CREATING LOGICAL CHANNELS AND IMPLEMENTING ADVANCED SPECTRUM MANAGEMENT

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Abstract

DOCSIS® 2.0 support for logical channels enables cable operators to increase the available upstream bandwidth. This paper will highlight the business and service advantages of creating logical channels and implementing advanced spectrum management to monitor performance and efficiently utilize HFC bandwidth.

INTRODUCTION

Operators can quickly deliver increased upstream performance to HFC networks consisting of mixed mode DOCSIS 1.x and 2.0 Cable Modems (CMs) as well as for new networks consisting entirely of DOCSIS 2.0 cable modems. But there are issues to address to reap these rewards, and this paper will explore them.

This paper will explain the technology, discuss the challenges involved in implementing logical channels, and provide examples of performance gains realized by deploying logical channels in both mixed-mode and pure DOCSIS 2.0 environments.

It will also discuss how cable operators can utilize a spare receiver on a CMTS to perform spectrum management and non-obtrusively measure spectrum impairments, predict the dominant impairment in any area of the spectrum by analyzing signal-to-noise measurements, and qualify any area of the return path spectrum so they can achieve the maximum data signaling rate for logical channels.

They can leverage logical channels and advanced spectrum management to increase the aggregate bandwidth. Automation is key to the successful implementation of logical channels and advanced spectrum management.

The CMTS, Advanced Spectrum Management and DOCSIS 2.0 Logical Channel Operation can begin the tedious process via a script and automatically compile the various CMs or MTAs into the up to 4 Logical Channel Configurations supported. From the perspective of maximum throughput being maintained, it is quite possible to eventually allow the CMTS to automatically make the decision regarding Logical Channel Assignments and to affect the change, thus allowing the cable operator to adaptively change the maximum throughput possible based solely on return path conditions presented to the CMTS.

Today, this is not performed due to the cable operator having to gain confidence in the Logical Channel estimation process which is being performed by doing the analysis automatically and assigning all DOCSIS 2.0 CMs and MTAs the correct Logical Channel Assignment, but first allowing the cable operator to make the final decision as to the throughput change. Once the cable operator gains confidence in the accuracy of the throughput estimation via Logical Channel Operation, it is logical to assume that the cable operator will take the next step in the process and allow fully automated Logical Channel Operation.

UNDERSTANDING LOGICAL CHANNELS

The concept of logical channels was introduced as a mechanism to allow legacy DOCSIS 1.0 and 1.1 CMs—which only support the Time Division Multiple Access (TDMA) protocol—to coexist with the Synchronized Code Division Multiple Access (SCDMA) protocol introduced with DOCSIS 2.0. That is, logical channels were created out of necessity to support the large, existing 1.x CM base already fielded. However, this feature supports so much more than just legacy operation.

Before exploring the benefits of logical channels, a clear definition is warranted. DOCSIS defines a logical upstream channel as, “A MAC entity identified by a unique channel ID and for which bandwidth is allocated by an associated MAP message. A physical upstream channel may support multiple logical upstream channels. The associated UCD and MAP messages completely describe the logical channel.”

Logical channels are a unique set of transmission characteristics that are dealt with via the use of different modulation (burst) profiles in the upstream direction. All Logical Channels (modulation profiles) are time division multiplexed into the same physical DOCSIS channel. A physical DOCSIS channel is defined by such parameters as: a) symbol rate (six rates from 160 ksym/sec to 5.12 Msym/sec in octave steps), and b) center frequency. Logical channels further define the channel with burst profile attributes.

Prior to the introduction of logical channels in DOCSIS 2.0, each physical channel was required to utilize only one value for each of the burst profile attributes. Thus, the configuration of an upstream channel in DOCSIS 1.1 or 1.0 was driven by the worst performing CM or tap in the plant. For example, if a CM was located at a point in which a significant micro-reflection was present which was beyond the modem’s ability to successfully transmit 16QAM using its 8-tap equalizer, then the operator was forced to configure the entire channel (and therefore all modems on that channel) to utilize the QPSK modulation. Now, if that micro-reflection characteristic was only present for 1% or 2% of the CM population on the channel, then we have a scenario in which the operational throughput of the channel is being dramatically limited by a small fraction of the modem population. The logical channel feature allows us to circumvent this problem by defining up to four logical channels on that one physical channel.

For example, logical channel 1 might be configured with a QPSK modulation and the 1-to-2% of poor performing modems would be assigned to that logical channel. Similarly, logical channel 2 could be configured for 16QAM and the remaining population would be assigned to this logical channel. Using this one configuration change, we have now reclaimed nearly a 98% increase in the upstream throughput. Another interesting fact is that we realized a significant increase in throughput by only leveraging DOCSIS 2.0 functionality within the CMTS. That is, we realized this improvement even with only 1.0 CMs present on the plant. It is easy to see how additional logical channels might be created which leverage higher-order modulations (32QAM, 64QAM, and even proprietary 256QAM). For these logical channels, only the corresponding modems which support such capabilities would be assigned to the logical channel.

While changes in modulation type provide for the most dramatic changes in realized throughput, the use of logical channels is not limited to this single parameter. In cable plants where micro-reflections or amplitude roll-off are significant issues, the use of preamble lengths may be exploited to yield improvements in throughput. For example, modems encountering greater linear distortion could be assigned to logical channels which utilize longer preambles and therefore yield better equalizer performance, while modems encountering less distortion would be assigned to logical channels utilizing shorter preambles. A similar technique can be applied to FEC [both codeword length (K) and number bytes corrected (T)], byte interleaving, guard times, or any combination thereof. This provides the needed mechanism to deal with the variances of modem signal quality resulting from such factors as system loss, amplifier cascades, and micro-reflections.

Cable operators can leverage logical channels to improve the throughput of legacy DOCSIS 1.0, 1.1 CMs as well as optimize performance for DOCSIS 2.0 and even 3.0 CMs. They can implement logical channels on pure DOCSIS 2.0 or 3.0 deployments, but the reality is that most cable networks also consist of legacy DOCSIS 1.0 and 1.1 CMs. Logical channels can support mixed-mode operation and they can optimize the performance of diverse CMs deployed throughout the access network.

MANAGING IMPAIRMENTS

DOCSIS 2.0 has opened opportunities in which increased efficiencies and greater throughput can be achieved within the return path. However, increasing efficiencies and enhancing throughput is not just a simple matter of enabling the new features in DOCSIS 2.0.

One must first understand the dominant characteristics and impairments of a given return path before channels can be reconfigured accordingly. When fairly simple characterizations are performed, dramatic increases in throughput can be achieved.

Channels which would be unusable with DOCSIS 1.0/1.1 can now be reclaimed, and throughput of legacy channels can be increased 50% or more with an optimal configuration. Further, the characterization methodologies presented in this paper will yield relationships between actual plant devices and dominant impairments present within a given return path. By identifying dominant impairments and actual plant devices causing such impairments, this methodology supports targeted maintenance activities for so-called low-hanging fruit improvements that yield major performance benefits.

The higher bit rates achieved with higher modulations come at the expense of greater Modulation Error Ratio (MER) requirements [sometimes incorrectly referred to as Signal-to-Noise Ratio (SNR)] on the upstream channel. These requirements go beyond the traditional first order issues, such as:

- Thermal noise
- Ingress noise
- Impulse noise

This paper focuses on the topic of increased modulation levels and the issues to be overcome to support such levels. Specific issues that will be discussed within this paper are:

- Linear impairments

- Non-linear impairments

ADVANCED SPECTRUM MANAGEMENT

A spare receiver architected into a CMTS module can allow cable operators to best understand the impairments on the DOCSIS infrastructure. It runs in parallel to the live ports to monitor performance of any one of the upstream ports without materially impacting the subscriber experience.

The receiver is connected in parallel with a selected receiver port so the operator can measure traffic and performance in real time on any given receiver port. The parallel 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 parallel receiver can non-obtrusively gain access to all of the return nodes connected to one of the receiver ports and perform tests on each upstream channel to assess its quality and take the time required to complete detailed, coherent MER measurements.

Cable operators can leverage advanced spectrum management to optimize the performance of cable modems and better understand how to automatically compensate for linear and non-linear impairments.

With the release of DOCSIS 3.0, spectrum management will become even more critical because the CMTS will be faced with maintaining quality of service on multiple bonded upstreams. Multiple upstream channels will require that MSOs reclaim more and more of their upstream frequency spectrum, including regions which have historically been avoided due to their greater susceptibility to various impairments. Maintaining quality of service across many service flows across multiple bonded upstream channels can not be performed manually by an operator and will require advanced spectrum management to make sure proper flows are assigned to physical channels capable of meeting quality of service requirements. With that stated, it is vitally important that the fundamental building blocks for a more detailed analysis that will be required for the future DOCSIS 3.0 be first proved out in all DOCSIS 2.0 services for the cable operators today.

LINEAR IMPAIRMENTS

Linear impairments refer to a class of impairments that are signal-dependent and largely unique to a given responding CM because its transmission path through the return path network possesses its own micro-reflection (impedance mismatch). Moreover, the number of amplifiers in cascade also impact the amount of amplitude distortion and group delay (phase) distortion that a CM signal will be impacted by, that is to say the more amplifiers in cascade the more diplex filters the CM signal must traverse. This simply means that the effects of a linear impairment can only be observed while in the presence of a signal. The signal required for evaluation of linear impairments can either be very expensive test equipment, or the cable operator can simply opt to use a very inexpensive DOCSIS CM as the source and a spare receiver architected into a CMTS access module as the measurement tool.

In the end, when it comes down to convenience, speed of measurement, and cost, there can be little question that the combination of a DOCSIS CM and DOCSIS CMTS is the most effective characterization tool available to the cable operator. Obviously, the measurement accuracy of a system using a DOCSIS CM and DOCSIS CMTS is considerably less than using a Vector Signal Generator (VSG) such as the Agilent E-4438C or Arbitrary Waveform Generator (AWG) such as the Agilent E5182A and a Vector Signal Analyzer (VSA) such as the Agilent 89640A, 89650S or N9020A or a second generation CATV Analyzer such as the Sunrise Telecom AT-2500RQ, but the speed of the DOCSIS CM/DOCSIS CMTS system more than makes up for the accuracy limitations. Consider the fact that the CM is already installed in the network and that even a detailed DOCSIS 2.0 CMTS – CM measurement takes less than 100 ms and a less detailed measurement takes less than 5 ms. The CATV engineer using any one of the devices mentioned above will have an average measurement time of no less than 10 seconds for a less detailed measurement and the measurement time can easily be over three minutes for a detailed analysis. Obviously, one isn't even discussing the time for a CATV technician to get to a remote site location and connect the VSG or AWG to the CATV network.

If a cable operator wants a definitive linear characterization of a return node cascade of amps and the optical link, then nothing substitutes for setting the entire circuit in a lab environment and using a classic RF network analyzer such as the Agilent 8753ES (75 Ohm network analyzer) to report the definitive amplitude and group delay response from 2 MHz to 52 MHz. Alternatively the VSG/VSA combination is actually more useful in that one can not only receive a detailed report regarding the amplitude and group delay distortion, but one can also receive a report regarding the definitive MER versus the carrier frequency as well. With lab characterization accuracies set aside, the realities of characterizing a live CATV node in the field poses a variety of issues that lab equipment simply cannot deal with such as:

- Physical distance
- Ingress noise
- Impulse noise
- Live traffic
- Time Synchronization

Therefore, the DOCSIS CM and DOCSIS CMTS system offers the cable operator the only characterization technique that is both non-disruptive to customer traffic and extremely convenient both from availability and from a time to measurement perspective.

It is also important for the cable operator to understand why until recently, linear impairments have not been a concern. This is due to the fact that QPSK modulation has no amplitude modulation associated with it, and it is fairly immune to linear distortion affects. This is fundamentally due to the typical micro-reflection tending to be in the 15 dB to 25 dB range and given that QPSK needs only an MER > 14 dB to be perfectly acceptable from a performance perspective, one can easily see why this linear impairment has not been a show stopper for QPSK modulation. Another more important point regarding all linear impairments is that the impact on MER performance is also a function of DOCSIS channel bandwidth.

That is to say the significance of a micro-reflection or even the effects of multiple diplex filters has a dramatically larger impact on a channel bandwidth of 3.2 MHz than it ever did for the older 1.6 MHz bandwidth services. One can then understand that linear impairments are a major impact on the wider DOCSIS 2.0 channel bandwidth of 6.4 MHz. This is the primary reason why the DOCSIS 2.0 Equalizer was increased from 8 taps to 24 taps in length. As a result, linear impairments have only recently generated attention as more and more operators have moved to a 3.2 MHz bandwidth first and are now moving to 16QAM modulation, which with the combination of wider bandwidth and 16-QAM modulation is more susceptible to these affects. As operators seek to enable more advanced modulations of 32QAM and 64QAM provided by DOCSIS 2.0 and utilize the widest channel bandwidth available of 6.4 MHz, these impairments will become even more critical.

As far as the HFC plant is concerned, linear impairments generally fall into one of three classes:

- Micro-reflections – impedance mismatches
- Amplitude and group delay distortion – diplex filters
- Amplitude tilt or slope – coaxial cable

NON-LINEAR IMPAIRMENTS

As in the case of linear impairments, system non-linearity is also a signal-dependent distortion. Moreover, while linear impairments such as micro-reflections and diplex filter effects can be observed in the way the noise floor is shaped; there is by definition no system non-linearity without the presence of the signal. In essence, if there is no signal there is no system non-linearity occurring. More importantly, the impact on a DOCSIS signal that a system non-linearity presents is also a function of the level of QAM that is being transmitted. Simply stated, since system non-linearity is signal dependent, then it also holds true that the larger the signal power the more severe the system non-linearity impacts the DOCSIS signal.

Traditionally, most users rely almost entirely on MER to understand channel quality and predict performance under various configurations. Because of the fact that non-linearities impact higher levels of QAM more so than lower levels, an operator must be careful when interpreting the MER (SNR) of a communications signal at say QPSK so as not to quickly extrapolate the capabilities of that channel to support higher levels of QAM.

Given that system non-linearity has a much greater impact on a higher power signal, it also follows that system non-linearity impacts the outer points of the transmitted signal constellation more than the inner points of the same transmitted constellation. This is fundamentally due to the fact that the outer points are transmitted at a significantly higher power than the inner points and thereby are impacted significantly more than the inner points. This, too, implies that an operator must be careful when interpreting the meaning of MER values reported for a communications channel.

For example, if a communications channel is configured to transmit 64QAM in a nearly perfect communications channel except for non-linearity, then all but the outer corner points of the constellation will be nearly perfect. However, depending upon the degree of non-linearity, the outer points may be so corrupted that they are compressed to a point of being non-distinguishable from inner points; that is, a very high error rate may still result. For example, if this non-linearity only impacts the 3 outer constellation points at each corner, then only 12 points (3 in each of the 4 corners) of the total 64 are impacted. The impact on MER is 12/64 or 19%, which implies that it will have only a minimal impact on the reported MER.

There is a significant difference in impact to a DOCSIS transmitted constellation when it is subjected to a 2nd Order Inter-modulation Distortion (IMD)—commonly referred to in the CATV Industry as Composite Second Order (CSO)—versus a 3rd Order IMD Distortion—commonly referred to as Composite Triple Beat (CTB). It is in fact the 3rd Order IMD Distortion that is far more damaging to the DOCSIS transmitted constellation since it impacts the outer points more significantly than the inner constellations, while 2^{nd} Order IMD tends to impact all of the constellation points evenly.

The system non-linearity that we have been referring to is created by two completely different circuit areas of the CATV Network. Common Path Distortion (CPD) is the result of dissimilar metals acting as a diode and exhibiting both 2nd and 3rd Order Distortion that occurs on the coaxial cable path that is common to both forward and return path directions.

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 spaced 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 or second-generation CATV analyzers with a DEMO function and a known reference signal installed on the network.

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

AUTOMATING LOGICAL CHANNEL CONFIGURATIONS

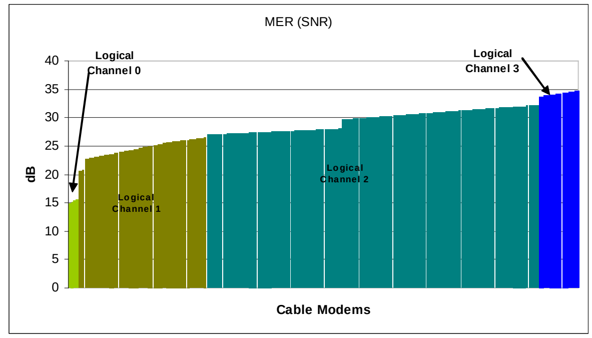
Logical channels allow cable operators to realize higher upstream bandwidth capacity per port by enabling different modulation profiles on a single port.

Proactive configuration tools are required so that cable operators can implement proactive maintenance strategies that enable automated decision making by providing actionable data.

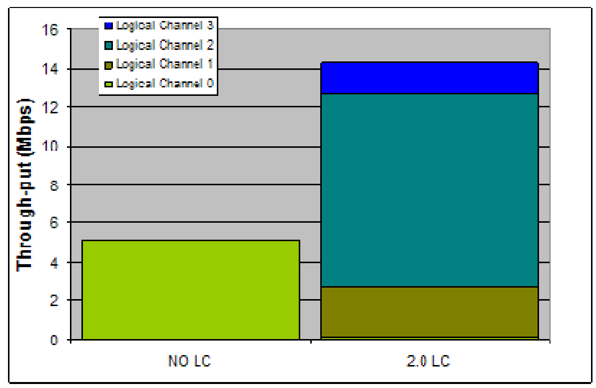
Much of the necessary data required to increase bandwidth and perform plant maintenance is captured in the CMTS; however, automated configuration management tools are needed so that cable operators can proactively allow automated decision-making that configures CMs for maximum performance based on rules and policies determined by the cable operator.

Now that we have quantified the improvements that can be realized using logical channels, we now turn to the issue of automated configuration. That is, how does an operator easily identify what logical channel configurations to define and which modems should be assigned to each logical channel. A software tool which supports the collection and sorting of various CM performance statistics is necessary.

DOCSIS 2.0 introduced requirements for a multitude of new performance statistics that are unique to each modem within the plant. Specifically, per modem statistics were added for MER, micro-reflections, and FEC statistics. The number of statistics in combination with the hundreds of thousands of modems makes for a large and complex data-mining problem that can not be solved manually by a human operator. By extracting these modem statistics, a tool could allow the operator to sort and analyze the distribution of modems on the plant and their associated performance measures. The following figure provides an example of a sample distribution. This distribution could then be used to isolate groupings of CMs with similar characteristics, and logical channels meeting the needs of each grouping could then be created.



This management tool could then be used to predict the throughput performance of a new configuration, illustrated in the following figure.

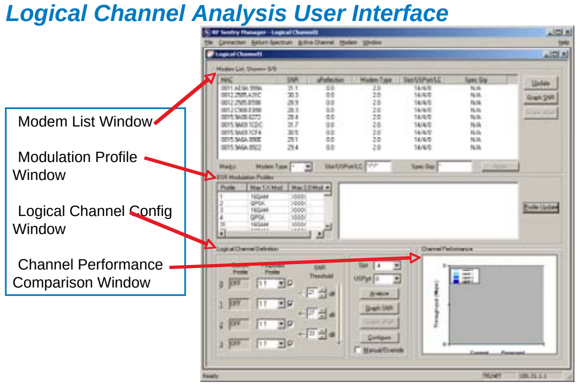


Logical channels offer huge opportunities to reclaim throughput efficiencies on the upstream. While the magnitude of improvement is dependent upon the characteristics of the cable plant, these significant benefits are even available to plant environments which are dominated by 1.0 CMs. The key roadblock to leveraging this technology is the need for automated tools that facilitate the cumbersome task of assigning each individual modem to the appropriate logical channel. However, as the benefits of this capability are realized within the industry, we fully expect vendors to begin offering tools to automate such a process.

Configuration management tools can serve as GUI-based front-ends for CMTS platforms, and they can leverage the insights gained from advanced spectrum management to automate the configuration of CMs to maximize performance.

Operations personnel could then benefit from a logical channel analysis user interface that graphically presents the salient performance information necessary for configuring logical channel operations.

Logical Channel Analysis User Interface



They will be able to easily analyze logical channels and monitor the automated configuration of logical channels. Graphing capabilities allow operators to quickly identify problem CMs and the corresponding percentage of the total modem population impacted. Operations personnel will be able to review summary update of CM profiles while gaining the flexibility to drill down into detailed windows that present full modulation profiling information.

Analysis features provide a graphical presentation of the total channel capacity for both the current profile configuration and the proposed profile configuration. Cable operators can allow the configuration manager to automatically initate reconfigurations of profiles and move modems to logical channels while retaining the option to manually accept or reject reconfigurations.

This powerful management tool therefore provides cable operators with the ability to automate configuration of CMs to maximize performance as well as the option to only allow the system to reconfigure CMs after an operator has manually accepted the reconfiguration recommendations.

SUMMARY

DOCSIS 2.0 support for logical channels allows cable to provide significant amounts of increased upstream bandwidth. Operators can quickly deliver increased upstream performance to HFC networks consisting of mixed mode DOCSIS 1.x and 2.0 cable modems as well as for new networks consisting entirely of DOCSIS 2.0 cable modems.

Cable operators can implement logical channels in both mixed-mode and pure DOCSIS 2.0 environments and they can concurrently deploy advanced spectrum management to utilize a spare receiver to non-obtrusively measure spectrum impairments, predict the dominant impairment in any area of the spectrum by analyzing signal-to-noise measurements, and qualify any area of the return path spectrum so they can achieve the maximum data signaling rate for logical channels.

They can leverage logical channels and advanced spectrum management to increase the aggregate bandwidth. Automatic logical channel configuration complements and adds value to advanced spectrum management, and it allows cable operators to successfully optimize the highest throughput of a given channel and better support the QoS demands of real-time services such as voice and video.