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# TECHNICAL BACKGROUNDER: DOCSIS 2.0 AND UPSTREAM AMPLIFIER REQUIREMENTS

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CableLabs® new Data-Over-Cable System Interface Specification (DOCSIS) 2.0 adds increased upstream capacity to hybrid fiber-coax networks through the use of higher-order modulation techniques. While these advanced techniques permit the transmission of more data within existing return path spectrum, they also demand higher signal-to-noise and signal-to-distortion ratios than were required under DOCSIS 1.0 and 1.1. This Technical Backgrounder explains the DOCSIS 2.0 specification and explores how DOCSIS 2.0 impacts the requirements placed on upstream amplifiers.

### THE MOTIVATION FOR DOCSIS 2.0

In a modern CATV network, between 700 and 800 MHz of bandwidth, is generally available for downstream transmissions from the headend to the subscriber, while less than 40 MHz is generally available for the return path – an 18:1 imbalance. This asymmetry had not been a concern due to the prevailing web-browsing model of Internet traffic, where upstream traffic was largely limited to upstream http requests for additional HTML or multimedia content. As a result, early proprietary cable modem systems and the initial DOCSIS releases called for spectrally efficient modulation schemes in the downstream path and relatively low-rate, but robust, schemes in the upstream.

Recent trends suggest that data traffic over HFC networks is becoming more symmetric as users demand more upstream bandwidth. Demand for upstream capacity is coming from wider deployment of truly symmetric services such as videoconferencing and cable telephony, from increased transmission of large multimedia files such as photos and video clips, and from peer-to-peer applications such as gnutella.

While measures such as tiered pricing may limit elastic demand to some extent, operators must almost certainly continue to increase return path capacity in response to the new use model.

Some of the upstream capacity shortfall may be made up by deeper fiber architectures that segment fewer households per optical transition node, but the capacity of individual upstream RF channels is likely to remain an issue. In order to transmit more bits per second in a given bandwidth in MHz, more spectrally efficient modulation types must be used. While DOCSIS 1.0 and 1.1 specified highly efficient 64QAM and 256QAM in the downstream, upstream modulation using QPSK and 16QAM was 1.5 to 4 times less efficient (see Table 1 on next page).

**TABLE 1: FUNDAMENTAL SPECTRAL EFFICIENCIES OF DOCSIS 1.0/1.1**

| MODULATION | DIRECTION | SPECTRAL EFFICIENCY |
|---|---|---|
| 256QAM | Downstream | 8 b/s/Hz |
| 64QAM | Downstream | 6 b/s/Hz |
| 16QAM | Upstream | 4 b/s/Hz |
| QPSK | Upstream | 2 b/s/Hz |

### THE DOCSIS 2.0 UPSTREAM

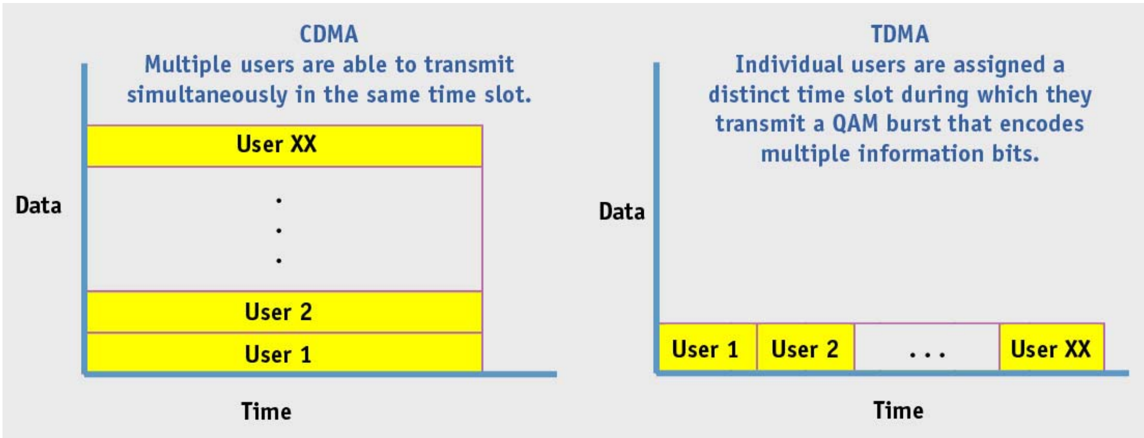
The DOCSIS 2.0 specification provides for both more efficient modulation techniques and increased RF channel bandwidth in the return path under two different allowed multi-access protocols – a time division multi-access (TDMA) protocol and a synchronous code division multi-access (S-CDMA) protocol. Under the DOCSIS 2.0 TDMA protocol, the maximum allowed RF channel bandwidth is increased from 3.2 to 6.4 MHz and three new higher-order modulation techniques are specified: 8QAM, 32QAM, and 64QAM. As a result, the maximum raw data rate is increased from 10.24 Mbps in the case of DOCSIS 1.0/1.1 (16QAM in 3.2 MHz) to 30.72 Mbps (64QAM in 6.4 MHz) (see Table 2 below).

**TABLE 2: DOCSIS 2.0 TDMA MODULATION SCHEMES (NEW CONFIGURATIONS ITALICIZED)**

| MODULATION | BANDWIDTH (MHZ) | RAW DATA RATE (MBPS) |
|---|---|---|
| QPSK | 1.6 | 2.56 |
| 16QAM | 1.6 | 5.12 |
| QPSK | 3.2 | 5.12 |
| 16QAM | 3.2 | 10.24 |
| *32QAM* | *3.2* | *12.80* |
| *64QAM* | *3.2* | *15.36* |
| *16QAM* | *6.4* | *20.48* |
| *32QAM* | *6.4* | *25.60* |
| *64QAM* | *6.4* | *30.72* |

Under TDMA, individual channel users are assigned a distinct time slot during which they transmit a QAM burst that encodes multiple information bits. Under CDMA, the in-phase and quadrature (I and Q) components of each QAM symbol are first encoded into a stream of sub-bits, or 'chips'. Each user is assigned one or more distinct code chip sequences that are recognized by a matched correlator at the receiver that rejects all other users' code sequences. In this fashion, multiple users are able to transmit simultaneously in the same time slot (see Figure 1). The DOCSIS S-CDMA protocol is actually a time-division multiplexed CDMA that employs 128-chip spreading codes and mini-time slots spanning multiple CDMA symbols.

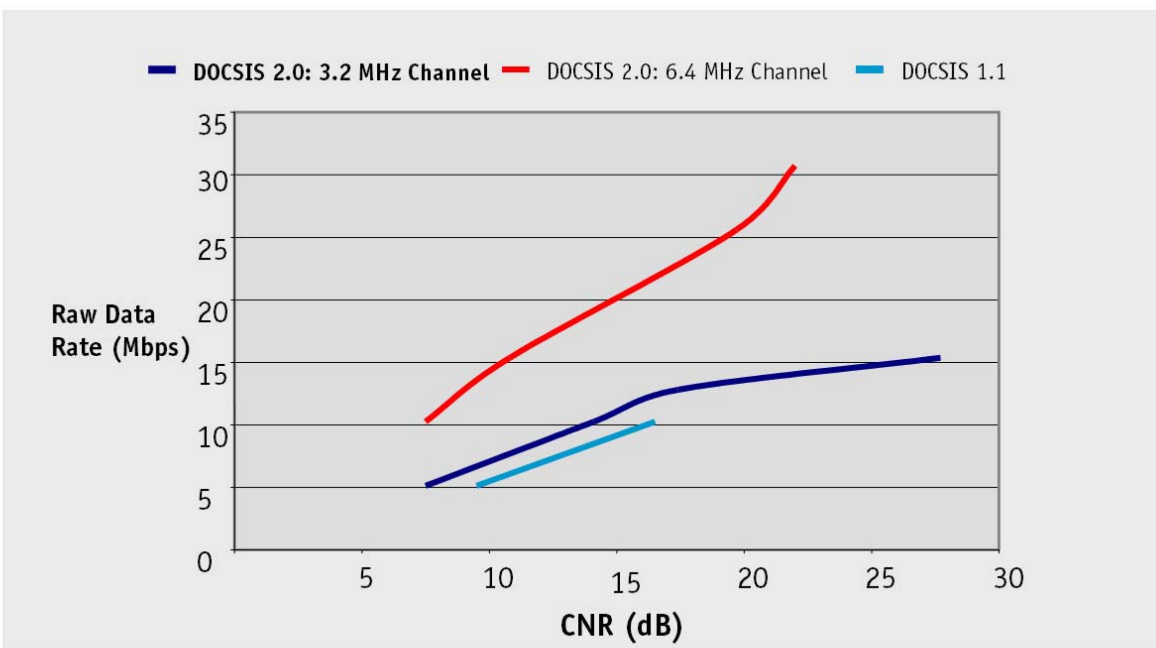
**FIGURE 1: TDMA AND CDMA**




**DOCSIS 2.0 UPSTREAM PERFORMANCE REQUIREMENTS**

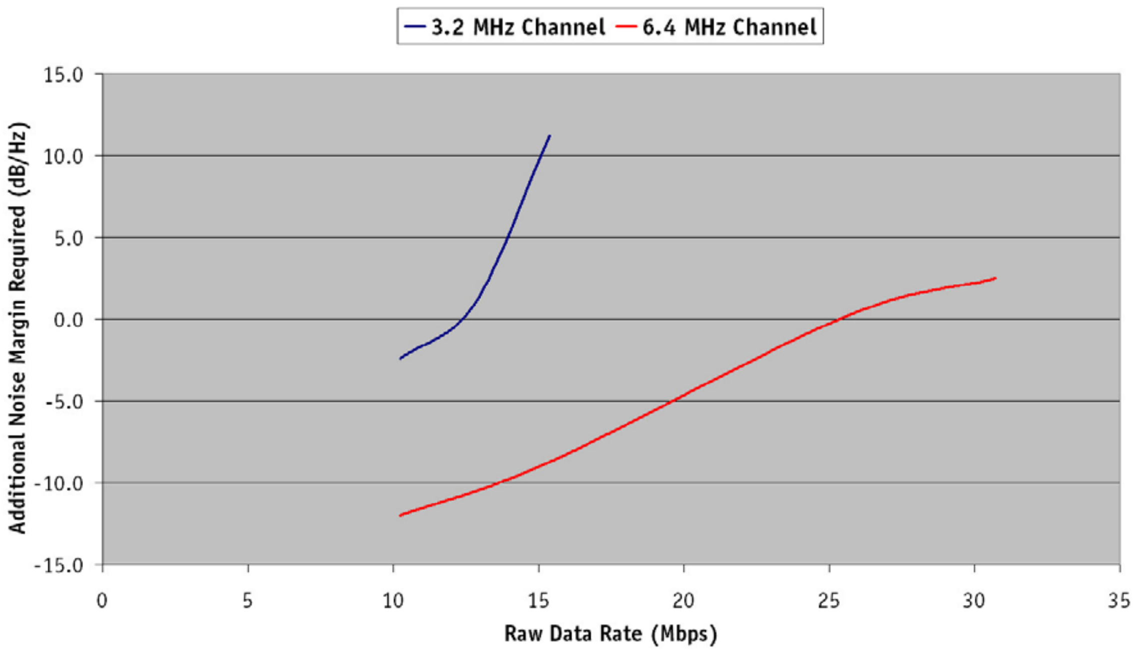
Although higher modulation orders lead to higher spectral efficiency – more bits per second per MHz – higher signal-to-noise ratios are required at the CMTS. Figure 2 illustrates the carrier-to-noise ratios required at the CMTS for DOCSIS 1.1 and DOCSIS 2.0.

**FIGURE 2: DOCSIS 1.1 AND 2.0 CARRIER-TO-NOISE REQUIREMENTS**




In the case of DOCSIS 2.0, the optimal modulation technique (TDMA or S-CDMA with and without Trellis code modulation) and order (4, 8, 16, 32, 64, 128QAM) is chosen for the given CNR. Depending on the channel bandwidth, the channel noise margin must improve by up to 11 dB in order to support the higher data rate modulations (see Figure 3 below).

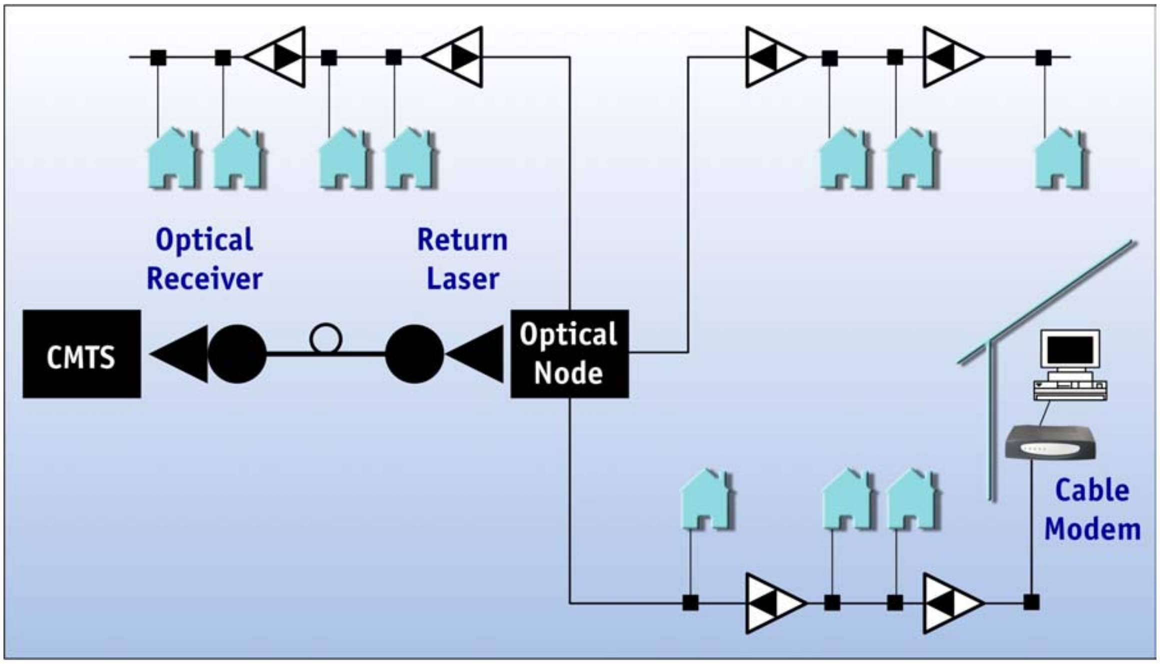
**FIGURE 3: REQUIRED NOISE MARGIN IMPROVEMENTS FOR HIGHER DATA RATES SUPPORTED BY DOCSIS 2.0 (RELATIVE TO NOISE MARGIN AT 10 MBPS UNDER DOCSIS 1.1)**




A typical HFC network path between cable modem and CMTS is shown in Figure 4 on the next page. Contributing to noise and interference at the input to the CMTS are:

- Thermal noise contributed by the cable modem upstream amplifier.
- Thermal noise contributed by distribution amplifiers and line extenders in the HFC network
- Relative intensity noise (RIN) contributed by the optical node return path laser
- Intermodulation distortion contributed by amplifiers and the return laser
- Shot noise and receiver noise within the optical detector at the headend
- Multireflections within the HFC plant
- Ingress and burst noise

FIGURE 4: TYPICAL HFC RETURN PATH




One important noise mechanism in HFC plants is noise funneling in the return path. Because inputs from multiple subscribers are combined at the fiber node, noise and ingress generated at each subscriber premises contributes to the overall C/I degradation at the input to the CMTS.

The DOCSIS radio frequency interface specification requires that the carrier-to-interference ratio – the ratio of signal to the sum of noise, distortion, and ingress – be no less than 25 dB at the input to the CMTS. In the past, operators have built in a relatively safe C/I margin in order to tolerate unpredictable impairments due to ingress and burst noise. Return path C/I end-of-line performance has generally been dominated by the performance of the optical node return path optical transmitter. For the last few years, the availability of relatively inexpensive uncooled distributed feedback (UDFB) lasers has allowed operators to maintain end-of-line C/I at around 40 dB – leaving a 15 dB margin for ingress and burst noise.

As Figure 3 shows, when DOCSIS 2.0 is deployed in the upstream of an existing HFC plant, ingress margins could be degraded to levels as low as 3-5 dB, depending on the RF channel bandwidth available. This means that very close attention must be paid to the modem and CMTS signal path design. The role of the cable modem upstream amplifier is particularly important, since noise from all cable modems attached to a particular node will funnel up through the node to the CMTS. Low output noise, high output level, and the ability to power down the amplifier when not transmitting are all key to controlling noise and distortion levels at the CMTS.

## IMPROVED UPSTREAM AMPLIFIER PERFORMANCE PROVIDES MORE MARGIN

The new DOCSIS 2.0 cable modem standard promises to increase data rates in the upstream path by 2-3 times. The new TDMA and S-CDMA modulation techniques used to achieve this improved performance, however, require higher carrier-to-noise and carrier-to-interference ratios to attain these higher data rates. Under the current 25 dB end-of-line DOCSIS carrier-to-interference spec and typical return laser performance, today's HFC plants have between 10 and 15 dB of margin for ingress and burst noise. The higher DOCSIS 2.0 CNR requirements for high data rate modulations could reduce this margin to between 3-5 dB. Improved upstream amplifier performance, such as that provided by Microtune's new MicroStreamer™ MT1560 Upstream Amplifier, within the DOCSIS 2.0 cable modem provides one means of recovering some of this margin.

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