHz
- Maximum power level relative to 6MHz
- Average MER
- MIN and MAX MER
- The MER performance of the 2^{nd} percentile.
- The Standard Deviation of the MER across the carrier
- In Channel Frequency Response (ICFR)

Table 2 – MER and Power requirements for different modulations

Carrier Modulation	Minimum CNR/MER	Minimum Avg Power (6MHz)
4096-QAM OFDM	41 dB	-6 dBmV
2048-QAM ODFM	37 dB	-9 dBmV
1024-QAM OFDM	34 dB	-12 dBmV
256-QAM OFDM	27 dB	-15 dBmV
64-QAM OFDM	21 dB	-15 dBmV
16-QAM OFDM	15 dB	-15 dBmV

1.4.1. Power Levels

OFDM carriers should be set up so they have the same POWER PER HERTZ as the QAM carriers. This is why they are referenced back in terms of Average Power per 6MHz. This means if we set the AVERAGE POWER of the 96 MHz wide OFDM carrier in a 6MHz Bandwidth to 5dBmV then we are hitting the amplifier with the same Total Integrated Power as 16 256-QAM carriers. In effect the this means that putting in a 96 MHz wide OFDM in place of 16 SC-QAM's will look transparent to the amplifiers.

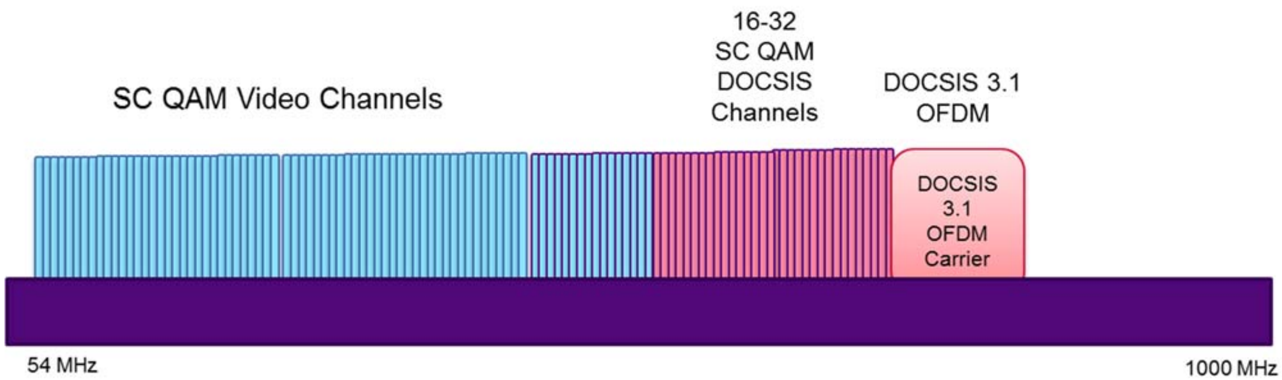


Figure 7 - OFDM Channels added to SC-QAMs at same power level

As operators turn on OFDM they are faced with a totally new carrier that spans up to 192MHz in width. To compound matters, Cable Labs specified that the power should be referenced back to 6MHz bandwidth.

What is the best way measure this and translate this? The simplest way is buy a Signal Level Meter (SLM) that was designed and calibrated for measuring DOCSIS 3.1 OFDM carriers. This does all the work for you. And a reputable meter vendor will calibrate the measurements to the golden standard of a thermocouple power meter and guarantee them over time, temperature and varying network loading conditions. If you don't have access to an SLM designed for DOCSIS 3.1 OFDM you can use a spectrum analyzer. Section 1.4.1 Measuring Power with a Spectrum Analyzer covers the methods for this.

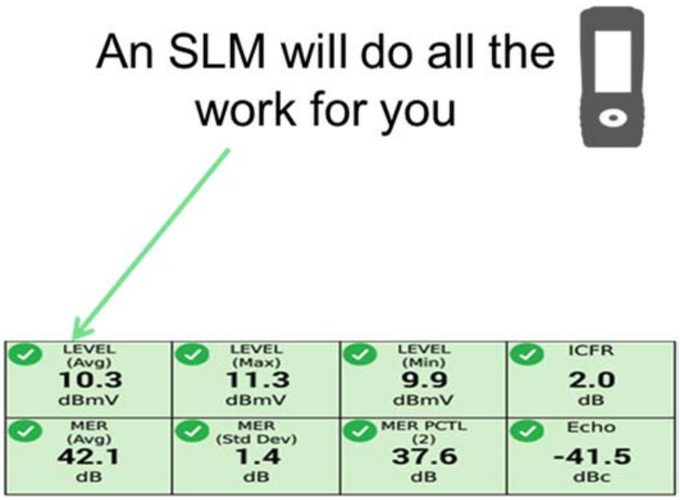


Figure 8 - OFDM average power measurement

For finer granularity than the overall average of an OFDM carrier and to see what is happening across the spectrum, you can measure across the carrier in stepwise 6 MHz steps. For each measurement, the power should be measured, averaged, and calculated to 6MHz bandwidth. Conveniently, most existing SLM's can be used to look at the power in 6MHz steps by setting up an unknown digital channel with a 6MHz wide bandwidth. For a more accurate measurement, the instrument should scan across the entire bandwidth and calculate the average integrated power instead of measuring a single point and then doing bandwidth compensation.

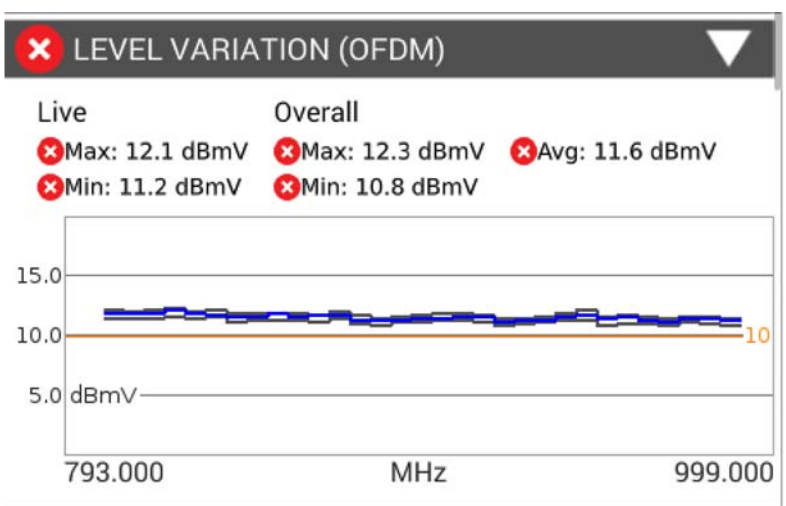


Figure 9 - Power across carriers in 6MHz Bandwidths

1.4.1. Measuring Power with a spectrum analyzer

1.4.1.1. Using Average versus Peak power

When measuring a digital carrier to obtain the average power in a specified bandwidth, it is important to use averaging in the analyzer. Digital carriers have a large difference between their peak power and the average power. HFC networks are set up based on the average power per hertz and not the peak power.

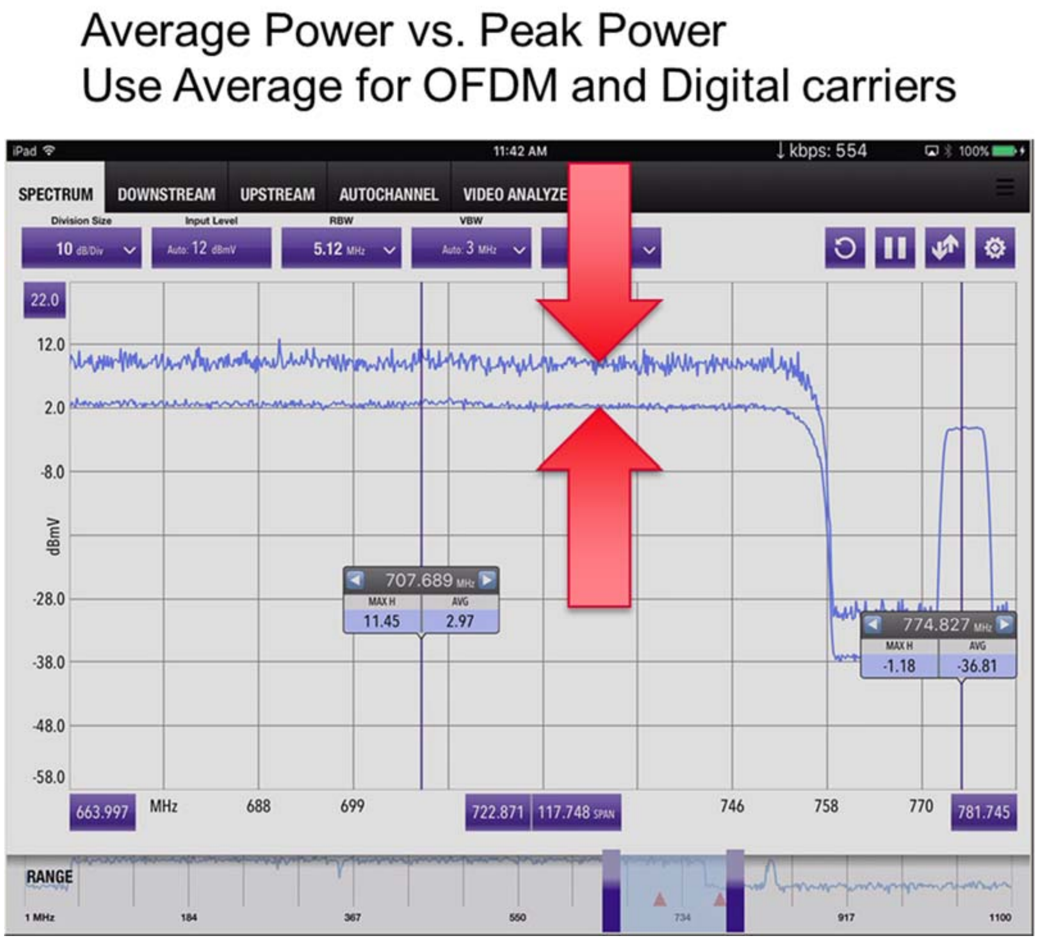


Figure 10 - Using averaging for measuring OFDM

1.4.1.2. Choosing the best RBW

Spectrum analyzer gives you an adjustable lens or “Window” to let you choose how wide of a window to let RF energy in when you’re looking at it. The wider the Resolution Bandwidth (RBW) the more energy from different frequencies it allows in. For example a 100kHz RBW allows in 100kHz wide of spectrum and a 5000KHz or 5MHz allows in 5MHz wide of spectrum.

The Video Bandwidth (VBW) determines how narrow or fine the analyzer looks at the spectrum when measuring or plotting the results. It is recommend you just set the VBW to AUTO when measuring average power.

By changing the RBW you will get dramatically different measurements. This is okay. BUT, you need to know what you are trying to measure and how to compensate for the measurement results

Ideally you want to choose an RBW that is as close to or matches the measurement bandwidth that you are trying to reference it to. So for an OFDM carrier that we are trying to measure the Average Power in 6MHz you want to set the RBW to as close to 6MHz as possible, then you don't have to apply correction factors.

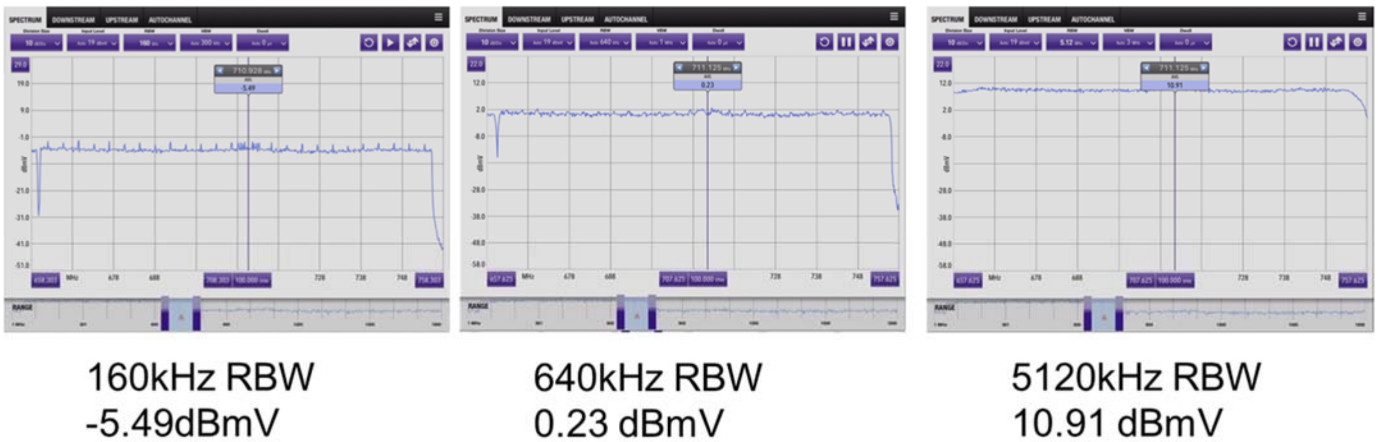


Figure 11 - RBW selection impacts measurement value

1.4.1.3. Using correction factors

When measuring a wide digital carrier, if you use a different RBW than the signals bandwidth, for example 160 kHz, your measured level will be dramatically different due to the small "window", so you will need to correct for that. Looking at measurements in the example in Figure 11 if you used a 160kHz RBW your measurement would be about 15dB Lower than if you used a 5.12 kHz RBW.

The equation for power correction is:

Total Power = Power + 10 x Log of the (Bandwidth)

Looking at the example in Figure 11 if we apply the corrections

160kHz RBW: Total Power $_{6MHz)}$ = -5.49 + 10*LOG (6,000/160) = -5.49 + 15.74 = 10.25dBmV

640kHz RBW: Total Power $_{6MHz)}$ = 0.23 + 10*LOG (6,000/640) = 0.23 + 9.72 = 9.95 dBmV

5120kHz RBW: Total Power $_{6MHz)}$ = 10.91 + 10*LOG (6,000/640) = 10.91 + 0.07 = 10.98 dBmV

As you can see, the correction factors give decent approximations but the measurement that uses the RBW similar or the same as the signal bandwidth gives a much closer measurement. In this case with a 5.12MHz RBW it is only 0.1dB off. On the smaller bandwidths you can see how critical averaging and cursor location selection are to getting the most accurate answer. By picking a peak or trough the value will be dramatically off.

If you are using a smaller RBW or VBW that show the peaks of the Pilot carriers you will want to choose a cursor location that is NOT on the peak of the pilots since you are trying to find the average power level. The Pilots are sent through at a higher level than the modulated sub carriers. Plus their duration is short so their max levels don't associate to the average power level. Figure 12 shows how the pilots and PLC are slightly higher.

Also note with a full 6MHz wide bandwidth window you will notice that the 6MHz average power at the PLC is about 0.8dB Higher than the rest of the carrier. This is due to the concentration of PLC pilots and the consistent duration of the PLC carrier.

Also the 6MHz Average power at the leading edge or high edge of the OFDM carrier will measure about 0.8dB lower due to the carrier roll-off.

So if you are trying to calculate the average power across the entire bandwidth you would be best served to take the measurements across the entire carrier and average them. Or you can use an SLM that does this for you.

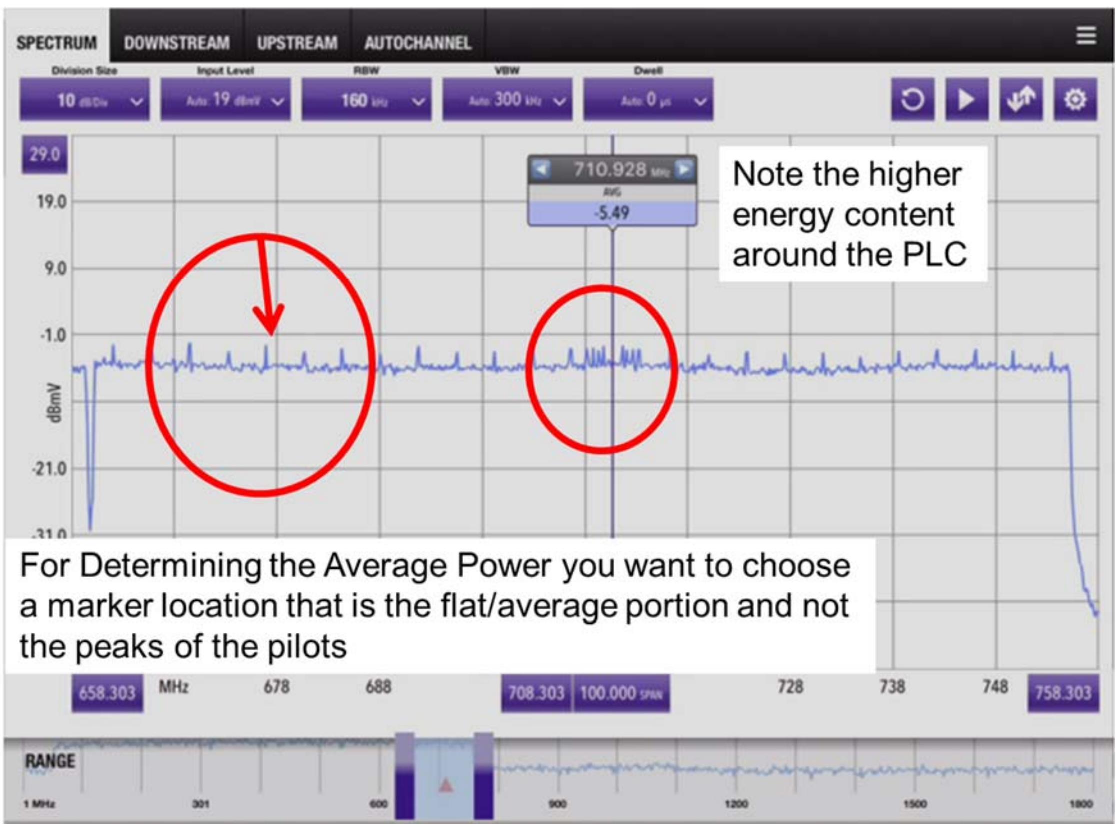


Figure 12 - RBW selection impacts measurement value

If you don't know how to correct the measurement from an analyzer or what the measurement means you could be setting your power incorrectly. Incorrectly setting an output power by 15dBmV would have big impacts on your network.

1.4.2. MER charcteristics

To assess the plant health where the OFDM carrier is, it is beneficial to look at the MER across the entire set of subcarriers in order to identify potential impairments or to predict the ability to carry higher profile levels.

Looking at the 2nd Percentile shows how good 98% of the subcarriers are working and weeds out a couple underperforming ones since LDPC error correction will likely clear it up.

Remember, if you want to run higher modulations like 2048-QAM and 4096-QAM it requires a clean HFC Plant. MER measurement tools can help identify and clean up problems as well help optimize the plant and the profiles.

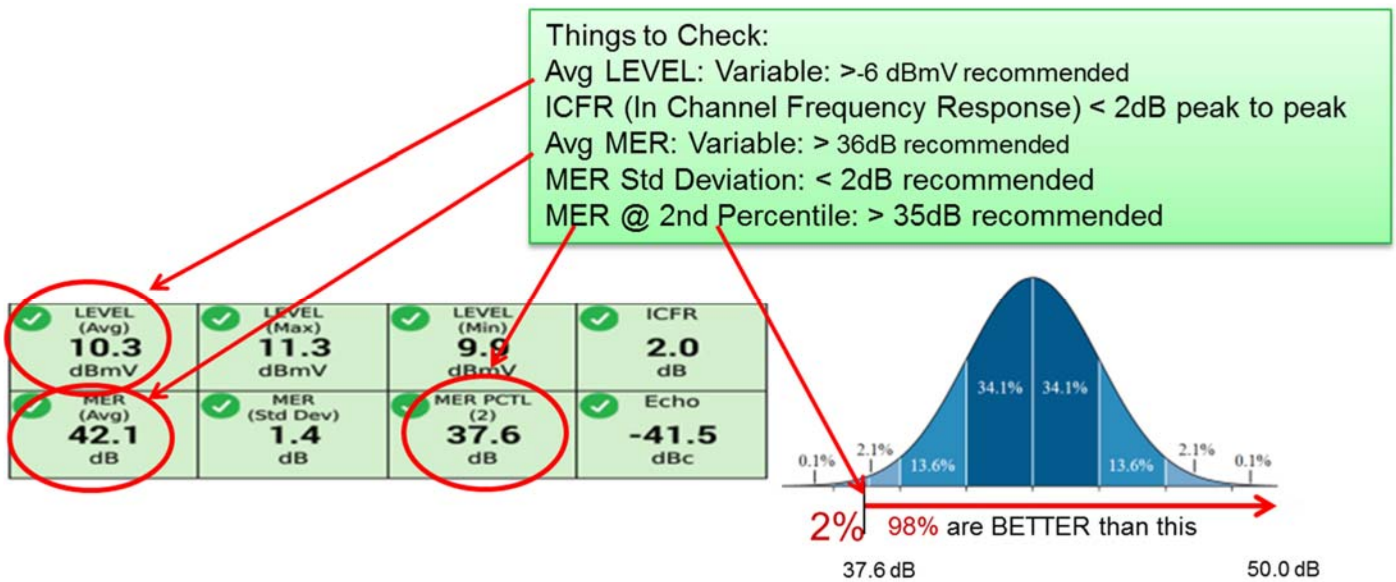


Figure 13 - Power Levels and MER Metrics

In a clean plant, the MER should be stable and not varying. Figure 14 shows an example of an OFDM carrier with stable performance. In this case the MER is stable enough to provide the ability to utilize 4096-QAM modulation for one of the profiles.

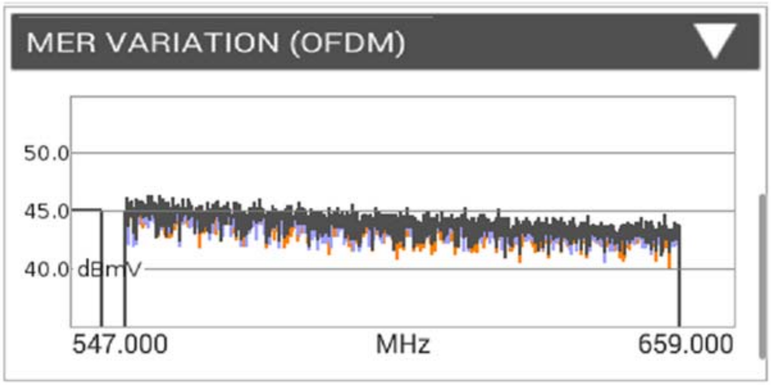


Figure 14 - Stable MER across carriers

By looking at the MER stability and variations across the frequency range you can use the information to determine the ability to support different modulation profiles. Figure 15shows an unstable environment. In this case with the MER dropping down below 30 dB MER, a 256-QAM profile would likely need to be configured for Profile A in order to have stable communications.

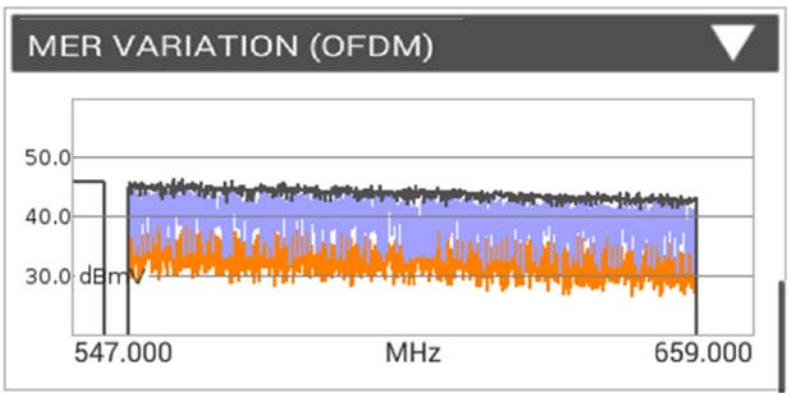


Figure 15 - Unstable MER across carriers

1.4.3. Spectrum and Ingress Under the Carrier (IUC)

OFDM is highly resilient to impulse noise and ingress due to the use of narrowband subcarriers that provide long symbol times that can outlast bursts of noise, and that limit the damage a narrowband interferer can cause. D3.1 also introduces more powerful FEC - Low Density Parity Check (LDPC) error correction – which contributes more recovery power in the face of these impairments Using tools such as Ingress Under the Carrier (IUC) you can identify if there are interference sources that are impacting the Signal to Noise Ratio (SNR) of the carrier. The Spectrum view can also identify other impairments such as suck-outs, excesive tilt, or roll off. Figure 16 show an example of using an IUC tool to identify noise spikes that lie underneath the OFDM carrier. Power level and Average MER would not be able to highlight these problems. Using IUC and spectrum, it is possible to either clean up the plant or utilize the information to help modify the modulation profiles for sub carrier exclusion zones or variable bit loading.

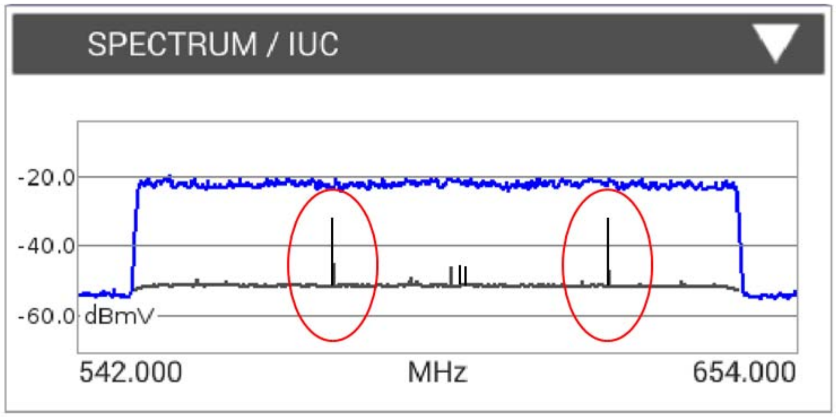


Figure 16 - Spectrum and IUC

1.4.4. Profile Analysis

Remember that 75% of the problems originate from the tap to the home. The same is true with DOCSIS 3.1. By using an active DOCSIS 3.1 test device, you can isolate where performance degradation is occuring by testing profile performance at the tap, GB and at the outlet or CPE. "While it may not affect a modems ability to come on line, differences in profile usage between test points (Tap, Groundblock, and CPE) indicate cabling issues that are reducing the spectral efficiency and should be addressed.

Using the profile performance helps identify where the degradation is occurring allowing a technician to fix the wiring and then validate maximum performance in the home. Figure 17 shows an example highlighting profile capability degradation being caused by the drop and home wiring.

	TAP		Ground Block		Outlet	
	Profile Locked?	Uncorrectable CWE	Profile Locked?	Uncorrectable CWE	Profile Locked	Uncorrectable CWE
Profile A	YES	NO	YES	NO	YES	NO
Profile B	YES	NO	YES	NO	NO	YES
Profile C	YES	NO	YES	YES	NO	YES
Profile D	YES	NO	NO	YES	NO	YES

Profile changes highlight problems in drop and or home wiring:

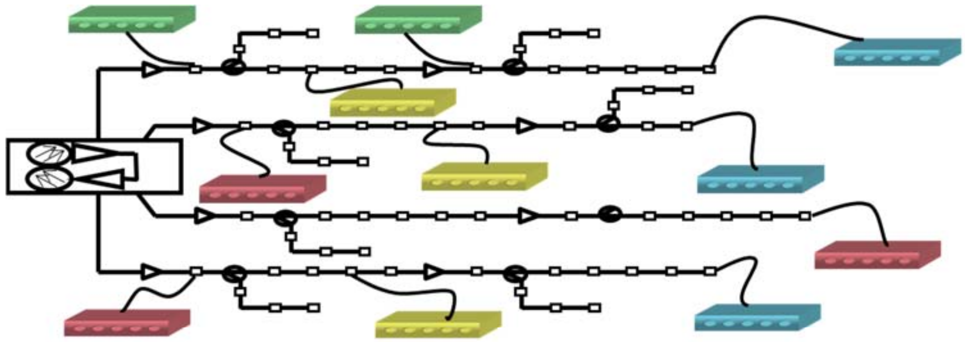
Figure 17 - Profile Analysis at different demarcation points

Profiles provide previously unattainable spectral efficiency by allowing modems with increased signal-to-noise to use higher downstream modulation rates. This increases the overall bandwidth available to individual modems, as well as reduces the amount of time utilized on the downstream during normal low bandwidth periods.

Not all parts of the network will be able to operate on the highest profile due to varying network conditions. Being able to test for different profiles can help improve plant performance and improve overall customer Quality of Experience (QOE).

Figure 18 shows how profiles can be tailored to maximize the plant efficiency and get the max bits/Hz out of the entire plant. Without profiles, the entire plant would be limited to the lowest bits per hertz of the worst portion of the plant. If you want to get even more efficiency by cleaning up your plant you can improve your higher profile usage.

By cleaning up the plan and migrating to the highest profile will provide better bits per Hertz efficiency. This makes the entire plant faster, which provides ALL end customers with an overall better experience.



		Example Modulation mix	Approx. bits/Hz
Profile A		Mixed 64 QAM & 256 QAM	6.5
Profile B		Mixed 256 & 1024 QAM	8.0
Profile C		Mixed 1024 & 2048 QAM	9.5
Profile D		Mixed 2048 & 4096 QAM	10.1

Figure 18 - Profile usage by plant variation

1.5. RF Service Level Testing

It is important to emphasize the importance of overall DOCSIS performance testing in the plant. You want to test ALL DOCSIS carriers, SC-QAM and OFDM, to make sure there isn't a network problem causing bonding or performance issues. If even one of the carriers is underperfoming, it can cause re-tries and lost packets that slow down everyone's performance.

Throughput or speed testing over DOCSIS is an important final check to make sure everything is up to par. It is important to be able to test up to 1Gb/s or even beyond over DOCSIS since these are the rates being offered with D3.1. Note that the LAN ports on todays CM devices will be GbE, which will limit payload speeds to below 1 Gbps no matter what service rate is provisioned. And, of course, WiFi comes with over-the-air variables that makes Gigabit seepds more dificult to guarantee. In either case, there is a strong dependency on the capability of the user's end device.

1.5.1. Channel Bonding

The first thing to look at is if the modem is operating in DOCSIS 3.1 mode. If there are problems with the OFDM Carriers, a 3.1 modem can still communicate using the SC-QAM carriers since it is backward compatible. To maximize the intended efficiency of the 3.1 network, it is important to validate that the OFDM carriers are being used by performing a range and registration test and validating the OFDM carrier RF performance.

If there are problems with the OFDM carriers the modem will will still use the SC-QAM carriers.

Looking at OFDM power levels alone doesn't assure 3.1 mode. Looking at Profile A performance and then the ranging & registration details including DOCSIS mode and bonding details can help alleviate any problems. Figure 19 shows an example of validating the bonding of two OFDM carriers with 32 SC-QAM carriers. If there are problems at the CPE or outlet, working backwards to the ground block and tap with a portable test device can quickly isolate the cause of problems.

Key items to look at:

- Make sure that the modem is coming on in DOCSIS 3.1
- Make sure the OFDM carriers are being utilized and properly bonded.

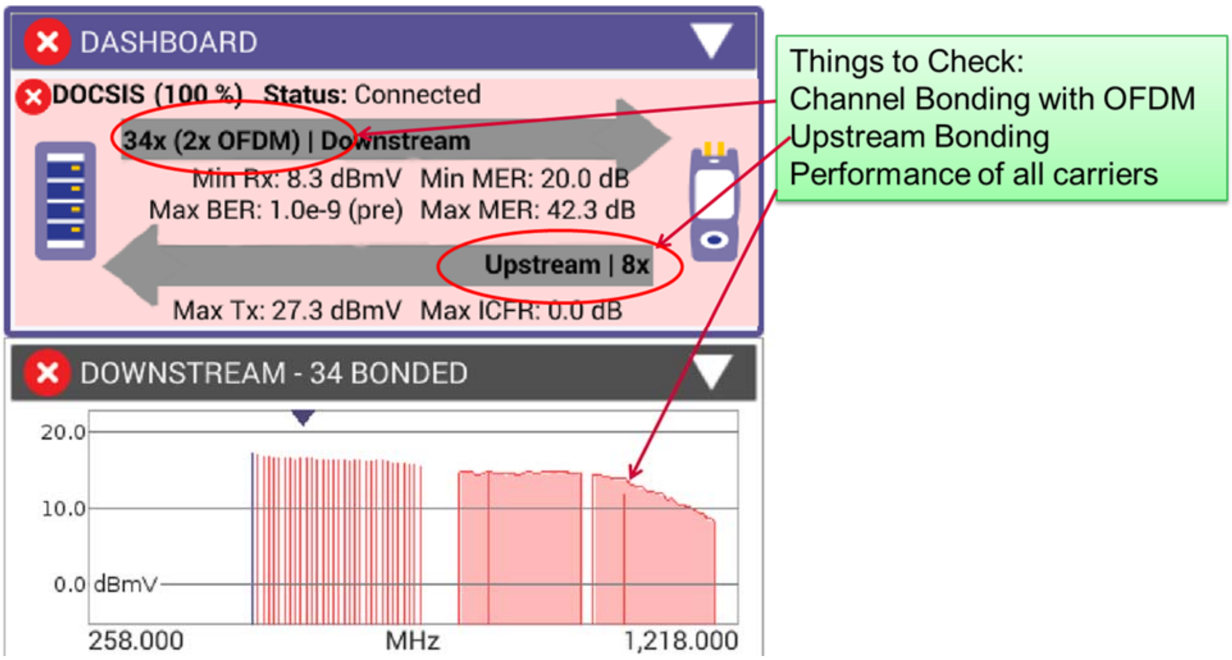


Figure 19 - Downstream Bonding of OFDM with SC QAM

1.5.2. Throughput over DOCSIS

Testing the throughput over the DOCSIS connection will identify that the RF layer is working and there are not plant degradations that are causing reduced data performance. In a properly operating plant you should be able to obtain speeed equivalent to your maximum provisioned service level. Figure 20 shows a DOCSIS throughput test result for a unit provisioned for 1 Gbps downstream and 100 Mbps upstream. Due to the overhead of TCP/IP frames, the actual data rate will typically be slightly less than the physical layer rate. In this example, receiving 935 Mbps is the normal expected rate for a 1Gbps provisioned unit. Operators will often overprovision by 10%-20% so the end user data rate exceeds the published rate. This would require provisioning for about 1.2Gbps to achieve a steady 1Gbps of actual data throughput. However, as mentioned previously, if a Gigabit Ethernet LAN interface is connected to the measuring device, its overhead will set the maximum speed that can be measured to below 1 Gbps.

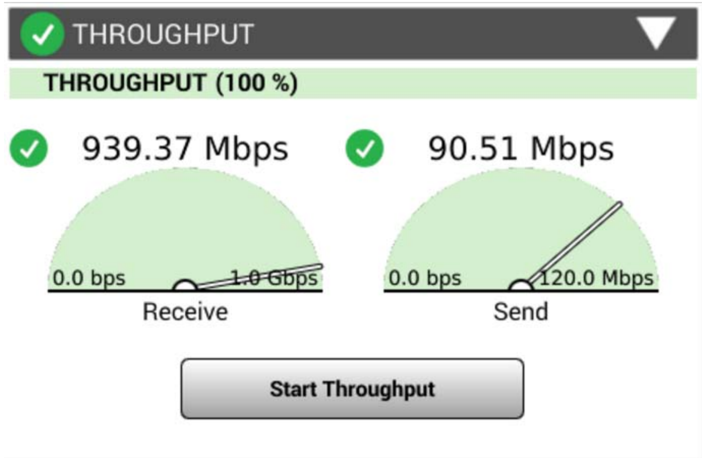


Figure 20 - Service Testing with good RF performance

If there are issues on the plant such as noise or ingress impacting any one of the DOCSIS carriers, the throughput may suffer and show markedly decreased performance. In a bonded environment, having just one underperforming carrier can cause packet loss and retries. The example below is from a live plant that was suffering from LTE ingress. This caused massive throughput loss and impacted the ability to reach the expected max speeds of 1Gbps

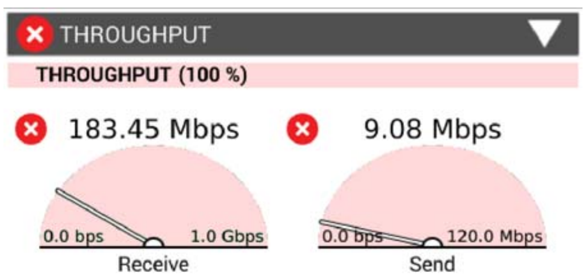


Figure 21 - Service Testing with bad RF performance

1.5.3. Throughput over Ethernet

The final test of actual customer performance requires testing at the Ethernet layer of the customers modem or gateway. Most consumer grade PC's have hardware limitations due to processors or NIC cards that prevent them from testing up to 1Gb/s and many top out around 600Mb/s. Wi-Fi limitations also come into play and can often be the critical link for data services. Test instruments are available that can provide both Ethernet and DOCSIS throughput testing up to 1Gbps and beyond.

Field Examples of DOCSIS 3.1 Testing

2. Multi Carrier DOCSIS 3.1 system running up to 1.2 GHz

Putting the basic testing of DOCSIS into practice highlights many of the capabilities of OFDM. The importance of knowing how to look at the different items that can affect an OFDM carrier and how to troubleshoot them in real scenarios help clarify the usefulness of DOCSIS 3.1 tools. For this section we will show some examples of a live DOCSIS 3.1 system running with 32 SC-QAM carrier and two OFDM carriers. In this system, full utilization of the DOCSIS 3.1 downstream is being exercised as the second OFDM carrier is operating in the 1GHz – 1.2 GHz region of the spectrum. Figure 22 shows a channel view of the SC-QAM's and the two OFDM carriers.

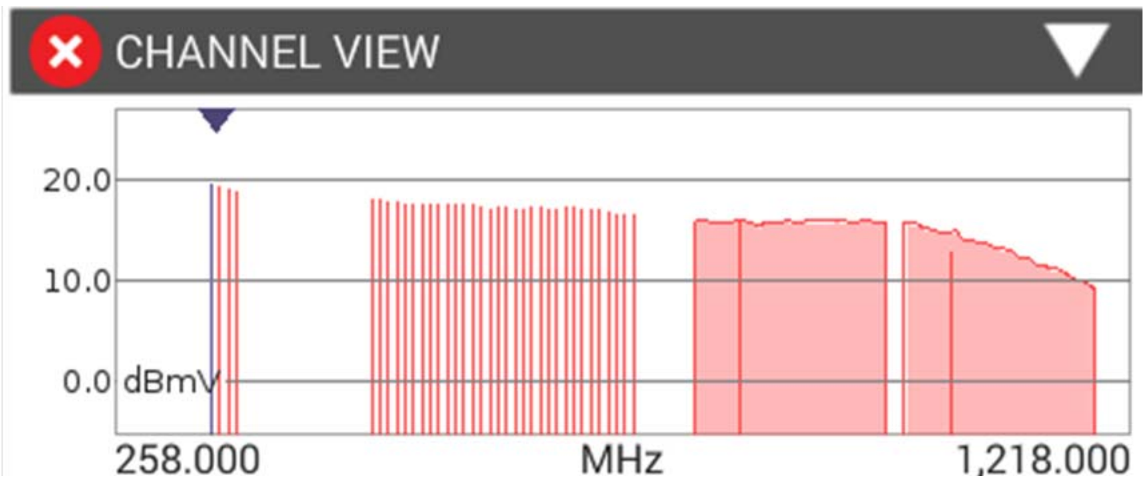


Figure 22 - Multi OFDM carriers and SC-QAM

2.1. Comparing metrics of both OFDM Carriers

In this DOCSIS 3.1 system, the carriers are all logically bonded together. But, to look at the DOCSIS 3.1 building blocks described earlier, each OFDM carrier should be looked at individually. Figure 23 shows summary results of the two separate carriers. In this example the first OFDM carrier which resides in the 800 MHz – 1GHz spectrum is having issues with Profile A while the second OFDM carrier which resides between 1 GHz and 1.2 GHz has good performance of all the basic building blocks, PLC, NCP, and Profile A. We will take a look at each of these carriers in more detail to show some recommended testing in practice.

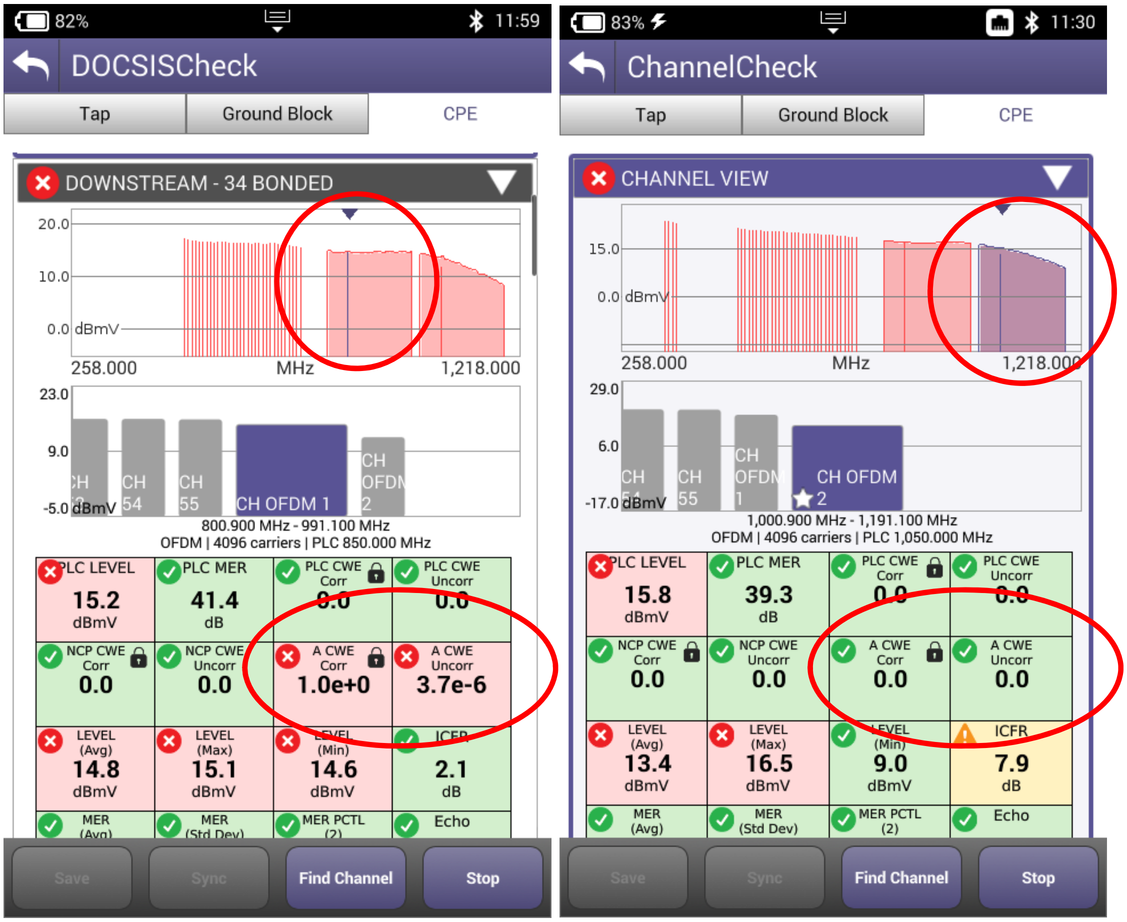


Figure 23 - OFDM with Profile A Errors on OFDM carrier 1 but not on OFDM 2

2.2. Analyzing first OFDM carrier with Profile A issues

2.2.1. Identifying noise with Spectrum and Ingress Under the Carrier

Since we have identified that the carrier is having issues with profile A, it is desrirable to identify what is causing the degradation and to clean up and fix the problems if possible. The first step is to look at the spectrum analysis and IUC of the carrier. Figure 24 show the plot of the spectrum view and ingress under the carrier. It becomes rapidly apparent that there are external noise sources that are entering the system and impacting the carriers performance

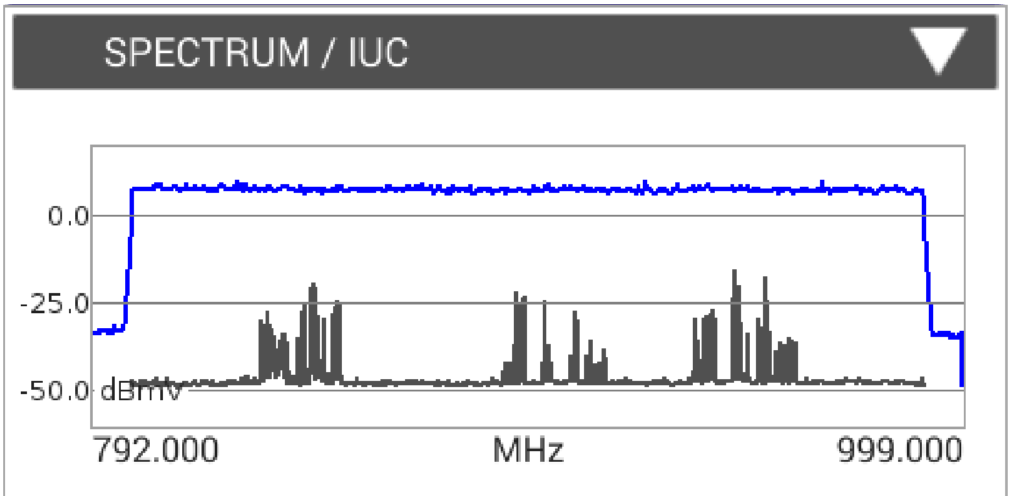


Figure 24 - Spectrum/IUC with bad MER related to IUC on OFDM 1

2.2.2. Identifying MER degradation corresponding to IUC

Once we have identified that there are noise sources getting in, we can look at how they are impacting the MER performance across the subcarriers of the OFDM carrier. Figure 25 shows the MER plot of the subcarriers across the entire 192 MHz wide OFDM carrier. It is rapidly apparent that the MER is impacted and would be impacting any profiles that use modulations of 256-QAM or above in the ill performing portions of the spectrum.

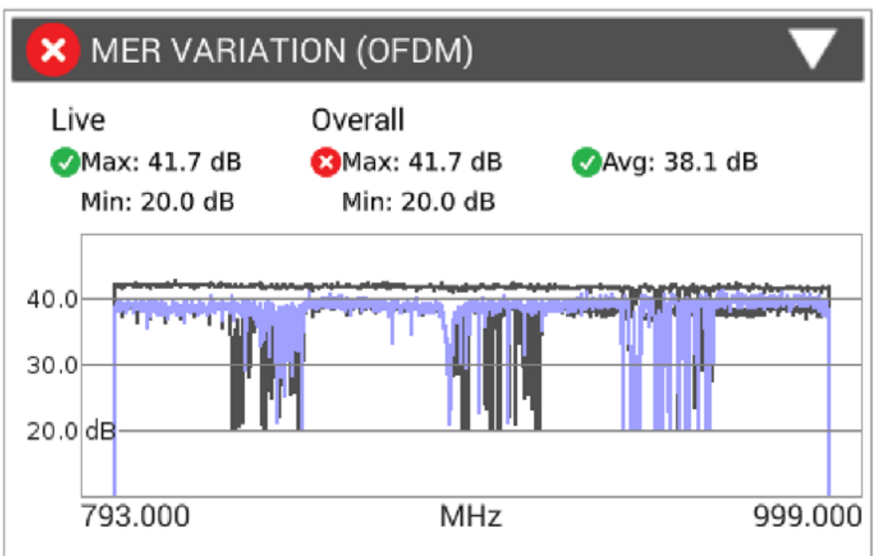


Figure 25 - MER variation related to IUC on OFDM 1

Looking at the next layer down you can see that only Profile A is being locked on to and that there are considerable UNCORRECTABLE CWE's. If the performance were better, more profiles would be present and the modem would be able to lock on to them.

PROFILE ANALYSIS

PROFILE	LOCKED	CWE (Corr)	CWE (Uncorr)
A	YES	8.9e-1	3.2e-4
NCP	YES	0.0	0.0
PLC	YES	0.0	0.0

Figure 26 - Profile availability on OFDM carrier 1

2.2.3. Service level testing with impaired OFDM Carrier 1

In an effort to see if the issues were truly service impacting, a DOCSIS throughput test was next ran. In this situation with the wide and persistent amount of noise and uncorrectable codeword errors, the throughput was actually being impacted. Even though the system had a capacity of over 4 Gbps the CWE's were causing retries and slowed the performance. In this case the modem was provisioned for service of 1Gbps.

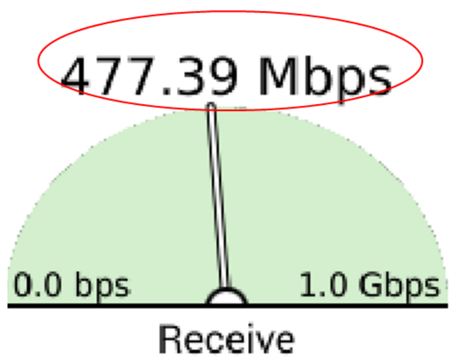


Figure 27 - Impact on Throughput – Decreased to about 50%

2.2.4. Cleaning up the carrier and validating throughput

Some basic mechanical troubleshooting was done and some loose connections were found in the last 100 feet of the drop/house that were letting an abundance of off-air interference in. This situation was in a location with an abundance of cellular and off air activity. Figure 28 shows some major improvements in the MER after some basic clean-up work. Obviously there are still some degradations of concern that should be cleaned up or accounted for in variable bit loading of the profile, but a retest of throughput as shown in Figure 29 shows that the LDPC is still working enough to provide the expected level of customer experience.

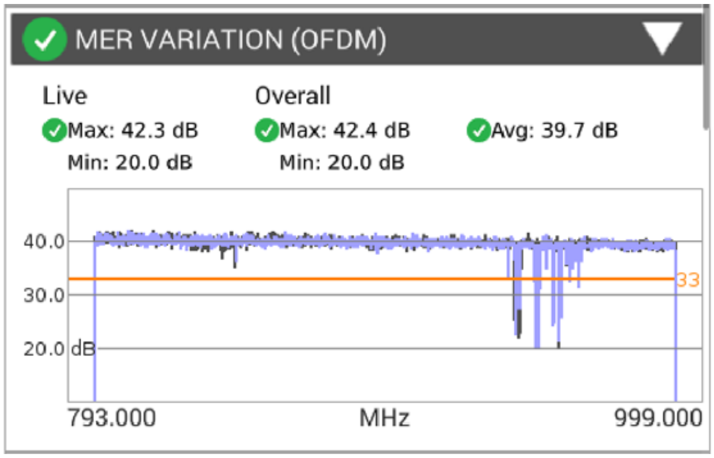


Figure 28 - "Improved" MER performance across bandwidth

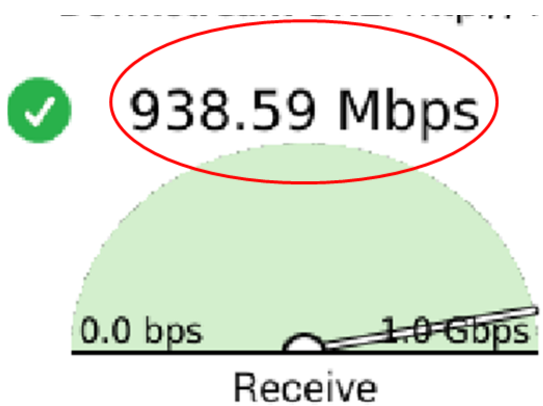


Figure 29 - Improved Throughput to expected levels

2.3. Analyzing the second OFDM carrier with an ICFR issues

Even though the second OFDM carrier was having adequate basic metric performance it is apparent from the visual graph of the carrier as well as the ICFR measurement of 7.9 dB that the carrier was experiencing some excessive loss.

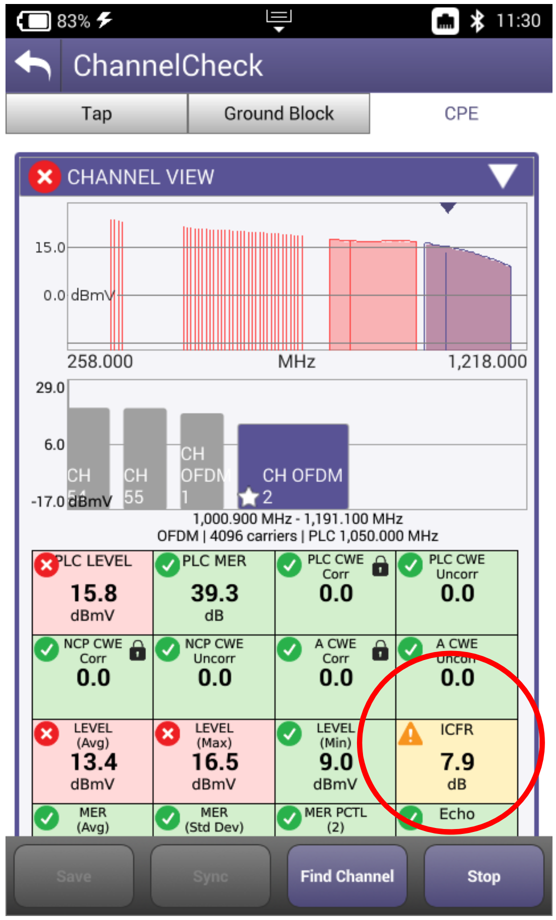


Figure 30 - Excessive Roll Off on OFDM Carrier 2

Looking at an ICFR graph of the OFDM carrier as shown in Figure 31 it is readily apparent that there is something causing about 8 dB of loss from 1GHz to 1.2GHz that is affecting this carrier. Investigating the components in the drop/home identified that there was a splitter that was only rated for 1GHz. This type of loss above 1GHz is common for 1GHz splitters. Passive components will be one of the biggest sources of carrier degradation in network expansions beyond 1GHz.

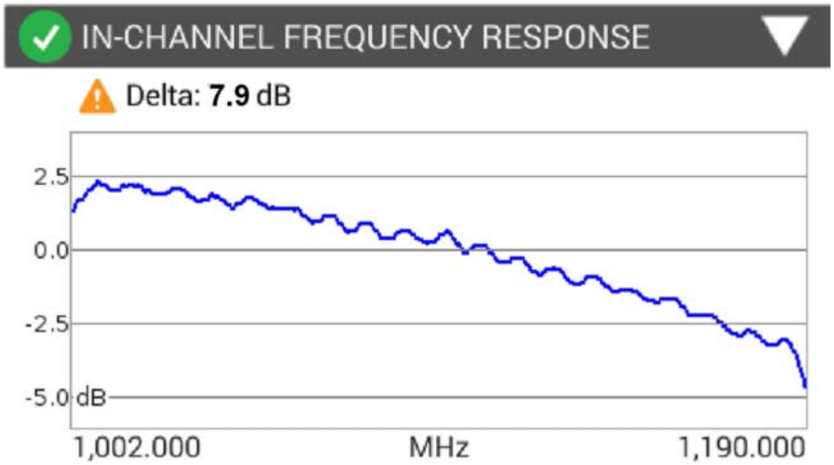


Figure 31 - ICFR graph showing excessive roll off on OFDM Carrier 2

2.3.1. Identifying noise with Spectrum and Ingress Under the Carrier

In an effort to show the other testing tools on the second carrier, you can see that the carrier above 1GHz is relatively noise free. The spectrum plot shows the frequency roll off. By zooming in and changing the dB per Division the roll off would be much more apparent

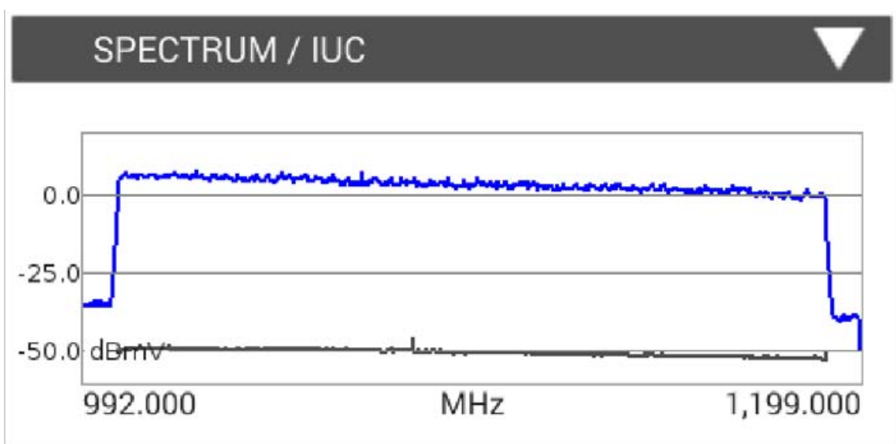


Figure 32 - Spectrum/IUC with good MER related to IUC on OFDM 2

2.3.2. Identifying MER performance across the carrier

Looking at the MER performance across the second carrier as shown in Figure 33 there is pretty steady MER performance with an Average MER of 39.2. This means that the carrier should be good for carrying at least 2048-QAM and probably 4096-QAM in some circumstances.

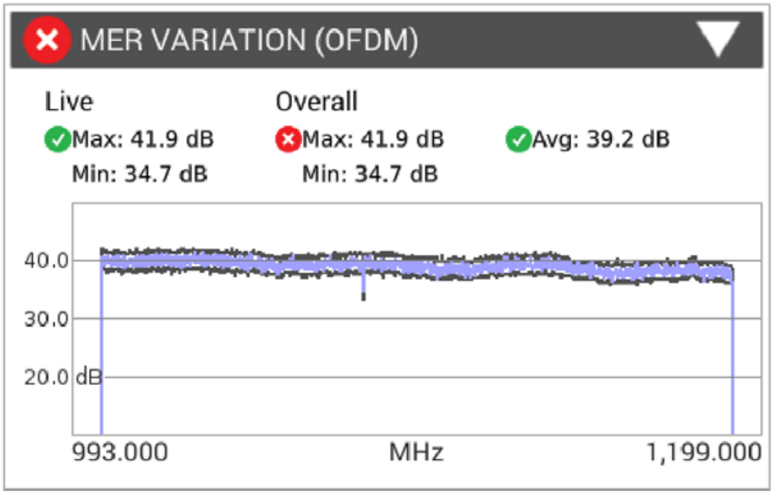


Figure 33 - MER variation of OFDM 2 with good performance

2.3.3. Profile Analysis of second OFDM carrier

Following up from the MER graph and looking at the profile analysis of the second OFDM carrier shown in Figure 34 shows that in fact, profiles B, C, and D are all performing with little to no Uncorrectable CWE's. In this case Profile D was set for all subcarriers to be 4096-QAM. Looking a bit closer, you will notice though that Profile D was operating at 100% CWE's. This means that every piece of data was being "corrupted", which is expected with MER Average being 39.4 dB and that LDPC is fully correcting every bit of data! This is a great example of the power of LDPC and OFDM to get maximum efficiency out of the plant.

PROFILE ANALYSIS

PROFILE	LOCKED	CWE (Corr)	CWE (Uncorr)
A	YES	0.0	0.0
B	YES	1.1e-2	0.0
C	YES	4.2e-1	0.0
D	YES	1.0e+0	0.0
NCP	YES	0.0	0.0
PLC	YES	0.0	0.0

Figure 34 - Additional Profiles available on Carrier 2

2.4. Improving performance by tailoring profile modulation

Variable Bit Loading of OFDM subcarriers allows each profile to adapt to varying network conditions, like LTE interference, by excluding subcarriers or changing its modulation in order to maximize the overall network efficiency. Each profile can have mixed modulation types across the different subcarriers. Figure 35 show an example of how variable bit loading or individual carrier modulation can be used to adjust to the specific plant characteristics.

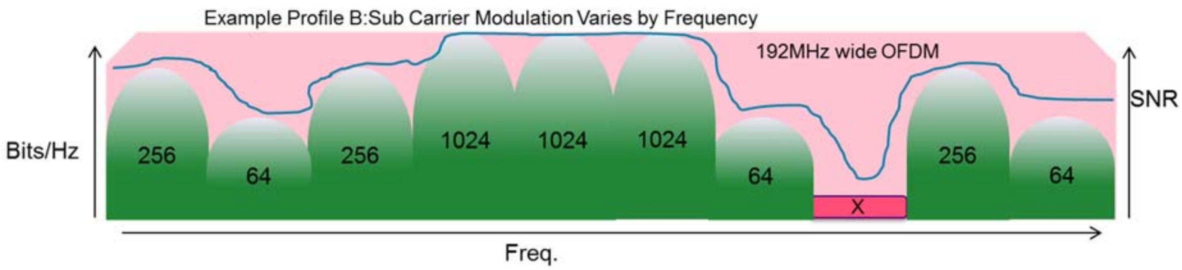


Figure 35 - variable bit loading of individual subcarriers

In the live example of OFDM carrier 1, the profiles were running constant modulations across the entire bandwidth. In the event that the spectrum couldn't be fully cleaned up, this lends a perfect opportunity to tailor the profile to modify the modulations to leverage the most out of the spectrum without having correctable CWE's. In the noisy portions, Profile A could be adjusted down to64-QAM or 16-QAM even so that the symbols would not be impacted. This would allow better overall performance and still have options for profiles B,C, D etc. to be turned up to higher modulations to be used in cleaner parts of the plant.

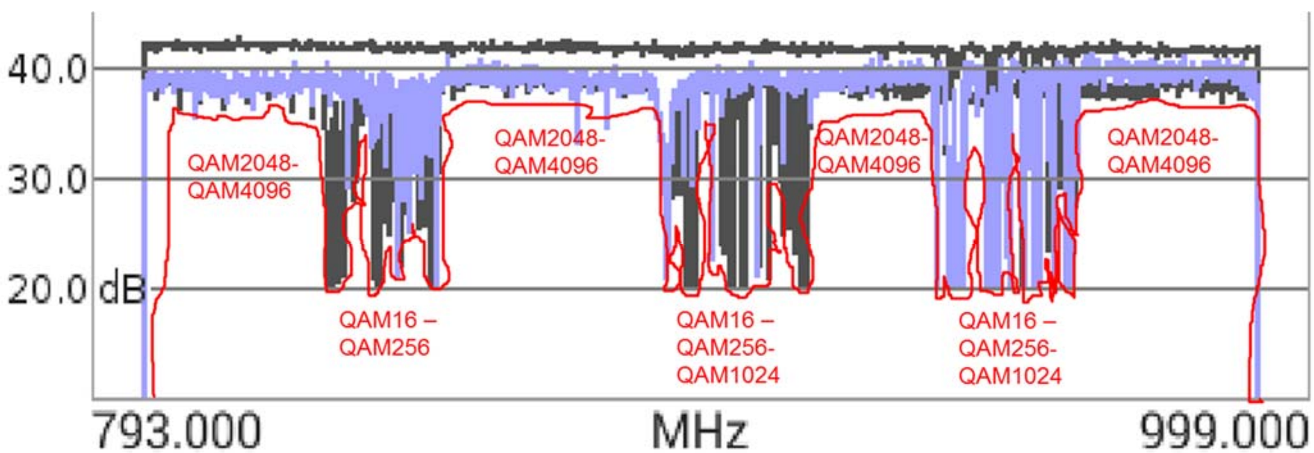


Figure 36 - Profile Grooming opportunity on Carrier 1

3. DOCSIS 3.1 OFDM carrier turn up without proper spectrum clearing

This section shows a brief example of how IUC and Spectrum can identify OFDM problems. The situation that occurred was in a lab environment. The system had turned on the OFDM carrier but had not turned off the uppermost QAM carrier by accident such that both the QAM carrier and the OFDM carrier operated in the same spectrum.

3.1. Using Ingress Under the Carrier to identify root cause

Interestingly enough, even with the carrier being present under the OFDM, the modem/instrument was occasionally able to gain OFDM lock. The basic building blocks showed major issues with NCP and Profile A. The PLC was in good shape since it was at the lower part of the OFDM spectrum. Once locked, it was clearly apparent with IUC that there was a carrier underneath the OFDM. Figure 37 shows the offending QAM carrier showing up in the IUC graph. The spectrum plot also showed that there was a lack of a guard band between the OFDM and the next adjacent carrier.

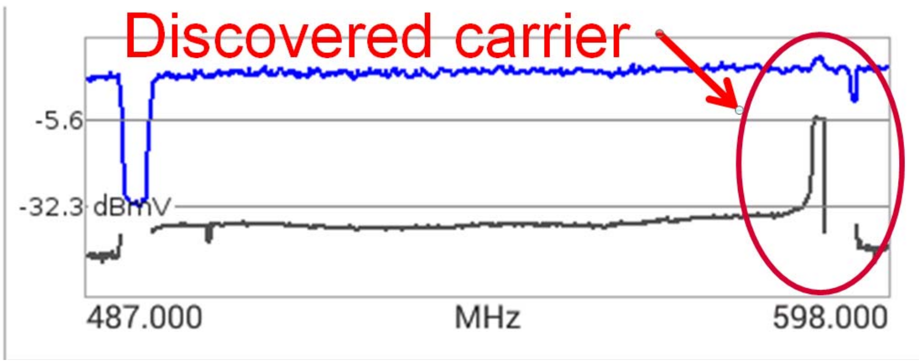


Figure 37 - Spectrum/IUC with Carrier left on at top of spectrum

3.2. Additional Metrics highlighting the issue

As an example of how the MER 2nd Percentile and Standard Deviation can highlight issues, in this case the MER 2nd Percentile was at 20 dB. So this shows that more than 2% of the carriers are operating in major distress. Similarly the standard deviation was beyond the recommended 2 dB deviation

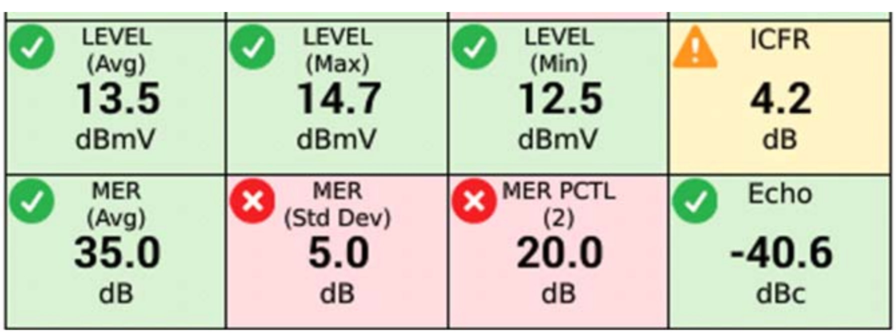


Figure 38 - Impact of interfering carrier on Percentile ans Std Deviation

In the problem identification phase the Spectrum Analyzer was used to look at the OFDM carrier. Figure 39 shows a spectrum plot of the upper edge of the OFDM carrier. The characteristic power hump shows the composite power of the OFDM carrier plus the SC-QAM carrier. As you can see from the delta markers the end of the OFDM carrier looks to be artificially extended exactly to the width of the SC-QAM carrier which is why the guard band looked excessively small.

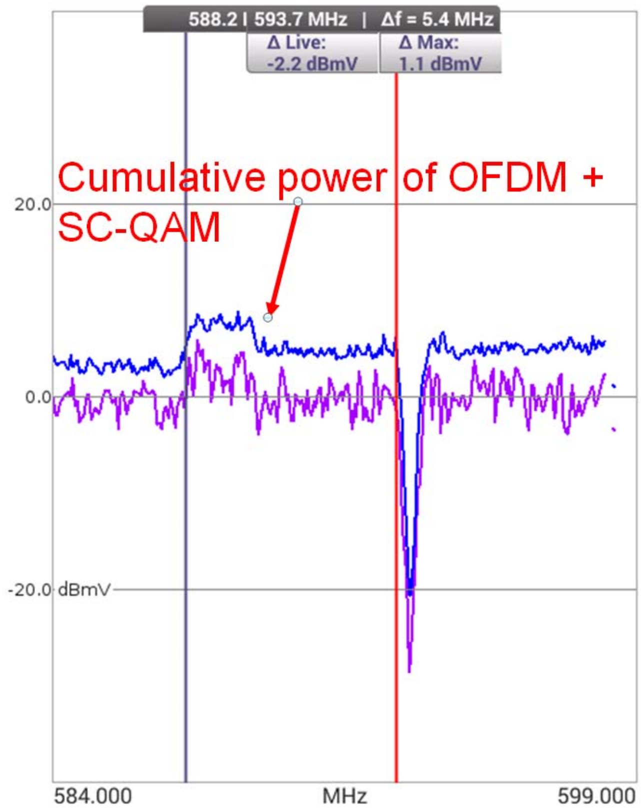


Figure 39 - Spectrum view of composite power

Conclusion

DOCSIS 3.1 power and flexibility provide new challenges for operators and their technicians as they adapt to new technologies. The new OFDM modulation scheme brings a new way of thinking for technicians who have become accustomed to the straight-forward approach of SC-QAM's. Some of the traditional concepts such as BER are less valuable as they are replaced with the notion of codewords.

By understanding the key components of OFDM including PLC, NCP, Profiles and CWE's, a technician can easily unwrap the mystery of OFDM to ensure maximum performance and efficiency. To understand the relationship and importance of channel bonding to the overall service performance, technicians now need to look at the complete DOCSIS lineup and not just a single carrier. It becomes important to test the entire DOCSIS system simultaneously and to validate the service level performance.

The introduction of multiple profiles adds opportunities to get more overall capacity and efficiency out of the HFC plant. These new profiles add yet another dimension for technicians to understand and troubleshoot. When provided with the relevant information and metrics, technicians can use profile analysis to improve plant and home performance.

Even with OFDM's advanced LDPC it is still susceptible to excessive noise and interference. With the right toolset and testing methodologies, an operator can easily determine impacting problems and use the tools to clean up and eliminate the issues.

Success with DOCSIS 3.1 is within easy reach of all operators and technicians with just a little bit of learning and understanding of what matters most.

Abbreviations

AWGN	Additive White Gaussian Noise
BSPK	Binary Phase Shift Keying
BER	Bit Error Rate
BW	Bandwidth
CMTS	Cable Modem Termination System
CNR	Carrier to Noise Ratio
CPE	Customer Premise Equipment
CW	Code Word
CWE	Code Word Error
dB	Decibel
dBmV	Decibel Millivolt
DOCSIS	Data Over Cable System Interface Specification
Gbps	Gigabits per second
GHz	Giga Hertz
HFC	Hybrid Fiber-Coax
IUC	Ingress Under the Carrier
ICFR	In Channel Frequency Response
Hz	Hertz
LDPC	Low Density Parity Check
LTE	Long Term Evolution (cellular service)
MHz	Mega hertz
MER	Modulation Error Ratio
Mbps	Megabits per second
OFDM	Orthogonal Frequency Division Multiplexing
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
RBW	Resolution Bandwidth
SC-QAM	Single Carrier QAM
SCTE	Society of Cable Telecommunications Engineers
SLM	Signal Level Meter
VBW	Video Bandwidth
ISBE	International Society of Broadband Engineers

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