DOCSIS 2.0: Upping Upstream Performance in Cable Modem Designs

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Additives in cable modem specifications and designs have led to a sophisticated communication system that provides differentiated services, enabling cable operators to offer voice, high-speed data, and video services to their residential as well as business subscribers. While previous cable modem specifications, DOCSIS 1.0 and 1.1, went a long way towards improving the opportunities for cable operators to bring new revenue-generating services online, some significant challenges still remain primarily surrounding the lack of available bandwidth in the return (also referred to as "upstream") channel.

These challenges have been addressed by the industry in DOCSIS 2.0, the latest version of the cable data specification, which enables symmetric upstream and downstream bandwidth by taking advantage of advanced physical layer (PHY) technologies.

Increasing Upstream Bandwidth
Cable operators around the globe have invested billions of dollars in physical network upgrades so they could offer customers two-way high-speed data services. During the initial deployments of cable modem service, the ratio of downstream to upstream traffic was as high as 35:1. Today, bandwidth needs are changing dramatically. In fact, cable operators are now observing downstream to upstream traffic ratios rapidly approaching 2:1.

This is due in large part to a dramatic change in the average subscriber's use of the Internet. Email sizes have ballooned as people increasingly send photos, video clips, and sound files. Peer-to-peer file sharing, popularized by Napster, is consuming upstream bandwidth as subscribers swap multi-megabyte files over the Internet. Add the increased use of residential personal Web servers, and upstream traffic could soon rival that of downstream. As a result, operators must begin exploring ways to increase their upstream capacity.

Further increasing the need for bandwidth, truly symmetric (1:1) services, such as cable telephony and videoconferencing, are poised on the horizon. As a result, the need for increased upstream bandwidth capacity is considerable.

One way to increase upstream capacity is to enable more upstream channels. In fact, many cable modem termination system (CMTS) platforms now support 8:1 or even 12:1 ratios of upstream to downstream channels, in an effort to boost upstream data rates. This is a short-term and inefficient solution, however, because the number of additional upstream channels is restricted due to the
limited availability and usability of the upstream spectrum. In addition, the parceling out of the upstream spectrum into numerous small channels is an inefficient use of the available bandwidth, especially when compared to deploying wider channels and taking advantage of the improved statistical multiplexing presented by a larger aggregated pool of subscribers.

Another approach being used by cable operators is node splitting — or segmenting the cable plant into smaller node sizes to reduce the number of users sharing the same upstream and/or downstream bandwidth. Unfortunately, this approach is very costly and still does not address the issue of bandwidth utilization efficiency.

Perhaps the most efficient and cost-effective approach is to continue using the existing cable transmission infrastructure, but to increase the bandwidth capacity of each upstream channel. This capacity increase can be gained in two ways: by increasing the amount of information transmitted per symbol through utilizing higher orders of modulation, and/or by increasing the effective channel width through increasing the number of symbols transmitted per unit time.

As an example, many field deployments of DOCSIS 1.0 systems use quadrature phase-shift keying (QPSK) modulation across a 1.6-MHz channel, which in turn yields 2.56 Mbps throughput (2 bits/symbol x 1.28 Msymbols/sec).

The second generation of the DOCSIS specification, DOCSIS 1.1, took a step to improve the upstream bandwidth by standardizing an upstream channel pre-equalization scheme. This scheme allowed for practical deployments to support the largest channel width and highest order of modulation originally described by the DOCSIS 1.0 specification. As a result, deployments of DOCSIS 1.1 can utilize 16-level quadrature amplitude modulation (16-QAM) across a 3.2 MHz channel, increasing the upstream throughput by a factor of four (4 bits/symbol x 2.56 Msymbols/sec).

Nevertheless, DOCSIS downstream channels in North America operate at information rates of either 27 or 38.8 Mbps and in Europe and Asia at 38.4 or 51.3 Mbps. So, even when operating at the maximum theoretical capacity, a DOCSIS 1.1 upstream channel still provides at most around one-third of the downstream bandwidth. In order to achieve near symmetrical or true symmetrical service, even wider channels and higher orders of modulation need to be employed.

DOCSIS 2.0 triples the maximum upstream capacity of DOCSIS 1.1, raising the upstream throughput to 30.72 Mbps by using 64 QAM or 128 QAM trellis-coded modulation (TCM) over a 6.4-MHz channel (Figure 1).

Click here for Figure 1

Figure 1: Comparison of the upstream modulation techniques employed in DOCSIS systems.

Reducing the Effect of Noise
Whether enabling an increase in overall channel capacity or allowing more modems to use existing cable deployments, improved noise-prevention techniques can unlock available bandwidth on a cable
There are numerous types of noise interference that may affect the quality of transmission via a cable network. Some noise on the channel affects the maximum amount of steady-state throughput while other types of noise can be more sporadic in nature, thus disrupting the ability to deliver high-quality advanced services such as telephony and videoconferencing. As an example, while sporadic noise is a significant problem for best effort data transmission (lost packets must be retransmitted), real-time applications are so susceptible to the degraded quality presented by noise that often times these services cannot be supported since the quality of service cannot be guaranteed.

Prior to DOCSIS 2.0, methods for suppressing noise ranged from installing upstream filters at each residence to segmenting the plant into smaller node sizes, but these approaches are labor intensive and costly for the cable operator. DOCSIS 2.0 not only specifies a higher maximum throughput per upstream channel, it also specifies enhanced noise combating techniques to ensure the optimal utilization of the channel.

The primary sources of noise and interference experienced on a cable plant can be grouped into the following categories: microreflections, ingress noise and common path distortion, impulse noise, and additive white Gaussian noise (AWGN).

To address microreflections and their increased impact on higher ordered modulation transmissions, DOCSIS 2.0-compliant transmit equalizers incorporate 24 T-spaced taps. This represents an excellent tradeoff by providing adequate channel predistortion to compensate for the channel characteristics while keeping the implementation size and complexity reasonable.

To address ingress noise and common path distortion, the upstream CMTS receivers employ ingress cancellation techniques. While the requirements in the DOCSIS 2.0 specification surrounding ingress cancellation have been left as an opportunity for vendors to provide product differentiation, all silicon implementations of CMTS receiver chips are expected to be capable of canceling multiple narrowband ingress noise sources. Common techniques range from providing adaptive notch filtering in the frequency band surrounding the interference to providing predictive equalization across both the time and frequency domains to track out the modulated interference.

A third major category of noise sources on cable plants is impulse noise, also referred to as burst noise. To combat the effects of this source of noise, DOCSIS 2.0 has specified an increase in the strength of the Reed-Solomon forward error correction (RS FEC) scheme used in a cable modem by extending its blocking size to T=16 and incorporating byte interleaving. While this does represent an improvement, the DOCSIS 2.0 specification also makes an unprecedented leap forward by incorporating an entirely different modulation scheme known as synchronous Code Division Multiple Access (S-CDMA).

**S-CDMA Uncovered**

In its most basic sense, S-CDMA is a synchronous form of direct-sequence, spread-spectrum (DSSS) access protocol in which each transmitted data symbol is multiplied by a "chip" sequence so that the signal can be spread over a longer time span and a wider band of spectrum (Figure 2). The process is reversed at the receiver, using a unique code in order to retrieve the original signal.
DSSS was originally developed in an effort to reduce the impact of noise and to enhance the security of transmissions. When applied to multiple data streams transmitted simultaneously, DSSS is called CDMA because it allows multiple users to share a common spectrum. Through the use of synchronous clocking at the CMTS and across all the modems in the system, the efficiency of the CDMA system is drastically improved and the complexity of the CMTS receivers is reduced.

As symbol rates increase and higher orders of modulation are employed, bursts are transmitted over a shorter period of time relative to those in the previous DOCSIS systems. While short burst durations improve the overall throughput of the plant, the transmitted bursts are more susceptible to being corrupted beyond recovery by an impulse noise event.

An important property of S-CDMA is that it simultaneously spreads packets from multiple sources over time and frequency, which extends the effective time duration of each individual burst while retaining the higher throughput of the overall system. This allows the impulse event to impact only a portion of multiple simultaneously transmitted bursts. The impacted portion of each burst can then be corrected by underlying FEC.

Using S-CDMA can provide far greater resistance to impulse noise, allowing for sustained communication in environments where a DOCSIS time-division multiple access (TDMA)-based system simply cannot operate. This property is particularly important when considering the deployment of voice-over-IP (VoIP) telephony systems where the voice packets are predominantly short in length and have strict quality of service requirements.

**Dealing with AWGN**
The fourth major category of noise present on cable plants is AWGN. Combating AWGN allows the cable plant operator to retain or even reverse the level of node splitting by allowing a higher level of combined noise floor on the system.

DOCSIS 2.0 incorporates multiple techniques to reduce the effects of AWGN. In addition to the improvement in the Reed Solomon FEC, DOCSIS 2.0 specifies an overall lower implementation loss in the data path, which reduces the self-generated noise contributions from the modems and can result in a lower overall noise floor for the cable plant.

Another significant change in DOCSIS 2.0 is the incorporation of trellis coded modulation (TCM) for the upstream PHY. Upstream TCM FEC is available only in the S-CDMA modulation mode of DOCSIS 2.0 and will have a dramatic impact in reducing the affects of AWGN.

Primarily for implementation complexity concerns, the specification indicates that TCM FEC support by the CMTS receiver is optional. Nevertheless, it will surely be a differentiating feature among CMTS silicon manufacturers since deploying DOCSIS 2.0 systems with TCM typically allows systems to operate at equivalent performance levels in the face of twice the amount of AWGN noise than
those without TCM.

**Migration Considerations**
Regardless of its impressive benefits, any significant cost involved in an upgrade to DOCSIS 2.0 would prove to be a major concern for cable service operators already heavily invested in recent cable plant upgrades. Fortunately, DOCSIS 2.0 does not require a plant upgrade and is both compatible and can coexist with incumbent DOCSIS 1.0 and 1.1 cable data equipment.

To ensure compatibility between different versions of DOCSIS equipment, a DOCSIS 2.0 CMTS will recognize DOCSIS 1.x modems and allow them to operate at their maximum capability current 1.x mode along side DOCSIS 2.0 modems (Figure 3). In addition, DOCSIS 2.0 modems will register and respond as a DOCSIS 1.x modem when talking with a DOCSIS 1.x CMTS. This will allow operators to deploy DOCSIS 2.0-ready modems right away and upgrade their CMTS headends to DOCSIS 2.0 independently.

![Compatibility Diagram](image)

**Figure 3:** To achieve compatibility, DOCSIS 2.0 modems will recognize DOCSIS 1.x modems.

The new specification was also designed so that a single 2.0 physical channel can simultaneously support modems in any combination of DOCSIS 1.x, A-TDMA, and/or S-CDMA modes of DOCSIS 2.0 (Figure 4). The benefits of allowing DOCSIS 2.0 modems to co-exist on the same RF as DOCSIS 1.x modems are tremendous since it allows operators flexibility in how they roll out new DOCSIS 2.0 equipment.
The benefits for deploying a DOCSIS 2.0 CMTS will be apparent immediately, even for a system with a mixture of DOCSIS 1.x and 2.0 modems. For instance, the overall throughput of the system will be increased because transmissions from DOCSIS 2.0 users will spend less time on the channel as compared to those using a DOCSIS 1.x modem for the same amount of transmitted data. This will provide the remaining DOCSIS 1.x modems with more available bandwidth for their transmissions. In addition, the improved PHY of the DOCSIS 2.0 CMTS and modems will allow a higher percentage of homes to be reached with two-way data services.

**About the Author**

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