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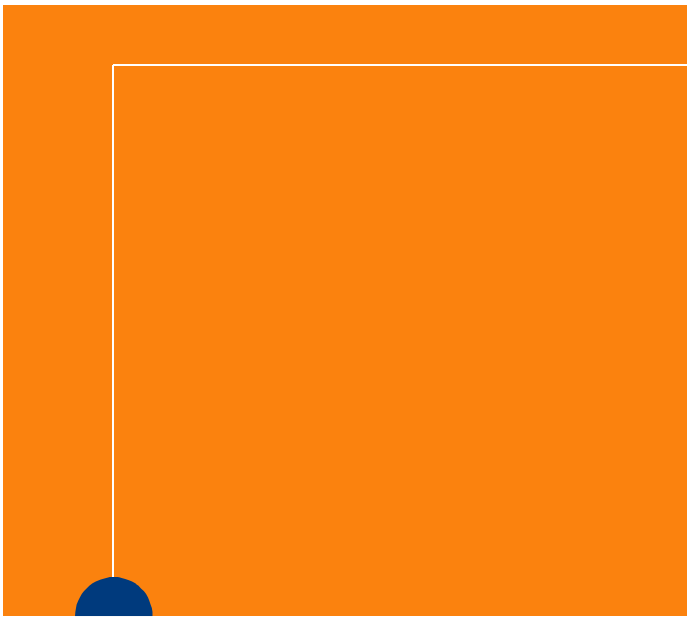
EFFICIENTLY MIGRATING TO DOCSIS 2.0



September 29, 2003

WHITE PAPER

Overview

With the approval of DOCSIS® 2.0 as an international standard, cable operators face tremendous opportunities to deliver high-performance and high-margin services to both residential and business subscribers. However, they face the challenge of efficiently migrating to DOCSIS 2.0 while leveraging investments in DOCSIS 1.0 and 1.1 equipment and infrastructure. This white paper provides an overview of the advantages of DOCSIS 2.0 and presents a cost-effective migration strategy for existing DOCSIS 1.X environments.

It provides a historical perspective on the progression of the DOCSIS specification and explains and compares the two physical layer protocols defined by DOCSIS 2.0. The white paper then explores the challenge of deploying DOCSIS 2.0 while concurrently improving the performance of the installed base of 1.0 and 1.1 cable modems, and provides an overview of how the Broadband Services Router 64000 and end-to-end solutions from Motorola allow operators to efficiently migrate to DOCSIS 2.0.

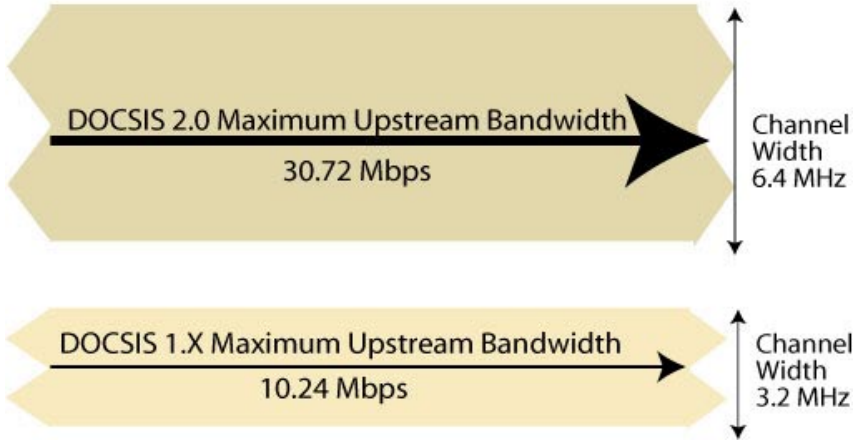
DOCSIS: A Historical Perspective

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 faster 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. 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.

The Evolution of the DOCSIS Specification

The DOCSIS initiative was begun by a consortium of cable operators in the United States to develop a standards-based approach for delivering bi-directional high-speed data over the HFC network. Previously, cable modems and CMTS platforms were proprietary, thus restricting interoperability and leading to fragmented development efforts.

Cable operators wanted a unified initiative for establishing standards-based solutions and for certifying compatibility with industry specifications. A single set of standards would provide a benchmark for interoperability, and would allow vendors to build equipment that worked together to help operators increase the size of the market and establish cable as the preferred broadband medium.

DOCSIS 1.0: Setting Interoperability Standards

The first DOCSIS specification was geared primarily for the residential market and it was designed to enable multi-vendor interoperability. It supports best-effort transmission and introduces some basic concepts for multiple service classes, but it does not offer the capability to guarantee performance of a given service. DOCSIS 1.0 also includes baseline privacy features to provide subscriber security over the shared HFC access network.

With DOCSIS 1.0 data transmission is asymmetric, with most of the bandwidth reserved for the downstream link from the CMTS to the cable modem. This enabled the operators to quickly deploy applications like Web browsing and e-mail while efficiently utilizing available bandwidth. CableLabs began interoperability certification in June of 1998 and the first cable modems and CMTS platforms were DOCSIS-certified in the spring of 1999. Vendors scrambled to gain DOCSIS certification, and the race to build out broadband infrastructure accelerated worldwide.

DOCSIS 1.1: Adding QoS Control

After the major success of the DOCSIS 1.0 standard, CableLabs fostered the development of an enhancement to the specification that built on 1.0 and added increased Quality of Service (QoS) control that went beyond the delivery of best-effort services.

This specification introduced QoS control features that enable services requiring more than best-effort capabilities. QoS control allows operators to deliver various performance levels — and to charge premium pricing for services that are delivered with guaranteed and measurable QoS levels. DOCSIS 1.1 complements enhanced QoS control with increased security measures. It supports cable modem authentication and offers enhancements to key distribution and encryption.

It adds support for the Simple Network Management Protocol (SNMP) version 3, enabling management of network equipment by industry-standard management and control systems. DOCSIS 1.1 is fully backwards compatible with DOCSIS 1.0, which has allowed MSOs to aggressively deploy DOCSIS 1.1 cable modems that coexist with already-deployed DOCSIS 1.0 equipment.

DOCSIS 2.0: Increasing Performance and Throughput

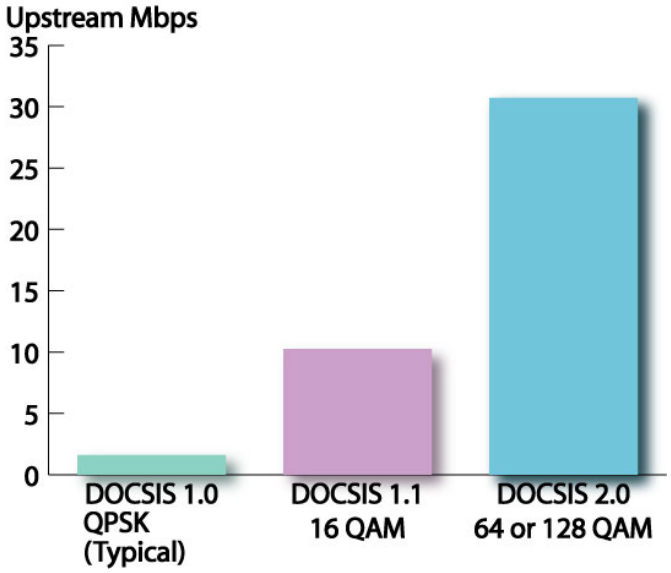
Since DOCSIS 1.1 provided the QoS control and enhanced security lacking in DOCSIS 1.0, the main focus of DOCSIS 2.0 became the improvement of performance and the more efficient use of network capacity.

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 DOCSIS 2.0 specification enables dramatically higher modulation schemes to deliver higher 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 Signal-to-Noise Ratio (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 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 system architecture designed to improve the SNR of both legacy and new DOCSIS modems. *For more information on spectrum management and understanding impairments, please download our white paper located at* **http://broadband.motorola.com/nis/**.

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 specification 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 & DOCSIS 2.0 cable modems is possible because it can be accomplished in the CMTS receiver since nothing is required of the transmitting modem

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 1.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 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.

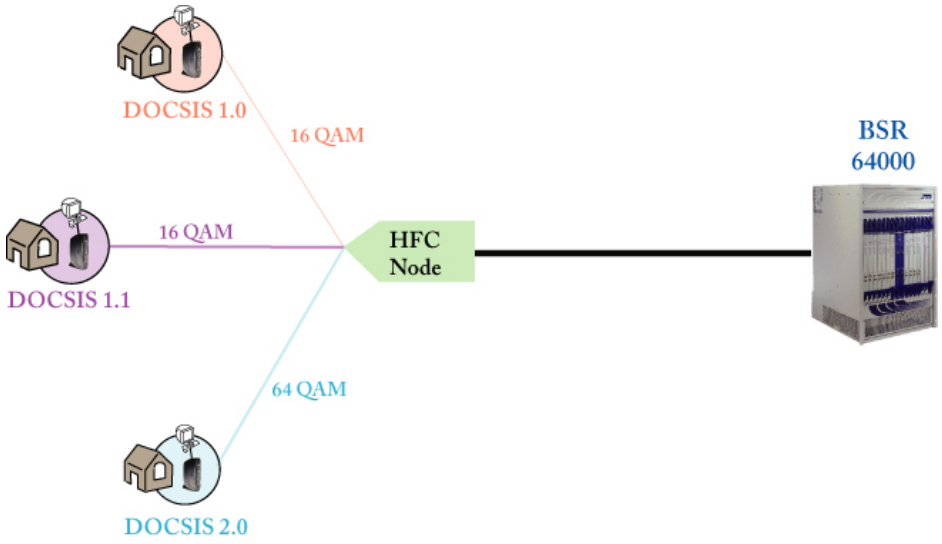
- Operators can transition to 2.0 without providing a performance burden to legacy subscribers because the ATDMA CMTS can operate in DOCSIS 1.X mode.
- The ATDMA receiver technology provides post-equalization support that can increase throughput for existing customers by at least 50 percent by enabling virtually all DOCSIS 1.0 cable modems to operate in 16 QAM mode.

- When there are 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.

The Motorola BSR 64000™ optimizes performance of DOCSIS 1.0, 1.1, and 2.0 cable modems



Migrating to 2.0 While Preserving Legacy Investments

Efficient migration to DOCSIS 2.0 requires a partnership with an established vendor that can help operators maximize the benefits and advantages of the new specification, and add value beyond the specification so operators can increase revenues and profits.

The Motorola Broadband Communications Sector (BCS) fully embraces the DOCSIS 2.0 specification across its broad line of industry-leading products and technologies. Motorola BCS provides complete end-to-end solutions consisting of products, professional services, and network management so that operators can swiftly increase billable capacity on the HFC network by migrating to DOCSIS 2.0.

As the company with the leading global market share of cable modems, Motorola recognizes that there are already over 25 million DOCSIS 1.X cable modems shipped worldwide and that operators naturally want to extend the life of these investments. DOCSIS 2.0 solutions from Motorola not only extend the life of legacy cable modems; they allow operators to increase performance and throughput of already-deployed DOCSIS 1.X cable modems.

The BSR 64000 CMTS/Edge Router

The Broadband Services Router 64000 (BSR 64000) supports DOCSIS 2.0 and adds value through architectural advancements and extensions.

The BSR 64000

DOCSIS flows can be consolidated onto the BSR 64000 for routing across access, metropolitan, and core networks. The BSR 64000 is a carrier-class CMTS/edge router that supports DOCSIS 2.0. It supports both ATDMA and SCDMA and offers full compatibility with DOCSIS 1.0 and 1.1 cable modems.

The BSR 64000 allow operators to efficiently manage impairments on the HFC network so they can continuously optimize performance, create bandwidth, and efficiently migrate to DOCSIS 2.0 while leveraging investments in deployed DOCSIS 1.X cable modems. It enables advanced spectrum management, which includes ingress noise cancellation, post-equalization, sophisticated noise measurement, and noise avoidance capabilities.

It adds value to DOCSIS 2.0 by allowing operators to implement end-to-end high-performance solutions. Through a combination of architectural advantages and extensions to the DOCSIS 2.0 protocol, the BSR 64000 allows operators to aggressively implement DOCSIS 2.0 while maximizing revenue from legacy infrastructure.

2x8 DOCSIS 2.0 CMTS Module

The BSR 64000 includes a 2x8 DOCSIS 2.0 CMTS Module based on industry-leading DOCSIS 2.0 silicon from Broadcom Corp. Up to 12 DOCSIS Modules can be configured in a single chassis. Each module occupies a single slot in the BSR 64000 and has two downstream and eight upstream ports. While eight receivers per module are available for servicing subscriber traffic, Motorola has architected a *ninth receiver* onto each module to enable advanced spectrum management.

The 2x8 DOCSIS CMTS Module includes a dedicated receiver that enables advanced spectrum management

Advanced Spectrum Management

The DOCSIS 2.0 CMTS Module's ninth receiver can monitor performance on any one of the upstream ports without impacting performance. It can 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.

The powerful onboard Spectrum Management System measures the diverse types of noise so the BSR 64000 can process this information and take measures to cancel it out in real time. The ninth receiver is effectively connected in parallel with a selected 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. The BSR 64000 offers 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

Motorola's DOCSIS 2.0 CMTS Module is based on Broadcom's BCM-3138/40 (ATDMA and full DOCSIS 2.0 technology) burst demodulator for the return path DOCSIS PHY Layer and the BCM-3212/14 IC for the DOCSIS MAC Layer. This technology offers superior ingress noise cancellation and enables fine-tuning of PHY-layer parameters. The BSR 64000 supports both ATDMA and SCDMA and allows DOCSIS 2.0 cable modems to coexist with DOCSIS 1.X modems.

Motorola has leveraged the DOCSIS ATDMA specification and adds 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. The BSR 64000 noise cancellation capabilities allow operators to optimize performance while operating in DOCSIS 1.X/2.0 mixed mode.

Higher Modulation

Motorola's implementation of the Broadcom technology results in upstream transmission speeds that exceed DOCSIS 2.0 specifications by 10.24 Mbps using ATDMA technology and 256-QAM, which is enabled by proprietary Motorola extensions beyond DOCSIS 2.0. This 256-QAM 40.96 Mbps technology is utilized on the BSR-64000 ATDMA-only DOCSIS 2.0 2x8 CMTS Module, and it works with every Broadcom 2.0-based cable modem in the field today, such as the Motorola-BCS SB5100.

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), Motorola BCS can 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, and 512 and even 1024 QAM downstream. These higher modulation schemes allow operators to achieve even greater throughput than offered by the DOCSIS 2.0 specification.

Motorola will eventually offer up to 1024-QAM downstream for a data signaling rate of 53.6 Mbps and, 512-QAM with a data signaling rate of 48.288 Mbps as a way of improving the downstream throughput beyond that provided by the standard DOCSIS 2.0 implementation.

Post-Equalization

The BSR 64000 supports both pre-equalization and post-equalization. Motorola's 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 BSR 64000 2x8 DOCSIS 2.0 CMTS Module 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

The Motorola BCS Spectrum Management System includes sophisticated algorithms to determine which cable modems are most representative of the return path under evaluation, and then uses 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 solutions from Motorola, operators can optimize performance across network infrastructure that consists of DOCSIS 1.0, 1.1, and 2.0 cable modems. Motorola offers the ability to 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.

DOCSIS Solutions from Motorola

Delivering high-performance services to residential and corporate subscribers requires the ability to optimize performance across the network. Motorola BCS offers the end-to-end solutions operators need to successfully migrate to DOCSIS 2.0 while optimizing investments in DOCSIS 1.X equipment.

Motorola BCS offers the subscriber equipment and the headend infrastructure solutions that allow cable operators to capitalize on the performance advantages of DOCSIS 2.0. The BSR 64000 is a high-performance, high-density CMTS and routing platform that extends DOCSIS 2.0 throughput so that operators can quickly increase revenues from existing infrastructure while generating new revenues from higher-performance services.

It provides not only the capabilities for a smooth transition from DOCSIS 1.X to 2.0 but also the ability to improve the performance of the existing installed base so operators can increase revenue during the transition.

No operator can afford the time and risk involved in cobbling together point-product solutions. Motorola BCS offers a broad suite of subscriber and headend equipment that allows operators to safely adopt DOCSIS 2.0. Motorola also offers the professional services and expertise that helps broadband network operators take advantage of the many advantages of the evolving DOCSIS specifications.

Additional Resources

For more information, please visit the following online DOCSIS 2.0 resources:

Motorola DOCSIS solutions	http://broadband.motorola.com/nis/
DOCSIS 2.0 specification	http://www.cablemodem.com/specifications/
DOCSIS 2.0 latest news	http://www.cablelabs.com/news/

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