MOVING BEYOND THE STANDARD: CREATING ADDITIONAL BANDWIDTH THROUGH EXTENDING DOCSIS 2.0

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Abstract

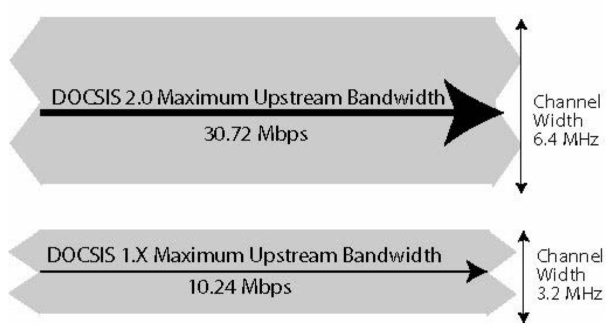
Advanced spectrum management can allow operators to understand the nature of the inevitable impairments on HFC networks so they can compensate appropriately for these impairments and create maximum billable bandwidth. This presentation will discuss how operators can more carefully monitor performance in a non-intrusive manner. It will show how operators can automatically correct for impairments and deploy extensions to the DOCSIS 2.0 specification to create more bandwidth for DOCSIS 1.0, 1.1, and 2.0 cable modems. It will also explain how post equalization techniques can allow operators to nearly double the throughput of their installed basis of DOCSIS 1.0 modems by enabling them to run 16 QAM modulation virtually anywhere that QPSK is currently running. By implementing noise cancellation simultaneously over diverse populations of cable modems, operators can provide throughput levels beyond that offered by the specifications to increase revenues while efficiently migrating to DOCSIS 2.0.

DOCSIS: A HISTORICAL PERSPECTIVE

Over just a few short years, the Data over Cable Service Interface Specification (DOCSIS®) has evolved as the industry standard for ensuring interoperability between cable modems at the subscriber location and Cable Modem Termination System (CMTS) platforms at the operator's headend.

DOCSIS 2.0 (SP-RFIV2.0-I02-020617) was specified by CableLabs® and approved by the International Telecommunications Union (ITU) in December of 2002 as Recommendation J.122. DOCSIS 2.0-certified equipment is now entering the market.

The primary advantage of DOCSIS 2.0 is upstream performance. DOCSIS 1.X offers a maximum 3.2 MHz upstream channel width and a maximum of 16 QAM modulation. The new 2.0 cable modems will allow operators to migrate to 32 or 64 QAM across a channel width of 6.4 MHz. With extensions to DOCSIS 2.0, operators now have the ability to double the bandwidth available to legacy modems while concurrently deploying DOCSIS 2.0 modems that triple the bandwidth available today to 1.X modems.



DOCSIS 2.0 doubles the channel width and triples the upstream capacity when compared with DOCSIS 1.X cable modems.

This requires selecting the appropriate technologies and solutions for taking advantage of the many benefits of DOCSIS 2.0. But the rewards for Multiple System Operators (MSOs) that successfully deploy DOCSIS 2.0 while leveraging existing network assets are highly appealing. They will be able to immediately deploy higher-performance services over existing infrastructure, and capture new revenues from premium services.

At the same time, they will be able to extend the life of legacy cable modems while increasing throughput. They will be able to more efficiently utilize existing infrastructure and deliver higher-speed services over existing Hybrid Fiber Coax (HFC) networks.

DOCSIS 2.0: INCREASING PERFORMANCE, THROUGHPUT

DOCSIS 1.1 provided the QoS control and enhanced security lacking in DOCSIS 1.0, so the main focus of DOCSIS 2.0 became the improvement of performance and the more efficient use of network capacity.

Upstream Capacity

DOCSIS 2.0 triples the maximum upstream capacity when compared to DOCSIS 1.1. It enables transmission across a 6.4 MHz channel and increases upstream throughput to 30.72 Mbps by using 64 or 128 QAM and Trellis Coded Modulation (TCM).

DOCSIS 2.0 cable modems utilize fewer timeslots to transmit a given amount of bandwidth than DOCSIS 1.X cable modems. This frees timeslots that can then be shared by other modems, which increases their throughput.

The asymmetric nature of DOCSIS 1.1 results in limited ability to support services that are more symmetric, such as video conferencing or packet telephony. But the new DOCSIS 2.0 specification focuses primarily on the upstream path from the subscriber to the network. It provides significantly increased capacity and improved robustness to the upstream path, thus helping operators make maximum use of their existing infrastructure.

Higher Modulation

Higher upstream bandwidth is enabled by adding a higher symbol rate and higher-order modulations. Operators can create a greater range of tiered services with graduated pricing plans, and thus have the ammunition to better compete with incumbent carriers for small- and medium-sized business accounts.

Providing modulation rates above 16 QAM does of course come at a price, because higher modulation rates require a higher SNR from the network. Fortunately, improved signal processing technology can allow operators to avoid the need for expensive plant upgrades, and DOCSIS 2.0 includes the ability to capitalize on advanced signal processing technology.

Impairment Protection

The new specification provides better protection from impairments on the CATV network. DOCSIS 2.0 enables operators to support up to 16 correctable symbols, rather than the ten symbols available in the previous specifications.

Operators can understand the various impairments present in their infrastructure through the use of advanced spectrum measurement. This is particularly critical because in real-world environments, most—if not all—of the following impairments are present at some level *the majority of the time*.

- ***Ingress Noise***, which is significant everywhere in the return path.
- ***Impulse Noise***, which is not significant above 18 MHz.
- ***Common Path Distortion (CPD)***, which is significant everywhere in the return path.
- ***Micro-Reflection***, which is a significant impairment everywhere.
- ***Amplitude Distortion***, which is significant only above 35 MHz in 42 MHz systems, 48 MHz in 55 MHz Systems and 55 MHz in 65 MHz systems.
- ***Group Delay Distortion***, which is also significant only above 35 MHz in 42 MHz systems, 48 MHz in 55 MHz systems and 55 MHz in 65 MHz systems.

DOCSIS 2.0 allows operators to improve the Signal-to-Noise Ratio (SNR). However, operators need the ability to more efficiently manage spectrum and improve noise cancellation simultaneously over diverse populations of DOCSIS 1.0, 1.1, and 2.0 modems.

This requires a CMTS that not only supports DOCSIS 1.0, 1.1, and 2.0 but also offers a system architecture designed to improve the SNR of both legacy and new DOCSIS modems.

Pre-Equalization

The DOCSIS 2.0 specification offers increased support for transmit pre-equalization. It enhances micro-reflection (multipath) protection by increasing the length of the equalizer to 24 taps—which is three times longer than the DOCSIS 1.1 eight-tap equalizer. With pre-equalization, the CMTS receiver equalizer convergences on a periodic burst and then sends the equalizer coefficients to the cable modems for implementation in their transmitters. This enables increased modulation and faster performance.

Advanced PHY

DOCSIS 2.0 includes advanced Physical Layer (PHY) modulation techniques that allow operators to run higher modulation levels. DOCSIS 2.0 enables enhanced management of RF spectrum so that operators can more efficiently cancel out or avoid noise impulses. This allows increased throughput and more reliable service delivery. The DOCSIS 2.0 specifications includes two separate technologies for achieving these goals:

- Advanced Time Division Multiplexing (ATDMA)
- Synchronous Code Division Multiple Access (SCDMA)

UNDERSTANDING DOCSIS 2.0 PROTOCOLS

These protocols allow operators to increase the channel size to 6.4 MHz and they support statistical multiplexing to optimize bandwidth utilization. They enable the use of a higher symbol rate and can deliver up to triple the capacity of a DOCSIS 1.X channel. Both protocols can coexist on the same channel because each logical channel type is assigned non-overlapping timeslots, and these timeslots are interleaved based on demand.

DOCSIS 2.0 supports immunity to Ingress Noise for both protocols, though ATDMA is more robust against this impairment and it supports enhanced channel equalization for both protocols to protect against system linear impairments. It enables improved immunity against Impulse Noise through the use of an improved Forward Error Correction (FEC) that includes the technique of Byte Interleaving for ATDMA and Frame Interleaving for SCDMA, though SCDMA is more robust against this type of impairment.

Both protocols support extended modulation formats up to 64-QAM for ATDMA and 128-TCM for SCDMA. Operators can implement either or both protocols, depending on their requirements and preferences.

ATDMA Supports:

- A maximum channel width of 6.4 MHz and a minimal channel width of 200 kHz
- A maximum modulation rate of 5120 ksym/s and a minimum rate 160 ksym/s
- Increased modulation orders, including QPSK and 8, 16, 32, and 64 QAM
- Enhanced transmit pre-equalizer (24 taps)
- Enhanced Reed-Solomon error correction with byte interleaving
- Ingress noise cancellation with both DOCSIS 1.X and DOCSIS 2.0 cable modems is possible.

SCDMA Supports:

- A maximum channel width of 6.4 MHz and a minimal channel width of 1600 kHz
- A maximum modulation rate of 5120 ksym/s and a minimum rate 1280 ksym/s
- Trellis Coded Modulation—QPSK and 8, 16, 32, 64 and 128 TCM
- Enhanced transmit pre-equalizer (24 taps)
- CDMA spreading to provide some immunity to impulse and ingress noise
- Interleaving of SCDMA frames to provide impulse noise immunity similar to that provided by byte interleaving on the ATDMA protocol

DOCSIS 2.0 specifies that the CMTS receiver must support DOCSIS 1.1, ATDMA, and SCDMA modulation technologies on the same carrier frequency, which is referred to as *mixed mode* operation.

INTEROPERABILITY WITH .X CABLE MODEMS

DOCSIS 2.0 is backward-compatible with the earlier specifications, and since it allows more subscribers and services on a single channel, operators can increase revenues from existing infrastructure while supporting symmetrical applications and leveraging the QoS features of DOCSIS 1.1.

DOCSIS 1.X cable modems of course do not support DOCSIS 2.0, so the new specification provides for mixed mode operation for supporting 1.X and 2.0 cable modems. Unfortunately, this results in additional overhead of roughly 5-15 percent for ATDMA mode and 15-35 percent for SCDMA. This means that the existing customer base of installed DOCSIS 1.X cable modems will experience a degradation in throughput performance as 2.0 is deployed.

However, there is an innovative approach to transitioning to DOCSIS 2.0 without incurring this performance overhead. Operators can implement ATDMA receiver technology that is by definition directly compatible with DOCSIS 1.X systems and is capable of operating in a true DOCSIS 1.X mode.

- Operators can transition to 2.0 without providing a performance burden to legacy subscribers because the ATDMA CMTS can operate in DOCSIS 1.X mode.

- The ATDMA receiver technology provides post-equalization support that can increase throughput for existing customers by at least 50 percent by using DOCSIS extensions that enable virtually all DOCSIS 1.0 cable modems to operate in 16 QAM mode where they could previously operate in QPSK.

- When there is a significant number of DOCSIS 2.0 cable modems installed, the cable operator can begin the ATDMA Logical Channel Operation in which the Symbol Rate remains the same (2560 ksym/s) but the DOCSIS 2.0 cable modems can begin to transmit in a pure ATDMA mode of operation, i.e. with extended FEC correction, byte interleaving (if necessary) using higher constellation rates such as 32 QAM or even 256 QAM.

- When the number of 2.0 modems exceeds the number of 1.0 modems, then the full logical channel operation of using ATDMA mode in a 5120 ksym/s operation can be implemented while the remaining 1.0 modems operate at 2560 ksym/s.

The financial benefits of this migration approach are compelling. Operators can accelerate revenue from 2.0 services, and they can implement gradual migration at the pace that makes the most economic sense for them. They can continue to support legacy modems while introducing new services to these subscribers, and they can concurrently support DOCSIS 1.X and 2.0 operation across the same infrastructure.

Cable operators can double the upstream bandwidth for a large population of modems, thus creating increased billable bandwidth without further network buildout. They can create upstream bandwidth that supports higher-speed services and enables new broadband services that command premium pricing.

ADVANCED SPECTRUM MANAGEMENT TO EXTEND DOCSIS 2.0

Efficient migration to DOCSIS 2.0 requires the effective management of impairments on the HFC network

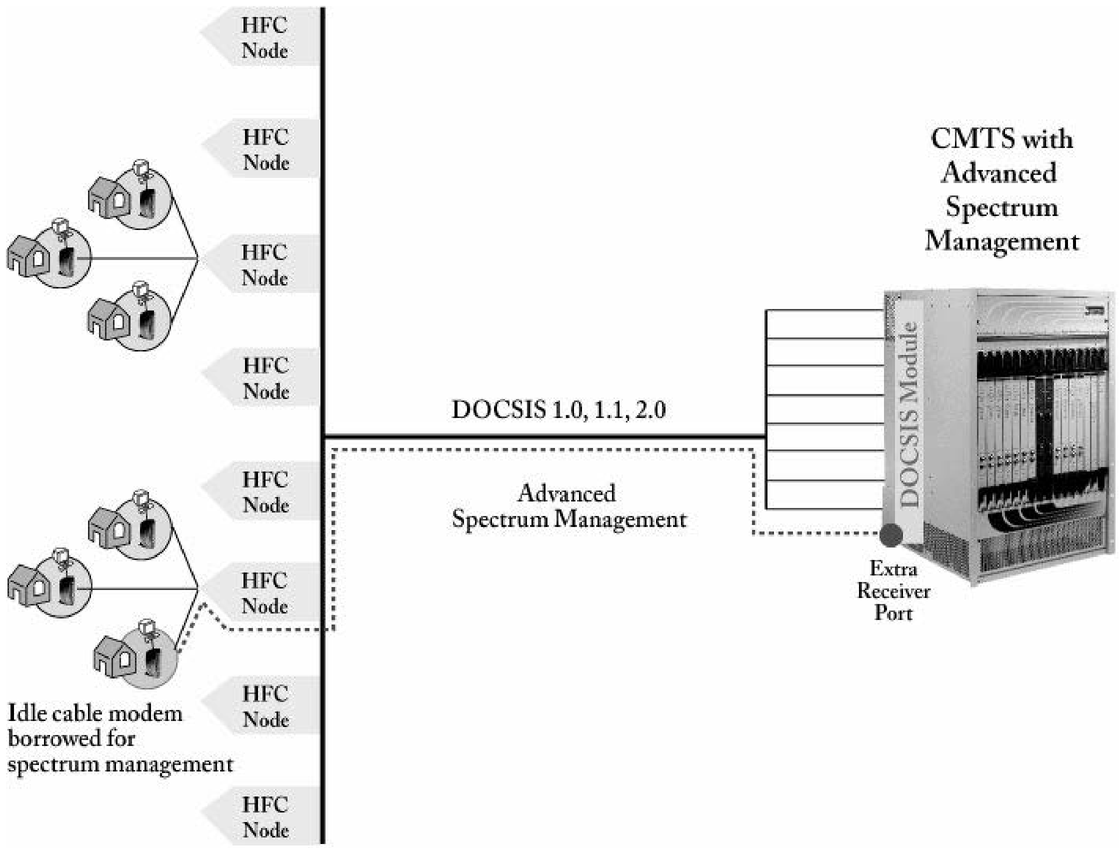
Spectrum management is essential so that operators can identify impairments and make the necessary adjustments to improve performance. The most problematic impairments—ingress noise and impulse noise—can be measured using the established Fast Fourier Transform (FFT) measurement technique.

However, FFTs alone cannot accurately assess the total impact of noise on network performance.

The fundamental challenge is that measurement time directly impacts throughput, because in the typical scenario operators cannot send data while taking measurements. Operators trying to improve performance are therefore hard-pressed to impose increased demands on the infrastructure by performing continuous testing that degrades the bandwidth being tested.

But the implementation of advanced spectrum management on an extra receiver avoids the performance burden and allows operators to collect the performance information they need to optimize the use of network infrastructure.

The addition of an extra receiver on the CMTS allows operators to monitor performance on any one of the upstream ports without impacting performance. Operators can therefore non-obtrusively gain access to all of the return nodes connected to one of the receiver ports and perform tests on any available modem on any one of the receiver port's supported nodes.



MSOs can use the extra receiver to identify the diverse types of noise and then implement spectrum management enhancements that can process this information and take measures to cancel it out in real time. The extra receiver can be effectively connected in parallel with a live receiver port so the operator can measure traffic and performance in real-time on any given live receiver port.

It can access all of the mapping information as well as a full list of cable modems available to whichever receiver port is currently being evaluated. Therefore, while the receiver port being monitored is performing its function at full capacity, the ninth receiver has the luxury of time to perform detailed, lengthy, and coherent SNR measurements. This architectural approach to the CMTS enables continuous monitoring and adaptation so that cable operators can aggressively implement advanced noise cancellation in environments where the types and degrees of impairments change frequently.

Sophisticated Noise Cancellation for ATDMA and SCDMA

Extensions to the DOCSIS 2.0 protocol can leverage the DOCSIS ATDMA specification and add value by including advanced noise cancellation techniques that work with all DOCSIS 1.X and 2.0 cable modems to help operators increase throughput. Cable operators can double the performance of legacy modems while concurrently deploying DOCSIS 2.0 modems that enable new services and increased performance levels. Rich noise cancellation capabilities allow operators to optimize performance while operating in DOCSIS 1.X/2.0 mixed mode.

For example, operators can benefit from upstream transmission speeds that exceed DOCSIS 2.0 specifications by 10.24 Mbps using ATDMA technology and 256-QAM, which is enabled by proprietary extensions beyond DOCSIS 2.0. Therefore, while DOCSIS 2.0 has opened an opportunity for a standard cable modem to operate up to an information rate of 30.72 Mbps (64-QAM or 128-TCM QAM), operators can leverage extensions to offer significantly higher throughput beyond the capabilities of a standard implementation.

The advanced spectrum management capabilities, superior monitoring and measurement, and rich noise cancellation allow operators to achieve higher modulation rates. Cable operators can achieve 128 and 256 QAM for ATDMA implementations. These higher modulation schemes allow operators to achieve even greater throughput than offered by the DOCSIS 2.0 specification.

Post-Equalization

Post-equalization capabilities offer the operator the ability to increase the throughput of DOCSIS 1.0 cable modems by allowing them to operate in 16 QAM mode virtually anywhere that it is possible to operate in QPSK. The CMTS performs per-burst equalization which enables the receiver to equalize—and thus correct for—the effects of micro-reflections, amplitude distortion, and group delay distortion.

These impairments have historically been the limiting factors in achieving QAM modulation higher than 4 QAM (QPSK). The combination of post equalization and superior ingress noise cancellation capabilities results in a DOCSIS 1.X system today where 16 QAM, error-free operation is achievable virtually anywhere in the return path.

POWERFUL MONITORING, MEASUREMENT, AND MANAGEMENT

Sophisticated algorithms can be implemented on a CMTS to determine which cable modems are most representative of the return path under evaluation can use these modems to make signal quality measurements for the cable plant. This detailed monitoring is non-intrusive to the subscriber while enabling the operator to continuously monitor noise and improve performance.

Operators can give performance guarantees and implement flexible and automated means of continuously minimizing noise and increasing performance. For example, a cable operator can monitor performance and implement frequency hopping to a carrier frequency that will support guaranteed, error-free 16 QAM operation.

With advanced spectrum management capabilities on a robust CMTS platform, operators can optimize performance across network infrastructure that consists of DOCSIS 1.0, 1.1, and 2.0 cable modems. They can monitor and manage the use of spectrum in real-time without affecting performance so that cable operators can carefully measure the factors impacting spectrum utilization and compensate in real time to optimize throughput. Operators can implement a smooth transition from DOCSIS 1.X to 2.0 while gaining the ability to improve the performance of the existing installed base so they can increase revenue during the transition.

ABOUT THE AUTHOR

Jack Moran is a distinguished member of the technical staff for the Network Infrastructure Solutions (NIS) business for Motorola Broadband. He is responsible for DOCSIS Physical Layer performance over an HFC RF network system.

For the past four years, Moran has been modeling the return path for DOCSIS 1.0, 1.1, and now 2.0 performance capabilities. This modeling effort has included several live plant characterizations in an effort to simulate on a repeatable basis the type of real-world impairments that DOCSIS systems must overcome.

He is also a member of the DOCSIS 2.0 Technical Team PHY Layer Issue as well as a member of the former IEEE 802.14 Cable Modem Group.