MAXIMIZING BANDWDITH UTILIZATION VIA ADVANCED SPECTRUM MANAGEMENT

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Abstract

This paper discusses the impairments that must be addressed to maximize bandwidth utilization over DOCSIS infrastructure. It presents an effective approach for overcoming these impairments and delivering increased throughput for DOCSIS 1.X and 2.0 cable modems by taking advantage of DOCSIS 2.0 extensions. It also shows how extensions to DOCSIS can allow operators to implement advanced spectrum management to cost-effectively buildout standards-based infrastructure today while retaining the flexibility to support emerging or evolving architectures in the future.

INTRODUCTION

The twin demands of more cost-effectively utilizing existing buildouts while delivering increased capacity to the customer require innovative means of maximizing the utilization of existing bandwidth. Clever new approaches are required to optimize the use of existing cable modems while achieving increased throughput for DOCSIS 2.0 modems.

Advanced spectrum management can be deployed along with DOCSIS standards to allow operators to improve upstream throughput by dynamically evaluating the RF characteristics of available upstream spectrum and then selecting the spectrum frequency, modulation mode (16 QAM, 32 QAM, 64 QAM, 128 TCM, 256 QAM) and channel width (1.6 MHz through 6.4 MHz) to optimize throughput.

Extensions beyond DOCSIS 2.0 can allow operators to monitor RF performance in a non-intrusive manner to truly understand the impact of impairments.

Once these impairments are carefully measured, operators will then possess the information they need to operate at the highest throughput possible at all times. This is enabled by the ability to implement sophisticated ingress noise cancellation and impulse noise immunity techniques. With the majority of cable modems installed today supporting only DOCSIS 1.0, there are also advanced spectrum management extensions available to 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.

MEASURING SPECTRUM

The first step toward managing spectrum is to measure and understand the impairments on the DOCSIS infrastructure.

Without a clear understanding of the impacts of impairments, it is difficult to optimize throughput and meet or exceed DOCSIS performance goals.

What is truly required from a DOCSIS Cable Modem Termination System (CMTS) is the ability to intelligently assess the impairments on a given return path in real time. Unfortunately the time required to make an accurate assessment of impairments using traditional measurement tools far exceeds the time budget allotted for measurements.

Simply stated, the more time that is required to perform an accurate measurement, the more the throughput of the data traffic is impacted.

While Fast Fourier Transform (FFT) measurements are a useful analysis tool for ingress and impulse noises, this technique has little ability to accurately measure micro-reflections and group delay. Instead, coherent measurements are required to measure the effects of linear distortions such as micro-reflections, amplitude, and group delay distortion.

When discussing the system non-linearity class of impairments, only a coherent measurement can be be used. And, the larger the QAM constellation, the greater susceptibility to system non-linearity. This has been demonstrated by comparing the difference between 16-QAM and 64-QAM given the same non-linear circuit and the same RMS power for both constellations.

The entire point of advanced spectrum management is to assess the unused return path bandwidth for all impairments. This takes time an active data channel simply cannot afford to spend.

ADVANCED SPECTRUM MANAGEMENT DEFINED

Advanced spectrum management allows operators to identify impairments and make the necessary adjustments to improve performance. An effective method to perform advanced spectrum management is to utilize a dedicated receiver on the CMTS to monitor performance on any one of the upstream paths without impacting performance.

Advanced spectrum management is an extension to DOCSIS that essentially relies on a spare receiver to perform time-consuming measurements in the background.

Operators can therefore 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. Advanced spectrum management is a necessity for any cable operator to be able to efficiently support VoIP or other demanding real-time services.

Given the unknown limitations that exist in the return path, the DOCSIS CMTS must assist the cable operator in determining what any given return path is capable of yielding. Advance spectrum management must be completely transparent, with absolutely no impact on voice, data, or video throughput. It must also be able to discern between a linear and non-linear distortion to be truly effective.

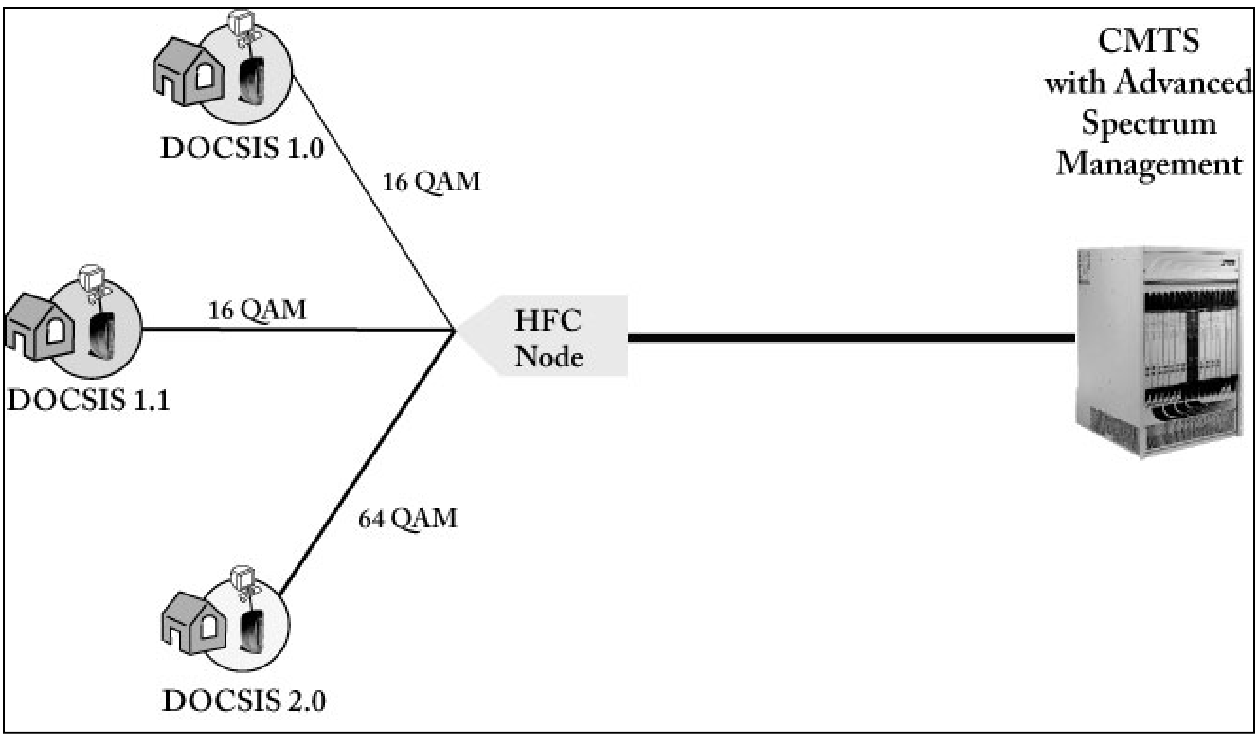
Advanced spectrum management is critical to the ability to optimize the billable capacity of the DOCSIS network. Operators simply cannot fix impairments that they cannot identify and measure. Hard data is necessary so that the effects of multiple impairments can be discerned and successfully addressed.

The only alternatives to advanced spectrum management are to ignore (or guess at) the impacts of impairments, or to deploy expensive, dedicated testing gear to measure the various impairments that are present on any given DOCSIS network. Operators have relied on advanced vector signal analyzers and next generation CATV Analyzers that support spectrum and DEMOD measurements for several years to characterize the return path characteristics.

But this approach is expensive, difficult to deploy and extremely time-consuming to measure. It also impacts the performance of the DOCSIS network, requiring operators to take a segment of the network out of service as the reference sources tend to be constant carrier signals that disrupt service in some instances.

IMPLEMENTING ADVANCED SPECTRUM MANAGEMENT

By implementing advanced spectrum management techniques in conjunction with the DOCSIS specifications, operators can ensure bandwidth-efficient co-existence between DOCSIS 1.0, 1.1, and 2.0 cable modems. They can deliver higher upstream bandwidth that can even exceed DOCSIS specifications while ensuring a successful transition to DOCSIS 2.0. Operators can transition to 2.0 without providing a performance burden to legacy subscribers because the CMTS can operate in DOCSIS 1.X mode.



The receiver technology provides post-equalization support that can double the throughput for existing customers because virtually all DOCSIS 1.0 cable modems able to run in QPSK would be able to operate in 16 QAM mode utilizing a post equalization technique. 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 Forward Error Correction, byte interleaving (if necessary), and higher constellation rates such as 32 QAM or even up to 256 QAM.

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 enable 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.

To take advantage of these business opportunities, operators first need to address the transient impairment issues that today constrain upstream bandwidth in the return path.

MEASURING IMPAIRMENTS

Operators need to be able to improve the Signal-to-Noise Ratio (SNR) so they can more efficiently manage spectrum and improve noise cancellation simultaneously over diverse populations of DOCSIS 1.0, 1.1, and 2.0 modems. Advanced spectrum management is important so that operators can understand the various impairments present in their infrastructure.

This is particularly critical because real-world environments face the following three major classes of impairment, which are present at some level the majority of the time:

- Linear Impairments
- Non-linear Impairments
- Transient Impairments

LINEAR IMPAIRMENTS

Micro-reflections are the most common distortions that exist in every plant, but they occur differently in each plant. They are caused by impedance mismatches, and the most significant micro-reflections tend to occur at the lower tap values of the coax plant.

The lower the tap value, the poorer the isolation between the other ports and the cable modem signal. Micro-reflections are frequency dependent, so that not all channel bandwidth is affected equally. A fundamental problem in isolating a micro-reflection lies in the fact the impedance mismatch resulting in a rather large micro-reflection tends to be dominated by a poor termination in a tap adjacent to the problem cable modem and not to the tap that the cable modem is connected to. This phenomenon is directly related to the poor isolation characteristics of the low tap values.

Amplitude tilt or slope distortion is also present in every cable plant, and can be caused by coaxial cable loss or more likely by the use of diplex filters. Every plant also faces group delay—or "phase" distortion—which becomes a bigger problem as filtering is introduced. The major source of group delay distortion is diplex filters. The more amplifiers in cascade, the more dramatic the impact of both amplitude and group delay distortion on a DOCSIS transmission.

Advanced spectrum management allows operators to address these types of linear impairments by:

- Migrating away from the problem frequencies
- Reducing the symbol rate, usually by half
- Equalizing the distortion

NON-LINEAR IMPAIRMENTS

There are no specifications that exist in DOCSIS 2.0 that address system non-linearity. DOCSIS 2.0 Technology—particularly any modulation type greater than 16-QAM—is inherently weaker against non-linearity than is DOCSIS 1.X technology.

This is due to the higher crest factor of DOCSIS 2.0 that ranges from a minimum of 3 dB higher to a maximum of 7 dB higher peak power. There are many variables that contribute to the final crest factor, such as the:

- Theoretical crest factor of the modulation constellation
- Number of diplex filters in cascade
- Carrier frequency

By definition non-linearity is a signal-dependent distortion, which simply means that the effects of a non-linearity can only be observed in the presence of a signal.

Non-linear impairments include Common Path Distortion (CPD) and not-so-common path distortion, often referred to as return laser non-linearity.

CPD is well understood by the CATV industry in general. It is the phenomena of a coaxial connector becoming or temporarily acting as a diode. It is easily observed by seeing analog video carriers spacing 6 MHz apart throughout the return path. While CPD is easily detectable, the return laser being either clipped or just becoming marginally non-linear can only be witnessed today by advanced spectrum management on a dedicated receiver on a CMTS card or by deploying vector signal analyzer test equipment on the network.

With advanced spectrum management, one can easily observe that the effects of any non-linearity is that the outer constellation points are impacted far greater than the inner constellation points.

TRANSIENT IMPAIRMENTS

Transient impairments include ingress noise and impulse noise. Narrowband AM modulation carriers such as shortwave radio signals can suddenly appear anywhere in the return path spectrum. Ingress noise refers to any interference that is coupled into the return path plant via an external source.

The predominant coupling mechanism for ingress noise is a poorly shielded drop coaxial cable that is acting more like an antenna than a drop cable. The overwhelming majority of ingress noise is narrowband AM modulated carriers whose bandwidth is usually less than 20 kHz and ingress noise in general seldom has a bandwidth 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 the 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 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 powerline 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. 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.

UNDERSTANDING PERFORMANCE

Advanced spectrum management allows tremendous flexibility for understanding the complex interaction of impairments on the DOCSIS network. 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, conducting an impulse noise performance test without also measuring ingress noise performance is not particularly insightful. Another 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 negatively impacts the bandwidth being tested. Hence the paradox; many CMTS platforms are only performing the nearly transparent FFT measurement because operators cannot afford to impose the overhead of measurement.

Many operators therefore 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.

Advanced spectrum management implemented on a CMTS with spare receiver ports on interface cards 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 spare 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 should have access to 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 spare 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.

Advanced spectrum management also requires support for adaptive noise cancellation at the receiver to measure the diverse types of noise, process this information and take action to cancel it out in real time. For example, an ingress canceller on the CMTS can track and cancel rapidly changing severe CPDs. 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 CMTS 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.

Continuous monitoring and adaptation allows cable operators to aggressively implement advanced noise cancellation in environments where the types and degrees of noise change frequently. 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.

SAMPLE MEASUREMENTS

The following is just a small sampling of the types of measurements operators can implement using advanced spectrum management:

- SNR per cable modem with post equalization enabled.
- SNR per cable modem with post equalization disabled, which reveals whether there is any significant micro reflection on a per-modem basis.
- SNR per cable modem with ingress noise canceller enabled.
- SNR per cable modem with ingress noise canceller disabled, which reveals whether there is any significant ingress noise present.
- RX level per cable modem, which when coupled with the cable modem transmit level from the SNMP MIB will allow operators to calculate network loss per cable modem.

The reality is that there is a virtually unlimited number of tests operators can perform using advanced spectrum management without impacting the performance of active cable modems.

CONCLUSION

It is very difficult to improve something that you cannot measure. Operators need hard data on network performance, but cannot afford the cost and complexity of deploying test equipment throughout the network.

Merely guessing at the impact of impairments is a wasteful and frustrating exercise. The ability to accurately measure and monitor impairments is essential to optimizing the productive use of bandwidth and ensuring the successful delivery of real-time video and voice services.

By implementing advanced spectrum management, operators can non-obtrusively monitor the impact of impairments on an ongoing basis and take corrective actions when necessary to improve performance of voice, data, and video services.

ABOUT THE AUTHOR

Jack Moran is a Distinguished Member of the Technical Staff for the IP Solutions

Group for Motorola Connected Home Solutions. He is the holder of 11 U.S. patents in data communications, with many more pending.

Moran is responsible for DOCSIS Physical Layer performance over an HFC RF network system. For over four years, he has been modeling the return path for DOCSIS 1.0, 1.1, and now 2.0 performance capabilities. This modeling effort has included many 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. Moran can be reached at jack.moran@motorola.com.