An Experimental Study of the Return-Path Performance of a DOCSIS System

Thomas K. Fong, Ph.D.
@Home Network

Bill Kostka
Cable Television Laboratories, Inc

John Chen
Cisco Systems, Inc

Abstract

This paper investigates the return-path performance of a DOCSIS system (Cisco uBR7223) over an experimental two-way cable testbed. The packet error rate (PER), as well as the downstream and upstream TCP throughputs are studied as a function of upstream noise levels. For our DOCSIS upstream burst profile, the Carrier-to-Noise Ratio (CNR) threshold for one percent packet loss was found to be 11.5dB. The corresponding TCP throughputs for a cable modem with an upstream bandwidth of 1.6MHz were 4 Mbps downstream and 1Mbps upstream, respectively. We also evaluated the effectiveness of the forward-error correction code (Reed-Solomon) in recovering corrupted bits. With the maximum value of T (T=10), the upstream CNR requirement improved by 3 to 4dB.

1. Introduction

Cable modems have become one of the highest profile communication appliances in the race to provide high-speed residential broadband services. This is a result of the exponential growth of the Internet and the development of the interoperable Data Over Cable System Interface Specification (DOCSIS) [1].

Historically, the cable network was optimized for downstream analog video broadcast. Sending data reliably in the reverse or upstream direction through the hybrid fiber coax (HFC) cable network poses a challenge to many cable service providers. The condition of the return-path varies greatly from traditional cable networks to newly upgraded HFC plant [2]. Recognizing this fact, DOCSIS allows operators to choose system parameters for their upstream channels that are suitable for their cable plants.

In this paper, we investigate the impact of upstream additive noise on the packet performance of both the upstream and downstream directions over an experimental two-way testbed. We also study the tradeoffs in the best utilization of the precious upstream bandwidth and power resources in delivering different digital services in a reliable and cost-effective manner. To assist cable service providers in facing these choices, we present an example to demonstrate the ability to tradeoff channel capacity with signal requirements. In the examples, we demonstrate that by changing the forward error encoding, the packet performance can be improved at the cost of useful capacity.

The rest of this paper is organized as follows. Section 2 presents an overview of the DOCSIS standard. In section 3, we outline the measurement techniques utilized for the experiment. Section 4 shows the performance of a DOCSIS system for a particular DOCSIS upstream burst profile. In section 5, we illustrate the tradeoff between bandwidth efficiency and impairment robustness of the upstream channel by changing forward error encoding. Section 6 contains the conclusion.

2. The DOCSIS Standard

DOCSIS is a series of interface specifications that permit the design, development and deployment of data-over-cable systems on a uniform, open and multi-vendor interoperable basis. The intended service is to provide transparent bi-directional transfer of Internet Protocol (IP) traffic, between cable system headend and subscriber locations, over an all-coaxial or HFC cable network. For two-way cable systems, the DOCSIS RF specification defines the RF communications path over the HFC cable system between the cable modem, and the cable modem termination system (CMTS) [1]. This specification includes the physical layer, link layer (MAC and LLC), and network layer aspects of the communication interfaces. It also includes specifications for power level, frequency, modulation, coding, multiplexing, and contention control.

In the upstream direction, cable modems transmit signals in a predefined portion of the upstream passband that is between 5 and 42 MHz. The modulation format and type for upstream channels are specified by the CMTS. The CMTS broadcasts periodically the parameters and frequencies for the upstream transmission to all the cable modems.

Recognizing that the quality of the upstream spectrum varies greatly in different cable plants, DOCSIS provides error correction encoding and a wide range of modulation types and formats for cable service operators to choose. An important feature in the upstream burst profile is error correction. DOCSIS has selected Reed-Solomon (RS) codes for its error detection and correction schemes.

Upstream traffic is error-protected using RS coding. Upstream packets are inserted in RS forward error correction (FEC) block codes. Block coding adds redundant parity bytes, which are used to detect and correct errors. For an RS code using GF[1](256), the number of parity bytes added is 2*T, where T is the number of bytes to be corrected [3]. The length of codewords is programmable based on shortened codes over GF(256). For DOCSIS systems, the CMTS specifies the strength of the FEC to be used by cable modems for upstream transmission. The FEC scheme is defined by the length of the FEC codeword and the value of T in the range of T=0 (no FEC) to T=10.

The expected theoretical performance of a DOCSIS cable modem is studied in detail by one of the Cablelabs' technical papers [4]. The paper illustrates the tradeoffs between bandwidth efficiency and upstream impairment robustness for DOCSIS modems and many commercially available modems. In the following sections, the experimental performance of a DOCSIS system is presented.

3. Measurement Techniques

In this section, we describe the experimental setup and measurement procedures. Section 3.1 reviews the characteristics of the upstream impairment and the performance parameters being measured while in section 3.2, the details of the experimental setup is revealed. Section 3.3 discusses the impact of error encoding on upstream performance.

3.1 Impairment and Performance Measures

For upstream channels, white Gaussian noise is generated by random thermal noise from 75-ohm termination impedances. The white noise from all terminators in all the amplifiers in the cable system is funneled into the headend in the return channel. This funneling effect exacerbates and increases the noise as it propagates through more amplifiers and connections in the cable network toward the headend. This noise is carried through each return amplifier, which adds its own noise contribution to the headend. All distribution points have their own 75-ohm terminator, and hence each leg adds its own noise contribution to the return system. This influence of additive white Gaussian noise (AWGN) is usually characterized by the Carrier-to-Noise Ratio (CNR). In this study, AWGN is simulated using a broadband programmable noise generator and the CNR is measured using a spectrum analyzer.

Since DOCSIS emphasizes delivering IP connectivity to residential subscribers, we focus our study on the performance of IP data packets (both TCP and UDP). In our experiment, we measure the performance of the following parameters:

- Packet Error Rate (PER): the number of packets dropped due to noise corruption. A packet is dropped at the receiver if the receiver cannot correctly decode all the bits in the packet.

  The upstream PER affects all traffic (TCP, UDP and DOCSIS management messages) traveling in the upstream direction. Losses of data and management frames degrade the ability of modems to transmit and receive data. Modems will drop off from the CMTS under severe loss of management messages.

- Transmission control protocol (TCP) data transfer rate, in Megabits per second, for both downstream and upstream channels. TCP throughput directly reflects on the

[1] Galois field: codes are constructed from fields with a finite number of elements. A finite field with q elements is denoted by GF(q) [3].

user's experience for applications such as HTTP and FTP [5]. For upstream channels, upstream impairments cause corruption of data packets, and hence reduce the data throughput. On the other hand, the return-path impairment degrades the downstream data transfer by causing losses of TCP acknowledgement packets and DOCSIS management messages.

TCP reacts to packet losses due to noise corruption in the same way as it does during network congestion, i.e., it slows down the transmission even though the network is not overloaded. This results in a decrease in TCP's performance. Details of the behavior of TCP over lossy links are beyond the scope of this paper. More information can be found in a paper by Cohen and Ramanathan, which analyzed the performance of TCP under different network conditions using computer simulation and proposed many methods of tuning TCP parameters [6].

3.2 Experimental Setup

Figure 1 shows the block diagram of the experimental setup. The CMTS is a Cisco uBR7223 router with an MC16 line card running Cisco IOS® software version 12.0. The CM is a Cisco uBR904 residential access router running Cisco IOS® software version 11.3(6)NA.

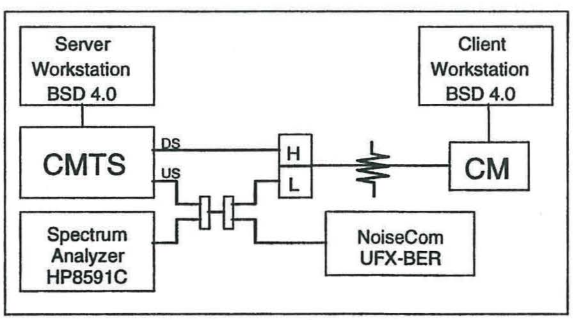

Figure 1: The Experimental Setup.

The Cisco uBR7223 series is a high-speed router with DOCSIS CMTS functionality. As a router, it has a 150K packet per second switching capacity and 600 Mbps backplane capacity. The main processor is a MIPS R4700 200-MHz CPU with 1MB of fast packet SRAM and 128 MB of DRAM. It connects to the server workstation via its 100BT interface. As a CMTS, the RF interfaces have an aggregate capacity of up to 80 Mbps in 2 downstream channels and a capacity of 120 Mbps in 12 upstream channels. The RF interfaces of a larger capacity router, the uBR7246 series, have an aggregate capacity of 160 Mbps in 4 downstream channels and 240 Mbps in 24 upstream channels. The uBR7200 series routers have passed CableLabs' CMTS qualification testing.

The Cisco uBR904 is a residential access router with a DOCSIS cable modem interface and an integrated 4-port Ethernet hub. The microcontroller is a 68EN360 33-MHz CPU with 8 MB of DRAM and 4 MB of flash memory. The flash memory is used to store remotely upgradeable firmware. The client workstation is connected to a port of its Ethernet hub.

The NoiseCom, Inc.'s programmable precision C/N generating instrument, UFX-BER acts as a broadband white noise generator. RF impairment is inserted in the upstream channel via a two-way RF combiner. CNR and power levels are measured using the spectrum analyzer following NCTA recommendations for upstream measurements [7].

In Table 1, the RF parameters for the downstream and upstream channels are shown. The center frequency for the downstream channel is 601.25MHz and 64-QAM modulation is selected. The downstream power and CNR is optimized so that the downstream RF channel is almost lossless. For the upstream channel, the center frequency is 31.184MHz. The upstream channel transmits at 1.28Mega-symbol/second and has a RF bandwidth of 1.6MHz. As shown in **Figure 1**, the downstream and upstream channels are separated with a 40/52 diplex filter.

Table 1: RF Channel Parameters

Downstream	
Center Frequency	601.25MHz
Modulation	64 QAM
Interleaving	I=32, J=4
Upstream	
Center Frequency	31.184MHz
Modulation	QPSK
Bandwidth	1.6MHz
Symbol Rate	1.28Mbps
Minislot Size	8 ticks

Two personal computers running Berkeley Software Distribution (BSD) UNIX 4.0 with 400MHz Pentium II processors and 64MB of

RAM are used as traffic source and sink. *Netperf* is used to generate and receive IP traffic. It is the de-facto standard for network performance measurement within the Internet community. *Netperf* can be used to measure various aspects of networking performance [8]. Its primary application is to measure bulk data transfer and request/response performance using either TCP or UDP.

After each test, *Netperf* reports the number of packets received and the data throughput. For UDP tests, it calculates the PER by dividing the number of packets lost by the number of packets transmitted while for TCP tests, it obtains the data transfer rate by measuring the number of bytes received over a fixed time interval.

In Table 2, the DOCSIS burst profile for this experiment is shown. It specifies the transmission formats for the different information elements (IE), including both control and data frames. Request is used by cable modems to initiate data transmission to the CMTS. Initial and Station Maintenance are management messages for maintaining communications between cable modems and the CMTS. Short and long data grants are used for carrying data packets. The distinction between them is the amount of data that can be transmitted in the grant. A short data grant uses FEC parameters that are appropriate to short packets while the FEC parameters of a long data grant takes advantage of greater FEC coding efficiency.

Table 2: Upstream Physical-Layer Burst Attributes.

Parameter	Configuration Settings	Request	Initial Maintenance	Station Maintenance	Short Data Grant	Long Data Grant
Modulation	QPSK, 16QAM	QPSK	QPSK	QPSK	QPSK	QPSK
Differential Encoding	On/Off	Off	Off	Off	Off	Off
Preamble Length	Up to 1024 bits	64	128	128	72	80
Preamble Offset	1024 config. settings	56	0	0	48	40
FEC Parity Bytes (T-bytes)	0 to 10	0	5	5	5	10
FEC Codeword Information Bytes (k)	1 to 255	16	34	34	78	235
Scrambler Seed	15 bits	338	338	338	338	338
Maximum Burst Size	0 to 255	1	0	0	7	0
Guard Time Size	5 to 255 symbols	8	48	48	8	8
Last Codeword Length	Fixed or shortened	Fixed	Fixed	Fixed	Fixed	Fixed
Scrambler On/Off	On/Off	On	On	On	On	On

Here is an explanation of the values in the burst profile:

- Modulation type is used to select between either two bits per modulation symbol (QPSK) or four bits per modulation symbol (16-QAM). QPSK carries information in the phase of the signal carrier only whereas 16-QAM uses both phase and amplitude to carry information. 16-QAM requires approximately 7dB higher CNR to achieve the same bit error rate (BER) as QPSK but it transfers information at two times the rate of QPSK. Only QPSK was used in this test.
- Differential Encoding is a technique wherein the information is transmitted by the phase change between two modulation symbols instead of by the absolute phase of a symbol. This technique makes the absolute phase of the received signal insignificant and has the effect of doubling the BER for the same CNR. Differential encoding is not required for the CMTS receiver used in this test so it is turned off.
- Preamble Length and Preamble Offset are used to define a synchronizing string of modulation symbols that is used to let the receiver find the phase and timing of the transmitted burst. A unique word in the

preamble is used to signify the start of the data portion in the burst.

- FEC Parity Bytes (T-bytes) is the number of bytes that the FEC decoder can correct within a codeword. A codeword consists of information bytes, called k-bytes and parity bytes for error correction. The number of parity bytes is equal to two times the number of correctable error (T). The size of T is dictated by channel impairments.
- FEC Codeword Information Bytes (k-bytes) for short data grant is set to 78 bytes to accommodate a minimum packet within one codeword. The minimum packet size = 64 bytes of Ethernet packet + 6 bytes of DOCSIS MAC header + up to 8 bytes of DOCSIS MAC Extended header (EHDR) typically used for baseline privacy. Information size (k-bytes) for a long data grant is set to the largest block size possible to minimize the number of FEC blocks needed to transmit a packet upstream. In more impaired upstream environments, the information size may be set to less than the largest possible block size to enable the parity bytes to act over a smaller number of information bytes and thus provide better data protection.
- Scrambler is used to create an almost random sequence of transmission symbols, which ensures an even spectral distribution of energy transmitted within the channel. The scrambler seed is an initial value that is used to start the pseudo-randomizer to "scramble" the bits. Because both the transmitter and receiver know the seed value, the scrambling can be reversed at the receiver leaving only the original data.
- Maximum Burst Size is only used to determine the breakpoint between packets that use the short data grant burst profile and packets that use the long data grant burst profile. If the required upstream time to transmit a packet is greater than this value then the long data grant burst profile is used. If the time is less than or equal to this value, then the short data grant burst profile is used.
- Guard Time is a blank time at the end of a burst transmission that exists to ensure that one burst ends before another burst starts.
- Last Codeword Length shortened enables an efficiency mode wherein all codewords except the last one are fixed in size. The last codeword may be shortened if there are not enough information bytes to fill it entirely. In a fixed operation, all codewords are the same size with the last codeword padded with nulls if there are not enough information bytes to fill it entirely. The efficiency is gained by not having to transmit the nulls that pad the last codeword.

In addition, a few MAC (media access control) layer parameters are fine-tuned so that the physical layer performance is measured accurately:

- Polling Interval: the CMTS grants a unicast Station Maintenance transmit opportunity to each cable modem, at least once every 30 seconds [1]. Each cable modem has a timer, the T4 timer, to keep track of time between station maintenance transmit opportunities. When the T4 timer expires, the cable modem is required to re-initialize its MAC layer. To reduce the effect of MAC re-initialization during a measurement, the CMTS is set to transmit a Station Maintenance message every second.
- SYNC and UCD Message Rate: Time Synchronization (SYNC) and Upstream Channel Descriptor (UCD) messages are broadcast downstream to all cable modems for initial upstream timing and frequency acquisition. We found that the rate of these messages does not affect the return-path performance measurement, and hence the vendor's default values were used for this experiment.
- Packet Transmission Rate: For the PER measurements, the source sends packets at a low transmission rate so that packet loss is caused by RF noise corruption and is not affected by other factors, such as buffer overflows and CPU workload, in the CMTS or CM.

Tables 3, 4 and 5 present the overhead in burst transmission for three frame sizes using the burst size described in Table 2. 64bytes is the minimum MAC frame size and indicates the performance of TCP acknowledgement, which is usually the dominant type of traffic in the upstream channel for a typical residential subscriber. The MAC frame sizes of 594 and 1518 bytes correspond to IP datagram sizes of

576 and 1500 bytes. These two sizes are commonly used for carrying Internet traffic.

Table 3 shows the forward error correction (FEC) overhead. For 64 byte MAC frames, a FEC T-bytes value of 5 is used. The value of T is increased to 10 for long grants to provide added protection for larger FEC blocks using 594 and 1518 byte MAC frame sizes. For short data grants, the transmission overhead is proportionally higher and the FEC scheme is less efficient for the same value of T. The Pre-FEC Bytes row includes the 6-byte DOCSIS Physical Media Dependent (PMD) header. If baseline privacy is enabled, this header increases to 11 bytes.

Table 3: Post-FEC Bytes, Upstream.

Frame Size, bytes	64	594	1518
Pre-FEC, bytes	70	600	1524
Grant Type	Short	Long	Long
No. FEC Blocks × FEC k bytes	1×78 = 78	3×235 = 704	7×235 = 1645
No. FEC Blocks ×2×FEC T bytes	1×2×5 = 10	3×2×10 = 60	7×2×10 = 140
Post-FEC, bytes	88	764	1785

Table 4 shows the overhead associated with the TDMA bandwidth allocation for a mini-slot size of 16 bytes. The overhead may be reduced by a smaller mini-slot size of 8 bytes. However, smaller mini-slots may require more processing workload for the CMTS. Each upstream transmission begins with a preamble pattern, followed by FEC blocks, and ends with a guard time interval. The last row lists the actual number of bytes occupied by an integral number of mini-slots.

Table 4: Mini-Slot Bytes, Upstream.

Preamble, bytes	9	10	10
Post-FEC, bytes	88	764	1785
Guard Time, bytes	2	2	2
Time-Slot, bytes	99	776	1797
Bytes/Mini-Slot × Mini-Slots	16×7 = 112	16×49 = 784	16×113 = 1808

Lastly, the channel overhead is computed by dividing the overhead bytes by the MAC frame size. It represents the percentage of overhead in transmission of a data packet. From Table 5, we can see that the channel overhead for transmitting short data packets in the upstream direction is very high. 112 bytes are needed for each TCP acknowledgement packet.

Table 5: Channel Overhead, Upstream.

Mini-Slot, bytes	112	784	1808
MAC Size, bytes	64	594	1518
Overhead, bytes	48	190	290
Channel Overhead	75%	32%	19%

3.3 The impact of FEC

DOCSIS provides the flexibility to modify the robustness of the upstream RF channels. Here are some techniques:

- increase the amount of error encoding (shorter codewords and larger values of T).
- decrease the upstream symbol rate to reduce the impact of burst noise. This reduces the relative duration of the burst noise.
- increase the size of the preamble to provide better bit synchronization.
- increase the amount of interpacket spacing.

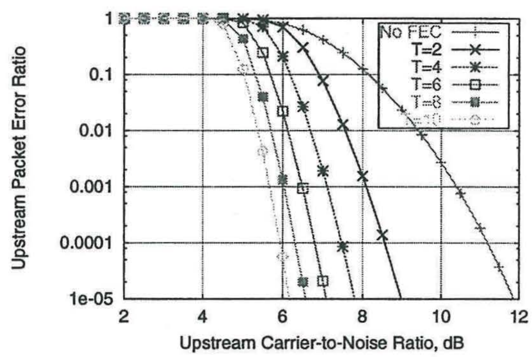

Figure 2: PER vs. CNR for DOCSIS QPSK with different values of T (packet size=46 bytes).

Figure 2 shows the theoretical PER performance for different T values. The different traces represent the range from no FEC to T=10. The maximum amount of FEC established in DOCSIS is T=10. From Figure 2, the coding gain at 1% PER is approximately 2dB for T=2 and 5dB for T=10. On the other hand, more parity bytes reduce the information rate. The traces begin to close together with higher values of T. Increasing the amount of FEC causes a rate of diminishing return. By using only T=2, about half of the possible coding gain is achieved. In Section 5, we illustrate the same relationship for a DOCSIS system in a laboratory setup.

4. Measurement Results

This section presents the measurements for the DOCSIS burst profile listed in Table 2.

4.1 Packet Error Rate

For the PER experiments, *Netperf* is configured to generate and receive UDP packets. The Packet Error Rate is obtained by dividing the number of packets lost by the total number of packets transmitted. Figure 3 shows the PER performance for packet size=46, 576 and 1500 bytes. The PER behavior for 576 byte packets and 1500 byte packets are very similar since they are both carried by the long data grant. The PER for 1500 byte packets is slightly higher than that for 576 byte packets as longer packets have higher probabilities of getting a bit error than shorter ones.

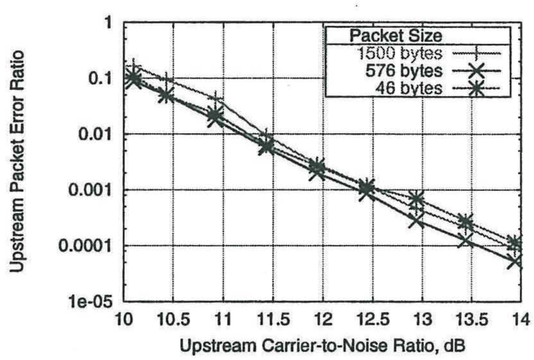

Figure 3: Packet Error Rate vs. Carrier-to-Noise Ratio for packet size=46, 576, 1500 bytes.

Note that the PER degrades very quickly as the CNR decreases (at about one decade per decibel of CNR). That means, a higher CNR margin is needed to ensure reliable data services against statistical fluctuations of CNR. For one percent packet loss, a CNR of about 11.5dB is needed.

The difference between the theoretical calculation in Figure 2 and the experimental measurement in Figure 3 is mainly due to the burst-mode characteristics of the upstream channel, the MAC layer overhead and other implementation losses. The theoretical curves are generated with the assumption that the bit synchronization for the upstream receiver is perfect and the MAC protocol does not incur any physical layer penalty.

4.2 TCP Throughput

For TCP tests, the source computer is configured to continuously send data over a fixed duration of time. The TCP throughput is obtained by dividing the number of bits received successfully at the receiver by the duration of the test. The TCP throughput is studied as a function of upstream CNR for different TCP window sizes.

4.2.1 Upstream TCP Performance: the impact of data packet loss

As seen in Figure 3, packet loss in the upstream channel increases as the noise level increases. Since TCP is a reliable data transport, the lost data packets are retransmitted using the TCP's sliding window protocol. Hence, an increase in the noise level reduces the downstream transfer rate.

Figure 4 shows the upstream TCP performance for different TCP window sizes (8, 16, 24, and 32Kbytes). We see that the TCP throughput starts to degrade when the CNR is less than 12.5dB. This means that PER of less than 0.1% does not penalize TCP performance.

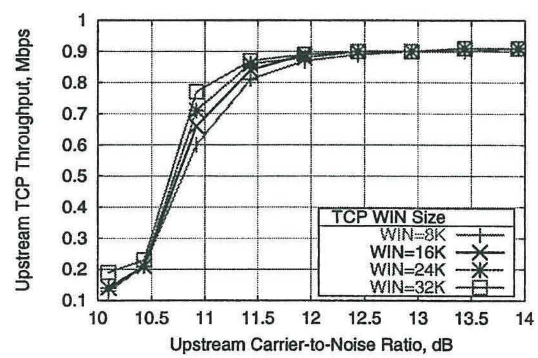

Figure 4: Upstream TCP throughput vs. US CNR for TCP window = 8, 16, 24, 32Kbytes.

As the PER increases above 0.1%, the TCP throughput degrades very quickly. At about 10% PER (CNR=10dB), the TCP throughput drops to less than 10% of its maximum value. Larger TCP window sizes do not improve the performance in a noticeable way.

4.2.2 Downstream TCP Performance: the impact of acknowledgement packet loss

For downstream TCP transfers, the upstream noise affects the performance in a completely different way as for the upstream data transfer in the previous section. Upstream noise causes loss in TCP acknowledgement packets. It reduces the downstream transfer by slowing down the growth of the TCP congestion window and causing TCP retransmission. In addition, it also affects the ability of cable modems to request bandwidth for transmission.

Figure 5 shows the downstream TCP performance for different TCP window sizes (8, 16, 32 and 64Kbytes). Since TCP uses positive acknowledgements, occasional loss of acknowledgement packets does not cause any penalty to TCP sessions with large TCP received window sizes. 3% degradation in throughput is observed for CNR=11.5dB (PER~1%) when the TCP window size is 16, 32 or 64 Kbytes. For small window size (8 Kbytes), the same loss rate causes 15% throughput degradation.

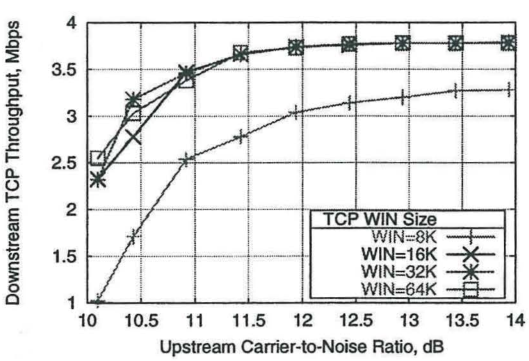

Figure 5: Downstream TCP throughput vs. US CNR for TCP window = 8, 16, 32, 64KBytes.

When the acknowledgement packet loss rate is greater than 1%, the TCP performance starts to degrade quickly. For 5% PER (CNR=10.5dB), the throughput is degraded by 50% for small TCP window sizes and 20% for large TCP window sizes.

5. Burst Profile Design Tradeoffs

This section evaluates the tradeoff between bandwidth efficiency and impairment robustness for upstream channels. The PER performance is measured for different values of T.

Figure 6 shows the PER curves for 1500 byte packets with T=0 (no FEC), T=2 and T=10. At one percent packet loss, the coding gains for T=2 and T=10 are 2dB and 4dB, respectively. As discussed in Section 3, half of the possible coding gain for DOCSIS is achieved using only T=2. Also, note that, the coding gain is higher for lower values of PER.

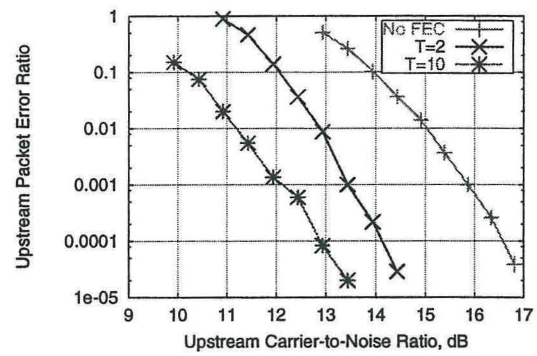

Figure 6: Packet Error Rate vs. CNR for different T values (packet size=1500bytes).

In Figure 7, the PER curves for TCP acknowledgement traffic (packet size=46bytes) is plotted for T=0 (no FEC), T=2 and T=10. The coding gains for T=2 and T=10 are 2dB and 3dB, respectively. Since short packets are less prone to packet loss than long ones, the FEC gain is also smaller.

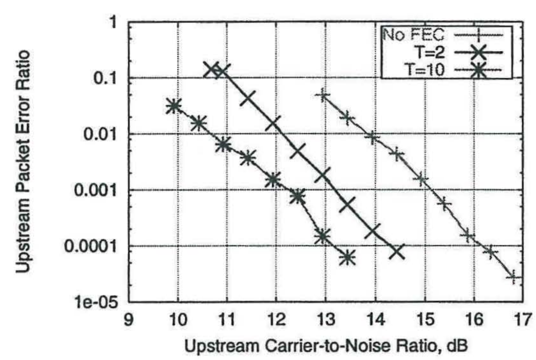

Figure 7: Packet Error Rate vs. CNR for different T values (packet size=46bytes).

Since DOCSIS provides two data grant types for carrying data packets, FEC parameters can be individually optimized for different packet sizes.

6. Conclusion

In this paper, we showed experimentally the impact of upstream additive white Gaussian noise (AWGN) on the packet error and TCP performance of a Cisco DOCSIS CMTS for different traffic types.

For the Cisco uBR7223, the upstream packet error rate (PER) decreases at approximately one decade per decibel of upstream carrier-to-noise ratio (CNR). The CNR requirement for one percent packet loss was found to be 11.5dB. It is possible to vary the signal requirement by changing the parameters in the upstream burst profile. This allows cable operators to tradeoff upstream robustness with data capacity. In this paper, we demonstrated the ability to modify the CNR performance by changing the FEC T values. For the Cisco uBR7223 using the maximum value of T specified by DOCSIS (T=10), the measured CNR improvement is about 4 dB. On the other hand, since PER degrades very quickly as CNR decreases, a higher CNR *safety* margin (at least 5dB) is needed to ensure reliable data services against fluctuations of power and noise levels.

Both the upstream and downstream TCP throughputs are dependent on the upstream CNR. For upstream TCP transfers, the throughput dropped 10% from the maximum transfer rate at CNR=11.5dB. At CNR=10dB, the upstream transfer rate fell to about 10% of the maximum value.

For downstream TCP transfers, the throughput is degraded by loss of TCP acknowledgement packets and DOCSIS management messages. Tuning the parameters of the TCP stack can reduce the impact of upstream noise on downstream TCP transfer. A larger TCP window results in a greater number of acknowledgement packets per transmission window. This reduces the probability of a timeout due to a loss of all the acknowledgement packets and thereby, increases the robustness of the TCP session to acknowledgement packet loss. In this paper, we illustrated that the throughput degradation at CNR=11.5dB is reduced from 50% (with 8Kbyte window) to 20% (with 16, 32 or 64Kbyte windows).

Using our DOCSIS upstream burst profile, the TCP throughputs at CNR=11.5dB for a computer connected to the cable modem system are 4Mbps downstream and 1Mbps upstream, respectively.

7. Acknowledgment

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