Expanding Bandwidth Via Advanced Spectrum Management Techniques

This whitepaper discusses the business opportunities that operators can capitalize on by implementing advanced spectrum management. It defines the typical types of impairments operators must overcome, and provides an overview of spectrum management solutions from Motorola that allow operators to increase performance and revenue.

By implementing advanced spectrum management techniques, cable operators can increase throughput, reclaim bandwidth, deliver additional services, and generate new revenues from existing plant. They can cost-effectively migrate from DOCSIS 1.X to DOCSIS 2.0 while efficiently generating revenue from the large installed base of legacy cable modems.

Operators can aggressively deploy DOCSIS 2.0 modems to offer enhanced services that take advantage of the performance capabilities of DOCSIS 2.0. They can benefit from the best of both worlds by extending the life of legacy cable modems while accelerating the introduction of high-value enhanced services.

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Capitalizing on Business Opportunities

By implementing advanced spectrum management techniques in conjunction with the DOCSIS specifications, operators can reap major economic rewards. They can ensure bandwidth-efficient coexistence between DOCSIS 1.0, 1.1, and 2.0 cable modems and accelerate the delivery of high-margin services across the Hybrid Fiber Coax (HFC) infrastructure that leverage the throughput and capacity advantages of DOCSIS 2.0

As residential cable modem penetration continues to grow and operators increasingly provide high-bandwidth services to commercial customers, the need for higher upstream bandwidth becomes paramount. Several options are available for an operator to provide more upstream bandwidth. Segmenting the cable plant and providing more upstream channels both require major capital investment, but operators also have the options of increasing the upstream channel width, moving to a higher-order modulation scheme, and implementing a full transition to DOCSIS 2.0.

Increased Channel Width/Higher Modulation

Over 25 million DOCSIS cable modems have already been deployed, and cable operators would like to achieve higher upstream bandwidth by operating them at 16 QAM and at the maximum channel width of 3.2 MHz. However, some form of equalization is essential for a cable modem to operate at these channel parameters in a typical upstream cable plant.

DOCSIS 1.1 mandates support for transmit pre-equalization, in which the Cable Modem Termination System (CMTS) receiver equalizer convergences on a periodic burst and then sends the equalizer coefficients to the cable modems for implementation in their transmitters. Unfortunately, DOCSIS 1.0 modems were not required to implement pre-equalization.

In fact, the information field containing the equalizer coefficients sent by a DOCSIS 1.1 CMTS to the cable modem, was changed significantly, thus rendering most DOCSIS 1.0 cable modems incapable of supporting DOCSIS 1.1 transmit pre-equalization. In fact, many DOCSIS 1.0-only cable modems actually de-register when sent the equalizer information from a DOCSIS 1.1 CMTS.

Thus, cable operators need to either find an alternate equalization mechanism for DOCSIS 1.0 cable modems or else remain constrained to QPSK modulation. Fortunately, emerging CMTS burst receiver technology is capable of providing equalization on a per-burst basis without any need for enhancing the cable modem. By implementing post-equalization—per-burst equalization—cable operators can operate DOCSIS 1.0 cable modems in 16-QAM mode instead of in QPSK. Therefore, they can effectively double the throughput of their installed base of modems.

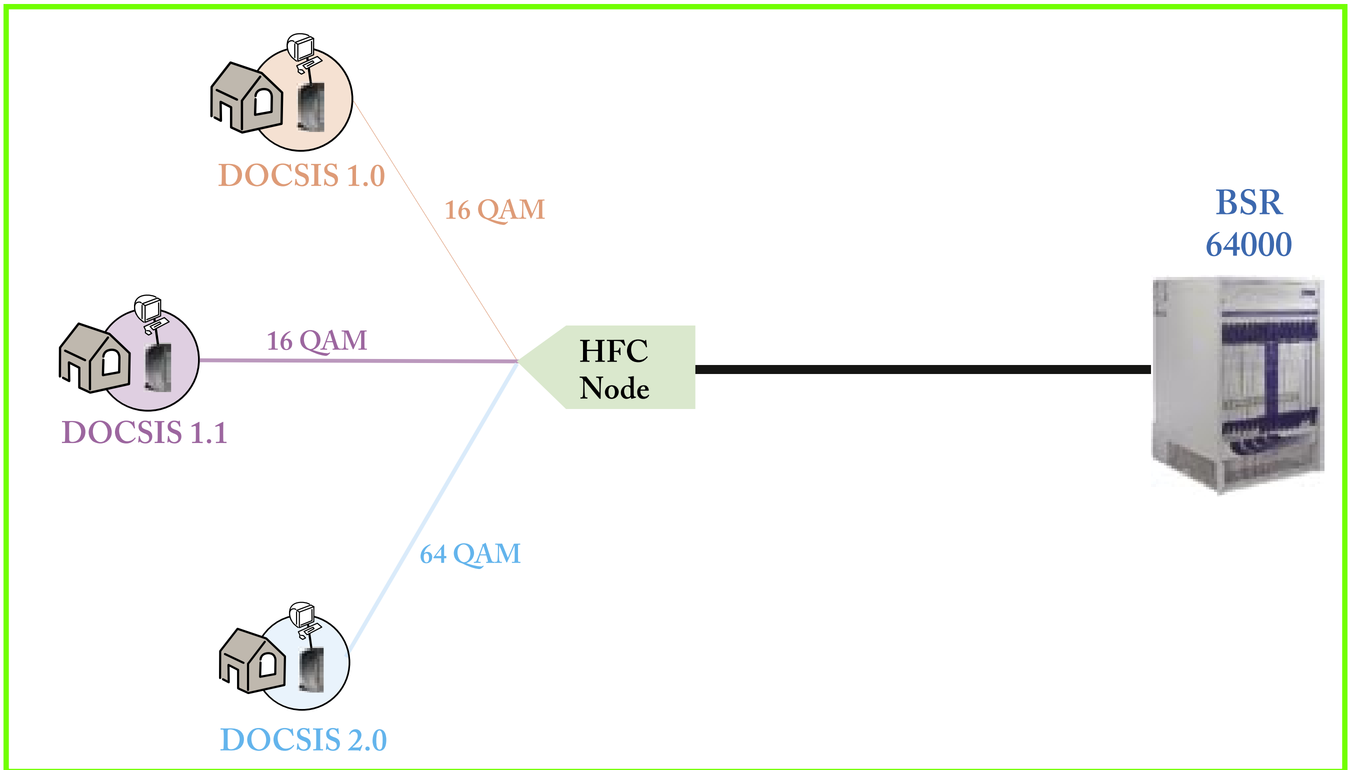
Transitioning to DOCSIS 2.0

DOCSIS 2.0 expands the physical layer to include two different modulation techniques that can coexist within the same channel: Advanced Time Division Multiple Access (ATDMA) and Synchronous Code Division Multiple Access (SCDMA). *For more information on ATMA and SCDMA, please download our whitepaper located at* **http://broadband.motorola.com/nis/**.

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. This accomplishes the following:

- 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, because all DOCSIS 1.0 cable modems would be able to operate in 16-QAM mode.



Motorola's BSR 64000 offers advanced spectrum management that allows operators to maximize performance of DOCSIS 1.0, 1.1, and 2.0 cable modems.

- 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), and 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. This approach is not only the most practical migration path; it is also the one with the lowest risk to the cable operator. But to capitalize on these business advantages, operators must be able to successfully address the transient impairment issues that today constrain upstream bandwidth in the return path.

Understanding Impairments

Whether an operator implements ATDMA or SCDMA—or both concurrently—there remains a need to improve the Signal-to-Noise Ratio (SNR). 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.

Advanced spectrum measurement and management is critical so that operators can understand the various impairments present in their infrastructure. 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

Narrowband AM modulation carriers such as shortwave radio signals can suddenly appear any where in the return path spectrum. Ingress noise is a term assigned by cable operators to describe any interference that is coupled into the return path plant via an external source. This term contrasts with egress noise, which is noise that the cable plant is emitting to the outside world.

The predominant coupling mechanism for ingress noise is a poorly shielded Drop Coaxial Cable that is acting more like an antenna then a drop cable. The overwhelming majority of ingress noise is narrowband AM modulated carriers whose bandwidth is usually less than 20 kHz and seldom over 200 kHz. Return path characterizations conducted by Motorola over time have found that this ingress interference ranges from around -25 dBc (25 dB below the DOCSIS signal power) to +15 dBc (15 dB above the DOCSIS signal power).

Occasionally, ingress noise is recorded that is as high as +25 dBc. It is therefore important to ensure that a CMTS receiver front end can take at least +31 dBc or 6 dB more than the +25 dBc ingress incidents. Frequency avoidance has been the sole technique to deal with this parameter until the development of advanced ingress noise cancellation techniques.

Impulse Noise

Impulse noise is also a reality in virtually all return path cable plants. It is made up of short bursts of high-level noise such as that resulting from the coupling of transients into a channel. Wideband noise events occur typically in bands wider than 6 MHz, and there are multiple sources of this type of impairment. However, the duration of this noise usually lasts in the 1-100 microsecond range.

There is another class of impulse noise that is power line related and when this type of transient event occurs, the duration is in the 1-10 millisecond range. The one saving grace of either type of impulse noise is that neither has any significant energy beyond 15 MHz. Impulse noise energy tails off in energy starting around 13 MHz to 18 MHz, and falls off dramatically in energy by 30 MHz. Evidence of this fact is that virtually all DOCSIS 1.X systems operate error free even in 16-QAM modulation with a moderate amount of Forward Error Correction enabled when operating over 20 MHz.

Common Path Distortion (CPD)

Unlike ingress noise, which is coupled into the coaxial cable plant, CPD is self-generated mainly due to connector corrosion and connectors acting as a diode. However, CPD shares many of the classic characteristics of ingress noise interference and has a similar effect on performance, especially for 16-QAM and above. CPD typically ranges from –40 dBc to –10 dBc.

However, recent characterizations have revealed that while CPD products are the direct result of non-linearity, higher-order distortions have been observed up to the seventh order. The end result of all non-linearity—especially that above the third order—is that the distortion products are dramatically beating up and down and that the rate of change for these products is in the hundreds of microseconds between the peak distortion product power and the minimum.

When the higher order distortion products occur, the number of distortion products in a 3.2 MHz bandwidth has been as high as 11 products as opposed to the more classic two or three products in a 3.2 MHz bandwidth. Therefore, the ingress canceller must be able to track this rapid rate of change in order to effectively cancel enough of the CPD to maintain a high order QAM modulated digital carrier.

Micro-Reflection

Micro-reflections are caused by impedance mismatches, and they are perhaps the most common impairment that exists in every plant, and they are unique to each cable modem path. The most common types of micro-reflections occur at the lower tap values of the coaxial plant distribution. The lower the tap value, the poorer the isolation between the other ports and the cable modem signal.

Micro-reflections are also by definition frequency-dependent and thus not all carrier frequencies and DOCSIS channel bandwidths (symbol rates) are impacted equally. The typical range for micro-reflections is -20 dBc to -3 dBc. DOCSIS systems can deal with micro-reflections through:

- Frequency avoidance by moving away from the frequency area impacted by micro-reflection. In the case where the cable operator is using a 3.2 MHz bandwidth DOCSIS channel, this choice is particularly unpopular because there is not enough bandwidth available to take advantage of this option in many return path networks.
- Reducing the symbol rate, usually by fifty percent. This has always been the best option available for enabling 16-QAM modulation mode when the system consists of DOCSIS 1.0 cable modems and a non-ATDMA DOCSIS 1.0 or 1.1 CMTS. Halving the symbol rate is a frequency avoidance technique for avoiding the most severe frequency area because the DOCSIS channel occupies half the bandwidth. This option of halving the symbol rate or DOCSIS channel bandwidth also has the side benefit of improving the system immunity to the other major problems on all return paths, including amplitude distortion and group delay distortion. Without transmit pre-equalization or receiver (post) equalization available to the cable operator, halving the symbol rate is the only choice for achieving 16-QAM operation. The only downside to this option is that the cable operator must use twice as many CMTS receivers.
- Equalizing the distortion. This is the preferred technique of addressing a micro-reflection. Obviously, until ATDMA technology appeared, this option was not available to the cable operator. ATDMA enables post-equalization for DOCSIS 1.0 cable modems.

Amplitude Distortion

There is amplitude distortion in every cable plant. The two major sources of amplitude distortion are coaxial cable loss (which is not a significant impairment in the return path direction) and diplex filters, which are the primary cause of amplitude distortion. Amplitude distortion is addressed in a similar manner to addressing the problem of micro-reflections.

Group Delay Distortion

There is group delay, or “ phase” distortion in every plant, and it becomes more prominent when there is filtering in a system. The major source of group delay distortion in the return path is the same diplex filters that cause the amplitude distortion. Group delay distortion and amplitude distortion are in fact inseparable due to the fact that in a CATV plant in which the vast majority of diplex filters are passive LC filters you cannot have one without the other. The more amplifiers in cascade, the more dramatic the impact of both amplitude and group delay distortion on a DOCSIS transmission. The solutions for group delay distortion are the same as for micro-reflections and amplitude distortion.

Intermodulation Distortion (IMD)

Non-linearity such as Composite Second Order (CSO) and Composite Triple Beat (CTB) can cause severe impairments for any QAM modulation. These distortions result from minor imperfections in amplifiers, and they are measurements of the peak of the RF signal to the average level of the cluster of distortion components centered around the carrier. The higher-level the QAM constellation, the more susceptible it is to IMD.

The Measurement Paradox

Merely understanding the types of impairments is not enough. It is important to appreciate the interrelationships and accurately perform spectral analysis. This allows the operator to truly understand the impact of noise on network performance and take the appropriate action to cancel it out or move the signal.

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, this technique alone cannot accurately assess the total impact of noise on network performance.

No single impairment can be clearly singled out for testing because most—if not all—impairments are present at some level the majority of the time. It therefore becomes a matter of assessing the magnitude of each impairment's impact on the DOCSIS service. For example, an impulse noise performance test without also measuring ingress noise performance is not truly insightful.

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

Hence the paradox: most CMTS vendors are only performing the nearly transparent FFT measurement because they cannot afford to impose the overhead of measurement. They cannot afford the time for a coherent measurement approach—even though it is universally agreed that coherent measurement is the only accurate assessment of any impairment's impact on a DOCSIS service.

But by selecting a CMTS that supports advanced spectrum management, operators gain hard data on real-world performance. They can understand the impact of noise on performance and bandwidth availability, and take steps system-wide to enhance throughput and enable new services.

The Motorola BSR 64000 is a carrier-class CMTS/edge router that offers advanced spectrum management so operators can continuously improve throughput and maximize revenues.

Advanced Spectrum Management Solutions from Motorola

The Motorola Broadband Communications Sector (BCS) offers innovative solutions that 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. The Broadband Services Router 64000 (BSR 64000) is a carrier-class CMTS/edge router that implements advanced spectrum management so operators can maximize performance.

The BSR 64000 includes a 2x8 DOCSIS 2.0 CMTS Module based on industry-leading DOCSIS 2.0 silicon from Broadcom Corp. It enables advanced spectrum management, which includes ingress noise cancellation, post-equalization, sophisticated noise measurement, and noise avoidance capabilities.

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.

Robust PHY Implemented in Silicon

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.

The DOCSIS 2.0 CMTS Module offers two downstream ports and eight upstream ports as well as an innovative ninth receiver port that enables real-time spectrum management.

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.

Adaptive Noise Cancellation and Post Equalization

The BSR 64000 offers the processing power and architectural support for adaptive noise cancellation at the receiver. 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. For example, Motorola's ATDMA ingress canceller on the DOCSIS 2.0 CMTS Module has demonstrated its ability to track and cancel rapidly changing severe common path distortions. The net effect is that the operator is able to maintain a high-order QAM modulated digital carrier.

If the noise cannot be cancelled out—such as a very large ingress noise or interferer—the BSR 64000 can avoid the noise by changing the modulation mode or moving frequencies.

Operators can therefore continuously improve performance, proactively recognize and resolve potential bottlenecks, and create more billable bandwidth. 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 noise change frequently.

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.

Flexible Analog Front End

The BSR 64000's DOCSIS 2.0 CMTS Module has an analog front-end—a traditional RF tuner—that offers greater flexibility for noise cancellation and avoidance. It allows the operator to select *individual channels* and move receiver frequencies and change modulation modes to optimize performance. This is difficult to perform with an all-digital front-end.

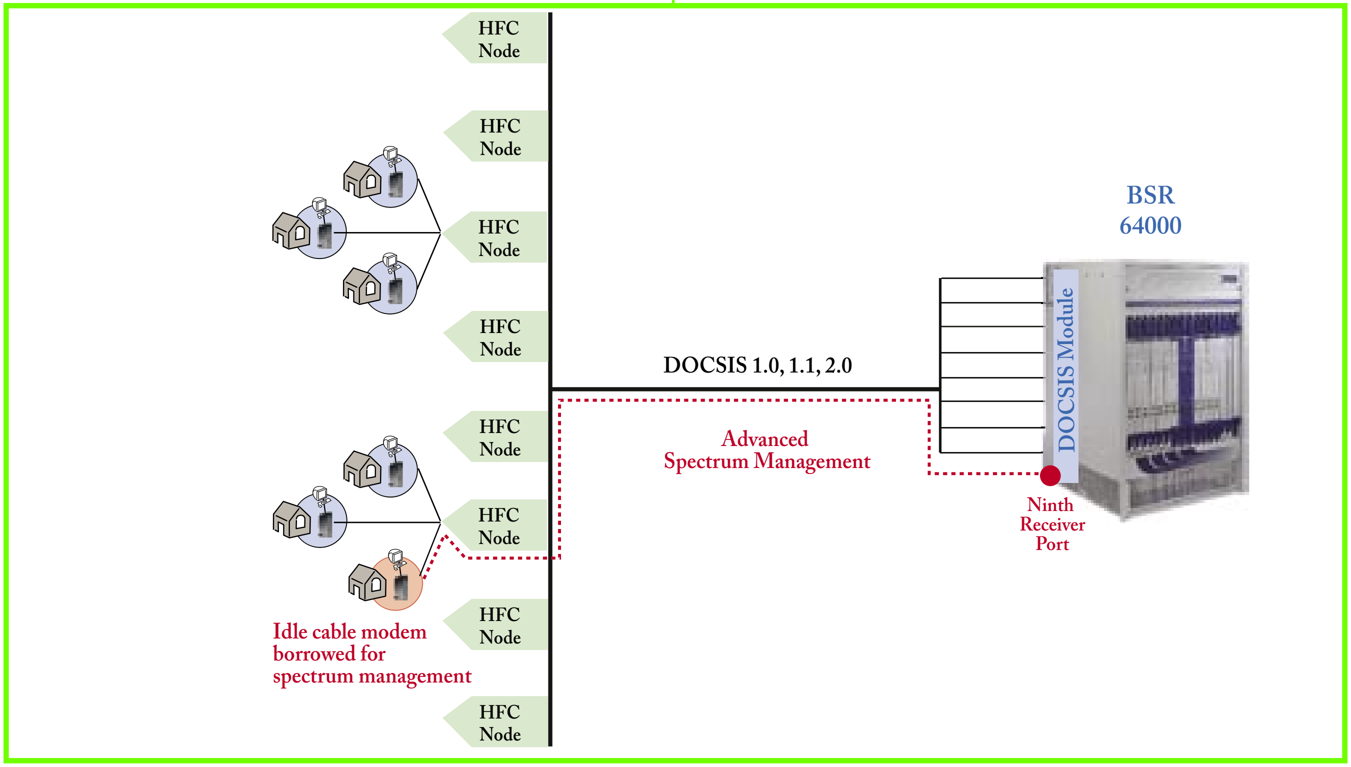
For example, if a digital front-end receives a large, wideband ingress noise that is difficult to cancel, moving to another frequency area where the ingress noise event is not occurring will not produce the same performance improvement result as would the RF tuner.

The reason is the Analog/Digital (A/D) dynamic range is being compromised by the large ingress noise event and moving to another frequency will not save the A/D dynamic range because it still sees the ingress noise. This limitation will become even more obvious in the future when trying to support the DOCSIS 2.0 higher QAM modulation.

Sophisticated, Onboard Spectrum Management System

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 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.



Operators can use the ninth receiver port to conduct detailed monitoring of the spectrum to continuously maximize throughput without negatively impacting performance.

The ninth receiver 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.

It can also perform a host of other measurements by simply borrowing an idle cable modem for a rich set of return path calculations. The borrowed cable modem is automatically released for service if demands are placed upon it and another idle modem is selected to ensure there is no intrusion on customer service.

The ninth port can measure the actual main receiver port carrier frequency or channel without imposing any burden on the channel being measured. It can also command a cable modem to transmit at different frequencies for full evaluation of all available DOCSIS and even non-DOCSIS bandwidth assigned by the operator.

The Motorola BCS Spectrum Management System includes sophisticated algorithms to determine which cable modems are most representative of the return path under evaluation. Since this detailed monitoring is non-intrusive to the subscriber while enabling the operator to continuously monitor noise and improve performance, it makes the BSR 64000 particularly appropriate for lifeline Voice over IP (VoIP) services.

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's DOCSIS 2.0 CMTS Module leverages market-leading silicon technology from Broadcom and offers a powerful analog front end and rich post-equalization capabilities that allow operator to efficiently cancel out impairments or shift channels.

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.

End-to-End Solutions from Motorola NIS

Motorola offers the end-to-end solutions operators need to implement advanced services. Cable operators can control migration from DOCSIS 1.X to DOCSIS 2.X while enabling maximum revenue from legacy investments.

The BSR 64000 is a high-performance, high-density CMTS and routing platform operators need to support new services and subscribers, and it delivers the advanced spectrum management that can help operators maximize revenues from infrastructure investments.

The Motorola Network Infrastructure Solutions (NIS) Group delivers the end-to-end solutions that allow cable operators worldwide to increase revenues, market share, and profits. Motorola offers the products for the subscriber location, headend, metro, and core networks, as well as a suite of highly tailored professional services that allow cable operators to successfully buildout new infrastructure and deploy advanced services.

For More Information

Motorola NIS
101 Tournament Drive
Horsham, PA 19044
Tel (800) 523-6678
Tel (215) 323-1000
http://broadband.motorola.com/nis/

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