DOCSIS 3.1 — Best Practices for Peak Performance

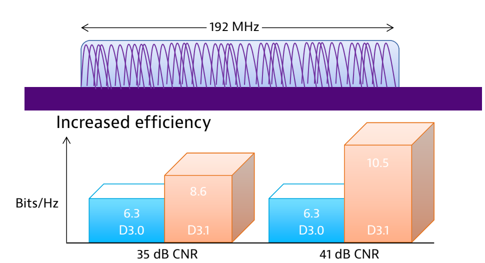
DOCSIS 3.1 completely changes the way DOCSIS works, increasing data capacity up to 50% and speeds up to 10 Gbps on the downstream and 2 Gbps on the upstream—rates that rival fiber.

It's no surprise that providers have taken notice. In the past year, DOCSIS 3.1 has come out of the lab and has been successfully field tested. As of the beginning of 2016, five new DOCSIS 3.1 cable modems have been certified and providers from around the world have begun initial deployments.

But what makes DOCSIS 3.1 so unique, and how will testing change? This paper looks at the two main technologies behind this latest version: orthogonal frequency domain multiplexing (OFDM) and low density parity check (LDPC). It also covers the best testing practices to get DOCSIS 3.1 running at peak performance levels.

Orthogonal Frequency Domain Multiplexing

The best way to understand OFDM is to take a quick look at DOCSIS 3.0. DOCSIS 3.0 uses a single carrier with 6 MHz boundaries (8 MHz in Europe). Modulation is based on single carrier QAM (SC-QAM) and symbols must run through the same carrier in a sequential order. If there is a problem within a carrier, the modulation must be reduced in order to keep data moving—not just for that carrier, but for all carriers in a plant. This means that modulations must be optimized for the worst part of a plant.



6.3	*Max bits/Hz DOCSIS 3.0*
10.5	*Max bits/Hz D3.1 4096 QAM*
8.5	*Typical bits/Hz DOCSIS 3.1* *(assumes mix of 256, 1024, 2048, 4096 QAM)*
35%	*More Efficient* DOCSIS 3.1 bits/Hz than DOCSIS 3.0

Figure 1. OFDM changes the game, providing more bits/Hz at the same signal-to-noise operating conditions

In contrast, OFDM has boundaries ranging from 24 MHz to 192 MHz. Within these boundaries, OFDM is able to run as many as 8000 subcarriers running at 25 kHz or 50 kHz over the entire bandwidth. All subcarriers are time synchronized across the bandwidth and communicate together to form symbols. These symbols carry codewords and are spread across multiple subcarriers and time slots.

The main takeaway is that symbols are no longer tied to specific frequencies, but instead, are allocated across different frequencies over the entire bandwidth. This creates some unique opportunities. Now, if a particular subcarrier is experiencing a problem, OFDM can simply exclude it by bridging the adjacent subcarriers together. This allows symbols to continue to travel over the entire bandwidth at optimal performance levels.

Since OFDM is modulated for a set period of time, the technology can shape subcarriers by controlling their phase relationship. If one subcarrier has a peak, the adjacent subcarrier can be shaped to have a null. This reduces interference and provides an opportunity for higher modulations.

Modulations are where OFDM makes significant improvements in network performance. Instead of using one modulation for the entire plant, OFDM can allow different modulations for each subcarrier. Profiles can be created that define what modulation is used on each subcarrier and multiple profiles can be created for this purpose.

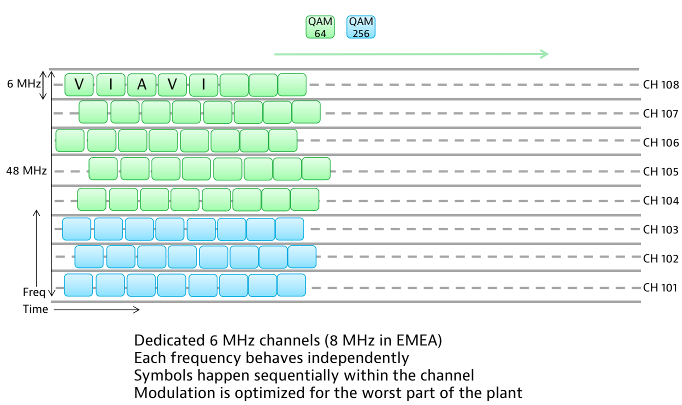


Figure 2. Modulation — SC QAM

As an example, let's look at one subcarrier. Each profile has its own modulation (for example, 64 QAM, 1024 QAM, 2048 QAM, or 4096 QAM). OFDM can use the profile that has the highest QAM that a subcarrier can handle for each portion of the HFC plant. In one part of the plant, that might be 4096 QAM. In another part, it might be 1024 QAM. There could be too much interference in the next, and so that spectrum is excluded in the specific profile. In the next piece of spectrum, the interference is gone and a profile with 2048 QAM is used. OFDM is able to do this using variable bit loading of the profiles.

Now, expand what is happening on this one subcarrier to cover all 8000 subcarriers. Each profile controls every subcarrier in order to maximize the performance on a particular subcarrier at a specific moment in time.

As mentioned before, all subcarriers are linked with each other to form symbols and those symbols carry codewords. The subcarriers are allocated to codewords on each symbol and their modulation is controlled by a profile. Each profile is assigned a letter (for example, A, B, C, and D). Not only is each subcarrier optimized for performance, all of the other 8000 subcarriers know what each subcarrier is doing.

Instead of modulations being optimized for the worst part of the plant, they can now be optimized for the best part of the plant at any given moment. This makes DOCSIS 3.1 much more efficient than its predecessor. Where DOCSIS 3.0 was able to achieve 6.3 max bits/Hz, DOCSIS 3.1 is able to achieve 10.5 max bit/Hz at 4096 QAM. In a more typical situation where multiple QAMs are being used at the same time, DOCSIS 3.1 is still able to achieve 8.5 bits/Hz—making it 35% more efficient without changing the HFC plant.

Low Density Parity Check

The advances made by OFDM would not be possible without some form of error correction. DOCSIS 3.0 used Reed-Solomon forward error correction and measured bit errors as a ratio (BER). BER is relevant on single carrier systems, but OFDM no longer uses single carriers. Since OFDM spreads the data across multiple subcarriers and potentially different subcarriers on every symbol, BER no longer makes sense.

DOCSIS 3.1 uses LDPC instead. LDPC is able to see across the entire bandwidth and looks for codeword errors instead of bit errors. If codeword errors are correctable, LDPC will automatically make adjustments to correct the codeword so that higher modulations can be obtained. This greatly reduces the need for retries and keeps subcarriers working at optimal levels. LDPC is designed to allow data to be transmitted at its theoretical limits.

But LDPC does have one downside. As LDPC makes real-time adjustments, it can reach its limits regarding power levels and modulation error ratio (MER) while trying to correct codewords. This means that LDPC gives less warning of impending failure. If LDPC goes over this edge, codewords can become uncorrectable and customer quality of experience (QoE) begins to decline. To keep this from happening, testing becomes even more important.

Testing for Peak Performance

For accurate testing to happen, it is important to understand the building blocks that make up OFDM. At the base is the PHY link channel (PLC) that contains information on how to decode the OFDM signal. Without the PLC, the modem cannot find the OFDM carrier or understand how to decode it. One level up is the next codeword pointer (NCP) that tells the modem which codewords are present and which profile to use on each codeword. Next is profile A. This is the boot profile that every DOCSIS 3.1 modem must be able to use in order to reach higher QAMs with the other profiles.

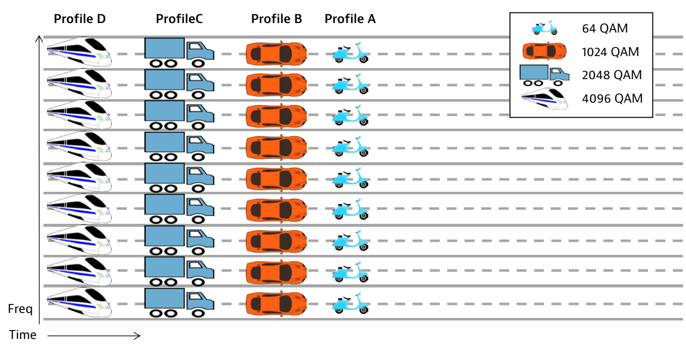


Figure 3. Profiles — a basic conceptualization. For simplicity, assume that the profiles use the same modulation for all subcarriers.

Beyond profile A is where power levels, MER, and noise levels are tested for OFDM. Once this is complete, profiles B and above can be used to reach higher QAMs and more efficiency. Profiles beyond A, B, C, and D are up to the discretion of the CMTS and CM manufacturers but there are no limits to the number of profiles that can be used.

When testing the PLC, it is important that it is locked and that there are no uncorrectable codeword errors (CWE). The PLC must be robust, so the power level and MER must be well within range so that it can be decoded. The DOCSIS 3.1 standard limits the PLC to use BPSK or 16 QAM.

Once the PLC is running properly, the NCP must also be locked and have no uncorrectable CWE. If there are lost messages at this point, there will be retries, or even worse, no communications at all. The DOCSIS 3.1 standard allows the NCP to use QPSK at 16 QAM or 64 QAM.

Since profile A is the boot profile, it can be assigned lower mixed QAMs such as 64 or 16 so that all DOCSIS 3.1 modems can communicate in the worst part of the plant. These lower modulation rates can operate at lower MER and power levels. Just like the two building blocks before it, profile A must be locked and have no uncorrectable CWE. If there are uncorrectable CWE, the modem will resort back to DOCSIS 3.0 and all efficiencies will be lost. Profile A can run at higher modulations, but will start to experience correctable CWE. This is okay as long as they do not become uncorrectable CWE.

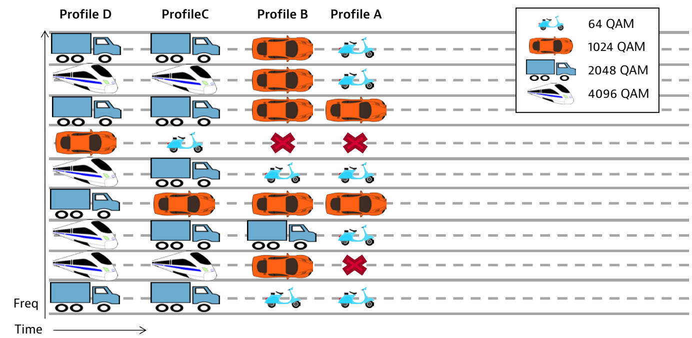


Figure 4. Profiles — a realistic conceptualization. OFDM enables excluding specific subcarriers and lets each profile vary the modulation on each subcarrier. This enables optimizing the overall carrier performance — each profile can have their own exclusions.

Now that these three building blocks are working within proper levels, it's time to look at the overall performance of an OFDM carrier. One mistake technicians can make is to test the power level across the entire 192 MHz carrier. Keep in mind that the total power of an OFDM carrier is equal to the total power of a 6 MHz carrier plus the channel bandwidth. Because of this, the total power of an OFDM carrier is greatly different than that of a single 6 MHz carrier. In order to make accurate power level adjustments, the power levels must be measured and referenced in comparison to the power in a 6 MHz carrier.

There are also a few unique characteristics to OFDM. The first and last 6 MHz of an OFDM carrier will be approximately 0.8 dB less than the other carriers due to roll-off in the guard band. This becomes important when using a standard meter or when looking at the power within individual 6 MHz blocks of OFDM. In addition, the PLC carrier will be approximately 0.8 dB higher than the other carriers due to the additional pilots and data patterns. Lastly, the overall flatness related to a 6 MHZ carrier in OFDM will show a 1.6 dB variance due to the low- and high-end roll-off and PLC variations.

For OFDM to operate at peak performance, the average power level must be within range, MER must be good, and noise levels must be as low as possible. Noise greatly affects OFDM and can prohibit the use of higher-profile modulations.

Once OFDM is performing well, higher profiles become possible. With each profile, it is important that they are locked. The higher profiles can have acceptable amounts of uncorrectable CWE since it is not as critical as it is in the lower building blocks, but uncorrectable CWE can restrict higher profiles from performing at their peak. For example, if profile C has some uncorrectable errors, profiles D and above will not be able to go beyond the modulation being used by profile C. In order for the higher modulations to occur, the HFC plant must be clean to prevent uncorrectable CWE.

Conclusion

DOCSIS 3.1 solves a major dilemma that providers have faced for years: "Do we spend money to completely upgrade the plant or make do with incremental improvements to our existing plant?" With OFDM and LDPC in place, providers can make significant performance improvements with few upgrades to the plant.

Very little needs to be done to the physical plant to gain 35% more efficiency out of a network, giving providers enhanced speed and throughput immediately. This also gives providers more time to make incremental improvements to a plant that can push DOCSIS 3.1 to even higher levels of performance.

However, providers must be careful in the way they deploy and test DOCSIS 3.1. If done incorrectly, a network may perform no better than how it did with DOCSIS 3.0. The best practices laid out in this paper will ensure that DOCSIS 3.1 is working at peak performance, reducing the number of truck rolls by technicians, and providing a higher level of QoE for customers.

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