RF TO IP - THE TOP MOST COMMON DOCSIS KILLERS AND HOW TO IDENTIFY THEM

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SECTION 1: OVERVIEW

This paper will discuss the most common impairments in a DOCSIS® (Data-over-Cable Service Interface Specification) network and how to identify them. It will begin with the method by which cable operators provide data and voice services over a data network. This will start with DOCSIS and VoIP primers in order to provide a common foundation of terminology and understanding of the subject matter.

Once a foundation has been provided, the paper will focus on high level DOCSIS impairments and best practice methods for identifying them. The methods employed will utilize both conventional test equipment and Cable Modem Termination System (CMTS) Command Line Interface (CLI) to investigate modem and network diagnostics. This paper will demonstrate how the CMTS CLI and headend test equipment can be used in conjunction to minimize truck rolls, perform preventative maintenance and improve subscriber satisfaction.

SECTION 2: DOCSIS PRIMER

DOCSIS is effectively a transparent Ethernet bridge over a hybrid fiber/coax (HFC) network. There are two (2) functional components in a DOCSIS network, the cable modem (CM) on the subscriber side and the CMTS in the headend or hub site. The CMTS communicates with the CMs on a 6 MHz wide (8 MHz in Euro-DOCSIS deployments), 64- or 256-QAM (quadrature amplitude modulation) digitally encoded RF signal on the downstream path of an HFC network between 88 and 860 MHz. The CMs communicate with the CMTS using a quadrature phase shift keying (QPSK), 8-, 16-, 32-, or 64-QAM digitally encoded RF signal, also transmitted on an upstream HFC frequency between 5 to 42 MHz (5-65 MHz Euro-DOCSIS). The digital data, transported via digitally modulated carriers, contains Media Access Control (MAC) information which enables the CMs to coexist with other CMs by using a Time Division Multiple Access (TDMA) scheme [DOCSIS 2.0 also supports synchronous “spread spectrum” code division multiple access (S-CDMA)]. In essence, the CMTS is the system scheduler which coordinates the power level, frequency, transmit time, and pre-equalization of all CM signals on the DOCSIS network.

By virtue of the fact that CMs and the CMTS are able to communicate digital data with each other over the HFC network for the purpose of “command-and-control” processes, they are also able to transmit packets containing other non-DOCSIS MAC related data. This is what fundamentally facilitates the ability to send Ethernet traffic bi-directionally over an HFC network. The CMTS-CM DOCSIS network transports IP based traffic in the same method that is used to communicate MAC protocol between the devices. Now that the IP traffic can traverse the HFC network, end users are also able to utilize this network for the purpose of transmitting content destined for the multitude of available data network services such as email, web browsing, IP video, and voice over IP telephony (VoIP).

In summary, each user is assigned a unique cable modem, which conforms to the DOCSIS standard. The CMTS works as a system scheduler enabling many cable modems to reside on the same RF network. TDMA and/or S-CDMA is employed in cable modem communications so that each modem is allocated a certain finite time over which it may transmit and receive IP data. IP data destined for a particular user is sent to that user’s modem by the CMTS on a downstream RF channel. This is the way an Ethernet network is able to be transparently bridged from a data backbone to a subscriber’s home or business location.

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SECTION 3: TERMINOLOGY

A number of new terminologies have been developed for hybrid fiber/coaxial and DOCSIS networks along with re-use of terminology from other communications networks. In order to help the reader with the many acronyms and initialisms throughout this document, this section is provided as a terminology primer and reference. The major terminologies covered are as followed.[1]

Availability - In cable television systems, availability is the long-term ratio of the actual RF channel operation time to scheduled RF channel operation time (expressed as a percent value) and is based on a bit error rate (BER) assumption.

Bandwidth Allocation Map (MAP) - The MAC Management Message that the CMTS uses on the DS to allocate US transmission opportunities to cable modems.

Carrier to Noise Ratio (CNR or C/N) – The ratio of signal power to noise power in the defined measurement bandwidth. For digital modulation, CNR = Es/No, the energy-per-symbol to noise-density ratio; the signal power is measured in the occupied bandwidth, and the noise power is normalized to the symbol-rate bandwidth. For analog TV channels, the measurement bandwidth is 4 MHz.

Bit Error Rate (BER) - The percentage of bits that have errors relative to the total number of bits received in a transmission, usually expressed as ten to a negative power.

Codeword Error Rate (CER) - The ratio of the number of uncorrectable code-words to the total number of code-words sent without errors, with corrected errors and with uncorrectable errors.

Composite Second Order Beat (CSO) - The peak of the average level of distortion products due to second order nonlinearities in cable system equipment.

Composite Triple Beat (CTB) - The peak of the average level of distortion components due to third-order nonlinearities in cable system equipment.

Decibel-Millivolt (dBmV) - A dB measurement system wherein 0 dBmV is defined as 1 millivolt over 75 ohms.

Decibels (dB) - A unit to measure the relative levels of current, voltage or power. An increase of 3 dB indicates a doubling of power, an increase of 10 dB indicates a 10x increase in power, and an increase of 20 dB indicates a 100x increase in power.

DOCSIS 1.x - Abbreviation for "DOCSIS 1.0 or 1.1." DOCSIS stands for Data-Over-Cable Service Interface Specification.

DOCSIS 2.0 Mode - A CM operates in this mode when: 1) Multiple Transmit Channel (MTC) Mode is disabled; 2) the Enable 2.0 Mode configuration setting in the REGRSP is set to 1 (Enable) explicitly or by default; and 3) it operates on at least one upstream channel using the burst descriptors associated with IUC 9, 10, and 11 as opposed to IUC 5 and 6. A CM is enabled for DOCSIS 2.0 Mode when the Enable 2.0 Mode configuration setting in the REG-RSP is set to 1 (Enable). A CM may be enabled for DOCSIS 2.0 Mode but may not be operating in DOCSIS 2.0 Mode. When a

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CM has MTC Mode enabled, the CM is not considered to be in DOCSIS 2.0 Mode even if some of the upstream channels it is using are operating with post-1.1 DOCSIS physical layer mechanisms. Therefore, "DOCSIS 2.0 Mode" does not have relevance for a CM operating in MTC Mode, which is associated with DOCSIS 3.0

Downstream (DS) - In cable television, the frequency spectrum used to transport RF signals from the headend to the subscriber.

Dynamic Host Configuration Protocol (DHCP) - An Internet protocol used for assigning network-layer IP addresses.

Forward Error Correction (FEC) - FEC enables the receiver to detect and fix errors to packets without the need for the transmitter to retransmit packets.

Group Delay - The difference in transmission time between the highest and lowest of several frequencies through a device, circuit or system.

Hybrid Fiber/Coaxial System (HFC) - A broadband bidirectional shared-media transmission system using fiber trunks between the headend and the fiber nodes, and coaxial distribution from the fiber nodes to the customer locations.

Impulse Noise - Noise characterized by non-overlapping transient disturbances.

Internet Protocol (IP) - The computer network protocol (analogous to written and verbal languages) that all machines on the Internet must know so that they can communicate with one another. IP is a layer 3 (network layer) protocol in the 7 layer Open System Interconnection (OSI) model. The vast majority of IP devices today support IP version 4 (IPv4) defined in RFC-791, although support for IP version 6 (IPv6, RFC-2460) is increasing.

Jitter - The fluctuation in the arrival time of a regularly scheduled event such as a clock edge or a packet in a stream of packets. Jitter is defined as fluctuations above 10 Hz.

Latency - The time taken for a signal element to pass through a device.

Micro-reflections – Short-delay echoes or reflections in the forward or reverse transmission path due to impedance mismatches between the physical plant components. Micro-reflections are distinguished from long-delay echoes by having a time difference (between the main signal and the echo) on the order of one microsecond or less. Micro-reflections cause departures from ideal amplitude and phase characteristics for the transmission channel.

Modulation Error Ratio (MER) - MER measures the cluster variance in dB of the transmitted waveform, and is expressed as the ratio of average signal constellation power to average constellation error power. It includes the effects of inter-symbol interference (ISI), spurious, phase noise, and all other degradations to the transmitted signal.

Phase Noise - Rapid, short-term, random fluctuations in the phase of a wave, caused by time domain instabilities.

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Physical Layer (PHY) - Layer 1 in the OSI architecture; the layer that provides services to transmit bits or groups of bits over a transmission link between open systems and which entails electrical, mechanical and handshaking procedures.

Quadrature Amplitude Modulation (QAM) - A method of modulating digital signals onto a radio-frequency carrier signal involving both amplitude and phase coding.

Quadrature Phase Shift Keying (QPSK) - A method of modulating digital signals onto a radio-frequency carrier signal using four phase states to code two digital bits.

Radio Frequency (RF) - In cable television systems, electromagnetic signals in the range 5 to 1002 MHz spectrum.

Return Loss – The difference, in decibels, between the amplitude of an incident signal and its echo or reflection.

Service Identifier (SID) - A Service Identifier assigned by the CMTS (in addition to a Service Flow Identifier) to an Active or Admitted Upstream Service Flow. [14 bits].

Time Division Multiple Access (TDMA) - A digital technology that enables a large number of users to access, in sequence, a single radio frequency channel without interference by allocating unique time slots to each user within each channel.

Transit Delay - The time difference between the instant at which the first bit of a payload data unit (PDU) crosses one designated boundary, and the instant at which the last bit of the same PDU crosses a second designated boundary. Also defined as the propagation time required for an RF signal to travel from a CMTS to CM, or from a CM to a CMTS.

Upstream (US) - The frequency spectrum used to transport RF signals from the subscriber location toward the headend.

Upstream Channel - Physical layer characteristics and MAC layer parameters and functions associated to a DOCSIS reverse channel.

Upstream Channel Descriptor (UCD) - The MAC Management Message used to communicate the characteristics of the upstream physical layer to the cable modems.

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SECTION 4: DOCSIS COMPLIANT NETWORKS

Table 1[2] is directly from the DOCSIS 2.0 Radio Frequency Interface (RFI) specification and details the assumed RF specifications for a DOCSIS compliant downstream HFC plant.

Table 1

Parameter	Value
Frequency range	Cable system normal downstream operating range is from 50 MHz to as high as 860 MHz. However, the values in this table apply only at frequencies >= 88 MHz.
RF channel spacing (design bandwidth)	6 MHz
Transit delay from head-end to most distant customer	<= 0.800 msec (typically much less)
Carrier-to-noise ratio in a 6-MHz band	Not less than 35 dB (see note 2,3)
Carrier-to-Composite triple beat distortion ratio	Not less than 41 dB (see note 2,3)
Carrier-to-Composite second order distortion ratio	Not less than 41 dB (see note 2,3)
Carrier-to-Cross-modulation ratio	Not less than 41 dB (see note 2,3)
Carrier-to-any other discrete interference (ingress)	Not less than 41 dB (see note 2,3)
Amplitude ripple	3 dB within the design bandwidth (see note 2)
Group delay ripple in the spectrum occupied by the CMTS	75 ns within the design bandwidth (see note 2)
Micro-reflections bound for dominant echo	-20 dBc @ <= 1.5 µsec, -30 dBc @ > 1.5 µsec -10 dBc @ <= 0.5 µsec, -15 dBc @ <= 1.0 µsec (see note 2)
Carrier hum modulation	Not greater than -26 dBc (5%) (see note 2)
Burst noise	Not longer than 25 µsec at a 10 Hz average rate (see note 2)
Maximum analog video carrier level at the CM input	17 dBmV
Maximum number of analog carriers	121

Notes to Table 4-1:

1. Transmission is from the head-end combiner to the CM input at the customer location.
2. Measurement methods defined in [NCTA] or [CableLabs1].
3. Measured relative to a QAM signal that is equal to the nominal video level in the plant.

Although CNR, CSO and CTB are generally considered to be "analog" impairments, they are also impairments that impact RF modulated digital signals. CSO and CTB from inter-modulating analog signals will fall under digital signals. These beats are not coherent, but will cause degraded MER.

Micro-reflections impact the transmissions of a cable modem by reflecting the transmitted signal back toward the signal source. The incident and reflected signals interact to produce amplitude and group delay ripple, which causes degraded MER and ISI. This may cause unexpected results including modem registration failures, intermittent data loss and poor voice quality in VoIP networks.

The DOCSIS standard also requires a post-FEC BER of 10^{-8} in a production network. This translates to no more than 1 error in every 100 million bits of data transmitted. In order to achieve this post-FEC BER, Table 2 shows the respective MER required for both 64- and 256-QAM downstream DOCSIS channels.

Table 2

BER	64 QAM MER	256 QAM MER	Quality
10^{-10}	>35	>35	Excellent
10^{-8}	27-34	31-34	Good
10^{-6}	23-26	28-30	Marginal
10^{-5}	<23	<28	Fail

Table 3, also directly from the DOCSIS 2.0 RFI, details the assumed RF specifications for a DOCSIS compliant upstream HFC plant.

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Table 3

Parameter	Value
Frequency range	5 to 42 MHz edge to edge
Transit delay from the most distant CM to the nearest CM or CMTS	<= 0.800 msec (typically much less)
Carrier-to-interference plus ingress (the sum of noise, distortion, common-path distortion and cross-modulation and the sum of discrete and broadband ingress signals, impulse noise excluded) ratio	Not less than 25 dB (Note 2)
Carrier hum modulation	Not greater than -23 dBc (7.0%)
Burst noise	Not longer than 10 µsec at a 1 kHz average rate for most cases (Notes 3 and 4)
Amplitude ripple 5-42 MHz:	0.5 dB/MHz
Group delay ripple 5-42 MHz:	200 ns/MHz
Micro-reflections – single echo	-10 dBc @ <= 0.5 µsec -20 dBc @ <= 1.0 µsec -30 dBc @ > 1.0 µsec
Seasonal and diurnal reverse gain (loss) variation	Not greater than 14 dB min to max

Notes to Table 4-2:

1. Transmission is from the CM output at the customer location to the head-end.
2. Ingress avoidance or tolerance techniques may be used to ensure operation in the presence of time-varying discrete ingress signals that could be as high as 10 dBc. The ratios are guaranteed only within the digital carrier channels.
3. Amplitude and frequency characteristics sufficiently strong to partially or wholly mask the data carrier.
4. Impulse noise levels more prevalent at lower frequencies (< 15 MHz).

The carrier-to-interference specification of >25 dB is effectively CNR plus any ingress junk that may exist in the return path. The upstream DOCSIS carrier is especially susceptible to impairments such as impulse noise which will cause errors in the transmitted data. Higher order modulations, such as 64-QAM may require more than 25 dB CNR to operate without errors.

Amplitude ripple and group delay can be grouped into a class together, because if you have problems with one you likely have problems with the other. Amplitude versus frequency, or flatness, should ideally be flat. As ripples in amplitude increase, so will group delay. Both will impact a CMTS's ability to recover the signals transmitted by cable modems as they travel upstream from the point of origin. Signals impaired by frequency perturbations and or excessive group delay will suffer packet loss at the CMTS. While group delay has typically been considered an impairment at the return path band edges due to the roll-off of diplex filters, it can be present throughout the return path any place spectrum amplitude may not be flat.

Micro-reflections are caused by impedance mismatches (bad return loss). Detecting it is challenging, but can be done with time domain reflectometers (TDRs), US sweep gear, Upstream Characterization Toolkits, or, though ill-advised without proper testing, by replacing suspect cables and components.

SECTION 5: DOCSIS IMPAIRMENTS

While seemingly simple in concept, the actual implementation of DOCSIS networks has many complex pitfalls which cause impairments and failures in the communications network. Impairments at the physical RF transport layer can result in poor or lost communications at the IP layer. Interoperability issues between various DOCSIS devices (multiple vendors of CMTS and CM devices) in addition to over-utilization of the DOCSIS network can result in packet loss, delay and jitter. Finally, all of the standard impairments that exist in Ethernet networks are also present in Ethernet networks over DOCSIS, such as collisions, delay, buffer-over flows, and routing errors, which results in packet loss, delay and jitter. So the DOCSIS network experiences all of the problems of a standard Ethernet network, while at the same time adding two additional levels of impairment probabilities; RF and DOCSIS protocol.

UPSTREAM RF IMPAIRMENTS

The upstream path in an HFC network can be considered the "Achilles heel" of a VoIP system since it usually contains the greatest source of impairments. A short list of the impairments follows, along with their DOCSIS specification as applicable:

- Linear Impairments such as:
  - Micro-reflections -10 dBc @ <= 0.5 µsec
    (per DOCSIS spec.) -20 dBc @ <= 1.0 µsec
    -30 dBc @ > 1.0 µsec
  - Amplitude ripple (0.5 dB/MHz per DOCSIS spec.)
  - Group Delay (200 ns/MHz per DOCSIS spec.)
- Non-linear Impairments such as:
  - Common Path Distortion (CPD)
  - Return Laser Clipping
- Transient Impairments such as:
  - Ingress & Impulse Noise (CNR > 25 dB per DOCSIS)

The wide variety of upstream impairments can cause data carrying signals from cable modems and embedded multi-media terminal adapters (eMTAs) to become corrupted before they reach the CMTS. If the CMTS is unable to properly demodulate a corrupted signal, it discards the frame. In normal data traffic, the data will be re-transmitted by a higher level application, but for VoIP, there is no such thing as a re-transmission since VoIP is a Real-Time-Protocol (RTP). Therefore, any lost frames are gone for good!

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CARRIER-TO-NOISE

One way of detecting noise in the upstream is by setting a spectrum analyzer on MAX-HOLD (maximum hold) at the headend or hub on the return path that goes to the CMTS upstream port. For a basic CNR measurement, place a marker at the top of the DOCSIS haystack and a delta marker on the peak of the noise floor adjacent to the DOCSIS haystack. The delta marker reading will yield the CNR. To be DOCSIS compliant one needs at least 25 dB CNR or greater. Figure 1 and 2 show good and bad CNR, respectively.

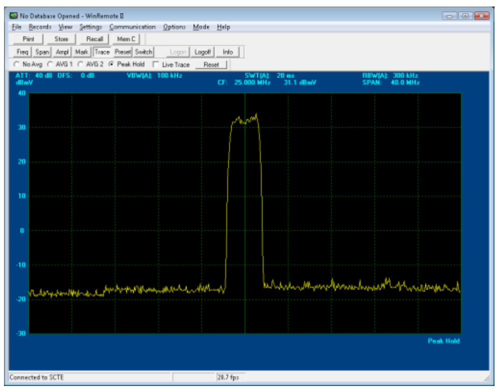


Figure 1: >45 dB CNR

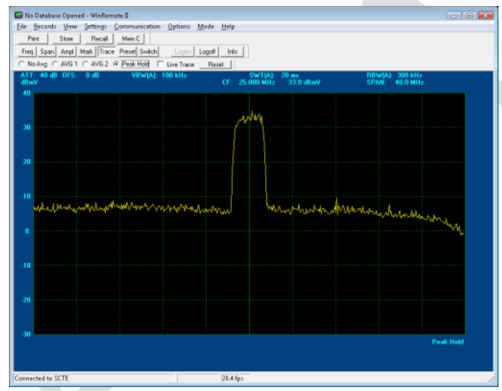
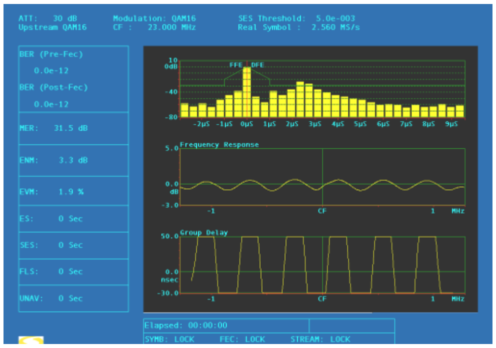


Figure 2: ~25 dB CNR

GROUP DELAY

Group Delay is an RF impairment which will create a number of effects on a DOCSIS network including modems to failing to register, frequent modem de-registration, slow data rates, inability to support higher modulation orders, very poor voice quality on VoIP calls, failure for calls to connect and many more. One troublesome function of group delay is that it often appears to be an IP-related impairment because it is virtually invisible in the RF domain. Group delay occurs when phase versus frequency is not linear (amplitude ripple/tilt occurs when amplitude versus frequency is not linear). Group delay usually occurs at the roll-off points of the diplex filters and its effect gets worse with more filters in the cascade (remember there are 2 for every active device). Group delay can also occur due to amplitude changes throughout the transmitted spectrum. The best method to observe group delay is to use a special QAM generator and a spectrum analyzer with QAM demodulator developed to characterize the upstream plant. An example of this test set is shown in figure 3. The top trace in this display, the test equipment's adaptive equalizer graph, shows a ~2.5 µs micro-reflection at about -23 dBc. The micro-reflection caused 1.6 dB peak-to-valley in-channel amplitude ripple (second trace) with the ripples spaced 400 kHz apart, and ~270 ns peak-to-peak in-channel group delay ripple (bottom trace). Note that the group delay ripple is off-scale in the third trace, but shown in full scale in the second screen shot, figure 4.



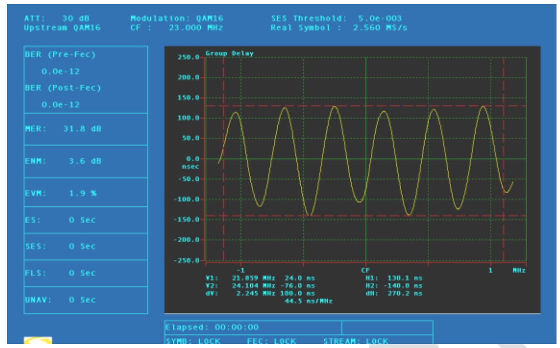


Figure 3: Group Delay Figure 4: Group Delay of 270 ns/MHz

The DOCSIS specification for upstream group delay is <200 nsec/MHz, but this channel has 270 ns/MHz far exceeding the specification and indication of a severe impedance mismatch.

One can use the formula D = 492 x Vp/F to calculate the approximate distance to an impedance mismatch. D is the distance in feet to the fault from the test point; Vp is the cable's velocity of propagation (typically ~0.87 for hardline cable); and F is the frequency delta in MHz between successive standing wave peaks on the sweep trace. The 400 kHz-spaced amplitude ripple suggests an impedance mismatch about 1070 feet from the test point. In order to see the 400 kHz-spaced ripples on a conventional reverse sweep, it would be necessary to have sweep points at least every 200 kHz.

LASER CLIPPING

Although the return path in a DOCSIS network is defined as 5-42 MHz, the return path lasers transport 0-200 MHz, so one will gain much more information about the system if the spectrum analyzer is set with a span of 200 MHz. This provides for an ideal method for identifying lasers that may be operating in a non-linear mode of operation, commonly referred to as “clipping”

Figure 5 shows a spectrum analyzer set with a span of 200 MHz. The upstream DOCSIS channel is the highest signal. There is also a 3rd harmonic and a complete image of the 5-42 MHz pass-band and DOCSIS carrier above 140 MHz. This is a clear indication that the laser is in compression and a likely culprit for dropped VoIP packets due to laser clipping.

Note: Always view below 5 MHz also for AM broadcast radio ingress (0.5 to 1.7 MHz) and/or ham radio ingress near 1.8 and 3.5 MHz.

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Figure 5. Return Path Spectrum with 200 MHz Span and Laser in Compression

CALL SIGNALING AND VOIP TRAFFIC FLOWS

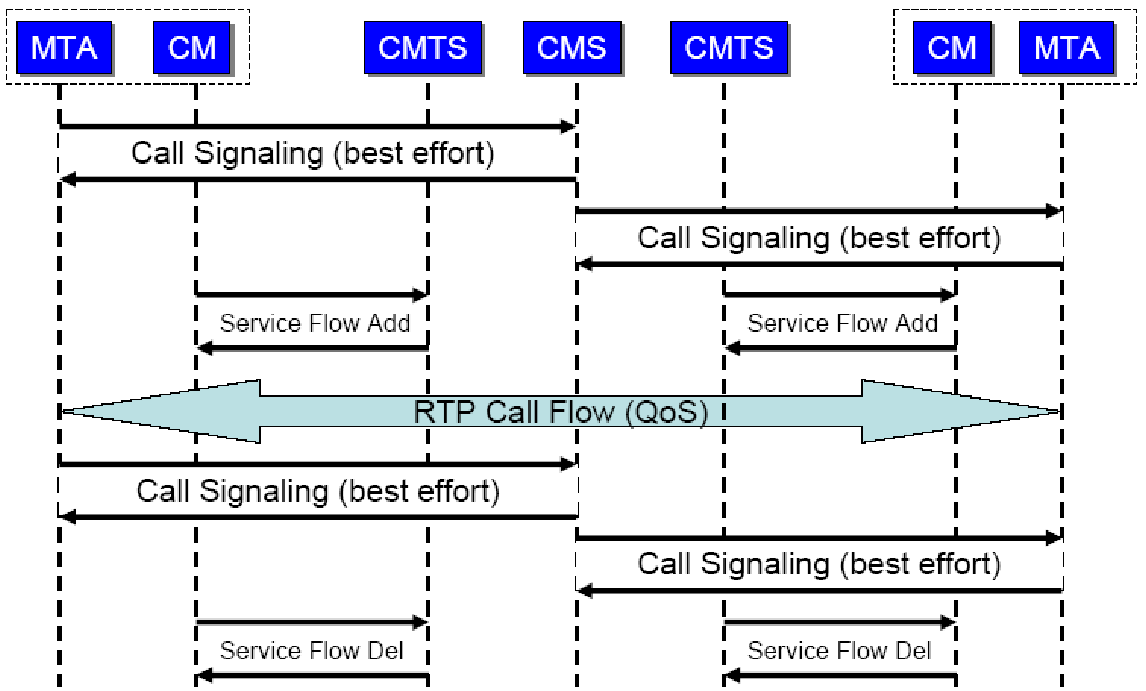
During a VoIP call, there are two distinct sessions. First, there is the call signaling session that sets up and eventually tears down the call. Second, there is the call session itself, which in a DOCSIS 1.1 or higher network, should reside in a **service flow** which ensures that the VoIP frames receive a higher QoS than other IP traffic on the network. It is the call session in which the voice communication takes place.

Figure 6 represents a very simplified flow of the call setup. This call represents an "on-net" call between two eMTAs, communicating across two CMTSs. A single Call Management Server (CMS) is used to setup the call.

Of importance in this diagram is the representation of the call signaling residing in the "Best Effort" class of service. This implies that call signaling may be in contention with other IP-based services, especially if the CMTS or eMTA is over-utilized. Symptoms of this often manifest as delay or no-dial tone, incomplete calls or fast-busy signal. Once the signaling is established and both sides of the call are connected, the eMTAs initiate the appropriate Service Flows (DQoS) for the voice channel. This service flow ensures that VoIP packets transported by DOCSIS frames have a higher QoS than other IP-based traffic, ideally ensuring their timely delivery to the end caller.

Once the call is completed, a second call signaling session occurs which notifies the CMS that the callers have hung-up (billing is over) and also notifies the CMTS that the service flows can be deleted. Deleting service flows at the end of a call is critical as there are a finite number of available service flows. Failing to delete service flows will lead to the CMTS eventually running out of service flow identifiers, which will result in no further calls being connected. This situation has occurred in a number of VoIP systems, but has been resolved by adding automatic inactivity time-outs on the service flows to safe guard against this possible failure.

Figure 6. Simplified Call Setup Flow Diagram



Call Signaling/Setup

Once a VoIP call is set up and the CMTS has scheduled UGS grants, the time is allocated just for that specific eMTA and can not be affected by best effort traffic. The bigger issue, however, is setting up the call. Congestion can affect the call setup. It's possible that non-real-time polling service (nRTPS) can be used for the signaling traffic for the call setup and/or setting a higher priority class for call signaling and a minimum guaranteed rate. nRTPS schedules enough minislots for a BW Request for all eMTAs on an US port regardless of how many are actually active. One example used by some customers is 100 msec nRTPS polling for call setup with a priority of 3 and 8 kbps of minimum guaranteed US speed. The polling rate should be something that is divisible by the call frame rate (typically 20 msec) and fit into the timing wheel used by the scheduler. We suggest a value of 60 or 100 msec for polling. If other polling rates are selected that don't fit into the scheduling wheel, then it will be converted to an integer that fits. So, if you select 250, it could cause issues since it may be converted to 150 and then it's not an integer that fits well with the scheduling of 20 msec G711 VoIP. 100 msec polling fits well with 20 msec VoIP and the scheduling wheel. The "con" to this approach is that more scheduling affects the total number of simultaneous calls that can be supported. One could get away from nRTPS and just configure higher priority BE flows for call setup. Another idea, if using the latest code, is to utilize low latency queuing (LLQ) for the call signaling. We could do UGS with the regular scheduler and LLQ for nRTPS set at a polling rate of 300. Also keep in mind that more service flows may equate to more required SFID/SIDs.

SECTION 6: TROUBLESHOOTING FROM THE CMTS COMMAND LINE INTERFACE (CLI)

While many RF and DOCSIS impairments require field test equipment, the CMTS can be a powerful tool for diagnosing problems within a DOCSIS network. Some of these commands are focused on physical layer impairments while others can be used to look at higher layer faults. **Note**: The following commands are from a Cisco CMTS. Refer to other manufactures for equivalent terms and commands.

At a very high level, the CMTS is able to let the user know if the CMTS is being over-utilized. An example of this is as follows:

```
Show interface cable 1/0 mac-scheduler upstream 0

DOCSIS 1.1 MAC scheduler for Cable1/0/U0

   Queue[Rng Polls] 0/128, 0 drops, max 2

   Queue[CIR Grants] 0/64, 0 drops, max 1

   Queue[BE(7) Grants] 0/64, 0 drops, max 0

   Queue[BE(6) Grants] 0/64, 0 drops, max 0

   Queue[BE(5) Grants] 0/64, 0 drops, max 0

   Queue[BE(4) Grants] 0/64, 0 drops, max 0

   Queue[BE(3) Grants] 0/64, 0 drops, max 0

   Queue[BE(2) Grants] 0/64, 0 drops, max 0

   Queue[BE(1) Grants] 0/64, 0 drops, max 0

   Queue[BE(0) Grants] 0/64, 0 drops, max 11

   Req Slots 170179701, Req/Data Slots 872698

   Init Mtn Slots 2423902, Stn Mtn Slots 89335

   Short Grant Slots 1631822, Long Grant Slots 8032

   ATDMA Short Grant Slots 0, ATDMA Long Grant Slots 0

   ATDMA UGS Grant Slots 0
```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```
Avg upstream channel utilization : 30% (Over ½ second periods)
Avg percent contention slots : 67%
Avg percent initial ranging slots : 3%
Sched Table Rsv-state: Grants 0, Reqpolls 0
Sched Table Adm-State: Grants 0, Reqpolls 0, Util 11%
UGS    :10 SIDs, Reservation-level in bps 928000
UGS-AD : 0 SIDs, Reservation-level in bps 0
RTPS   : 0 SIDs, Reservation-level in bps 0
NRTPS  : 0 SIDs, Reservation-level in bps 0
BE     : 6 SIDs, Reservation-level in bps 3000000
```

Some things to note are US utilization, how many VoIP calls are present utilizing UGS grants, how much data throughput is being allocated on the US for specific modems, and US modulation burst types incrementing. **Note**: the Avg percent contention slots does not indicate how much contention is happening. It only indicates how much time is open for contention if needed.

The following command can be used to verify the DS is enabled and properly set for level, frequency and modulation scheme intended.

```
Show controller cable x/y/z downstream
Cable1/0 Downstream is up
  Freq 453 MHz, Ch Width 6 MHz, 256-QAM, Symbol Rate 5.360537 Msps
  FEC ITU-T J.83 Annex B, R/S Interleave I=32, J=4
 Downstream channel ID: 24
```

Note: the DS ch ID is important when doing DS load balancing as these need to be unique between the DSs that are balanced for proper dynamic channel change (DCC) operation.

The next command can be used to verify US parameters and proper operation.

```
Show controller cable 1/0 upstream 0
Cable1/0 Upstream 0 is up
```


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```
Freq 18 MHz, Ch Width 3.200 MHz, 16-QAM Symbol Rate 2.560 Msps
This upstream is mapped to physical port 0
Spectrum Group is overridden
US phy MER(SNR)_estimate for good packets - 36.1280 dB
Nominal Input Power Level 0 dBmV, Tx Timing Offset 1507
Ranging Backoff Start 3, Ranging Backoff End 6
Ranging Insertion Interval automatic (60 ms)
Tx Backoff Start 3, Tx Backoff End 5
Modulation Profile Group 42
Concatenation is enabled
Fragmentation is enabled
Minislot Size in number of Timebase Ticks is = 2
Minislot Size in Symbols = 32
Bandwidth Requests = 0xA0DFC
Piggyback Requests = 0xF290D
Invalid BW Requests= 0x360
Minislots Requested= 0x238E902
Minislots Granted  = 0x19373E
Minislot Size in Bytes = 16
Map Advance (Dynamic) : 2027 usecs
UCD Count = 87857
```

Most of this output shows how the interface is configured and can be used to see if UCDs are incrementing, the US is properly set and enabled, and if the map advance is suspect.

MER (SNR) is calculated/averaged for the entire US port and is only a starting point for troubleshooting plant errors. Map advance is calculated based on the farthest CM, but one misbehaving modem could affect the map advance calculation and affect all modems.

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Another very powerful command on the CMTS is the “Show Cable Modem” command, which provides a summary of all registered, registering and de-registered (offline) cable modems. In addition, this command displays each cable modem’s MAC address, IP address, SID, Timing Offset, upstream receive RF power, QoS and number of CPEs connected.

Here is a sample output:

```
Interface  Prim Online   Timing  Rec    QoS CPE  IP address     MAC address
           Sid  State    Offset  Power
 C1/0/U0    2   online    2262  *-0.50  5    0  10.30.128.145   0090.8330.020f
 C1/0/U0    3  #online    2260    0.25  2    0  10.30.128.146   0090.8330.0211
 C1/0/U1    4   online   !2256   *0.75  5    0  10.30.128.143   0090.8330.0216
 C1/1/U0    2   online    4142  !-3.25  5    1  10.30.128.164   0050.7366.1245
 C1/1/U0    1   online    4141  !-3.00  6    1  10.30.128.185   0050.7366.17e3
 C1/1/U1    6   online    2807   -0.50  5    0  10.30.128.191   0006.2854.7319
 C1/1/U1    5  !online(pt)3840   -0.25  5    0  10.30.128.190   0001.64ff.e4ad
```

- **“*”** indicates the CMTS is using a noise-power adjustment method on this CM
- **“!”** indicates the CM has reached max transmit power, CM has reached max time offset limit, DMIC issue
- **“#”** indicates the CM has been marked for TFTP Enforce
- (**pt**) indicates BPI+ is utilized

Note the Timing Offset and Receive power. There are four groups of modems: Two groups on DS 1/0 and 2 groups on DS 1/1. One group with a high time offset may be farther away from the headend then the other. The farther group also has improper receive levels, which could indicate a misaligned system.

Note: Running the command “show cable modem offline” will show the last state a modem got to before going offline, which could help narrow down the problem.

Utilizing the show cable modem mac and mac summary commands allows us to see a modem’s capabilities and also how it has been provisioned. A modem can be provisioned as 1.0 or 1.1, but it could be capable of being DOCSIS 1.0, 1.1, or 2.0. In addition, we now have DOCSIS 3.0 capabilities even though it could be provisioned as 1.0 or 1.1.

```
Show cable modem mac

MAC Address     MAC          Prim  Ver     QoS     Frag Concat PHS Priv DS    US
```

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	State	Sid		Prov					Saids	Sids
0013.7115.f998	online(pt)	84	DOC2.0	DOC1.1	yes	yes	yes	BPI+	15	16
0013.7184.892a	online(pt)	85	DOC2.0	DOC1.1	yes	yes	yes	BPI+	15	16
0012.c9db.ecb6	online(pt)	86	DOC2.0	DOC1.1	yes	yes	yes	BPI+	15	16
0013.7186.9996	online(pt)	87	DOC2.0	DOC1.1	yes	yes	yes	BPI+	15	16
0012.c9c9.8024	online(pt)	88	DOC2.0	DOC1.1	yes	yes	yes	BPI+	15	16
0013.7118.1e96	online(pt)	89	DOC2.0	DOC1.1	yes	yes	yes	BPI+	15	16

Show cable modem mac summary

Cable Modem Summary

\-------------------

		Mac Version			QoS Provision Mode		
Interface	Total	DOC2.0	DOC1.1	DOC1.0	Reg/Online	DOC1.1	DOC1.0
Cable1/0/U0	6	6	0	0	6	6	0
Cable1/0/U1	5	5	0	0	5	5	0
Cable1/1/U0	7	7	0	0	7	7	0
Cable1/1/U1	6	6	0	0	6	6	0

Note: US Pre-EQ is related to a modem's capabilities (1.1 or 2.0); it does not matter how it is provisioned (1.0 or 1.1). On the other hand, US fragmentation requires a modem to be provisioned as 1.1 or greater.

Further, adding "phy" after the "show cable modem" command, one will also see the US transmit power, MER (SNR), micro-reflections, DS receive power and DS MER (SNR) of each CM. This will enable the user to help isolate US and DS RF impairments in the HFC network, if present. An example of "show cable modem phy" is as follows:

Show cable modem phy

MAC Address	I/F	Sid	USPwr (dBmV)	USMER (SNR) (dB)	Timing Offset	DSPwr (dBmv)	DSMER (SNR) (dB)	Mode	DOCSIS Prov

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0013.7115.f998	C1/0/U0	84	**42.20**	**36.12**	1502	**-**	**3.90**	**39.50**	tdma	1.1
0013.7184.892a	C1/0/U0	85	42.20	36.12	1501	-	3.90	39.40	tdma	1.1
0012.c9db.ecb6	C1/0/U1	86	41.90	30.79	1505	-	2.60	39.80	**tdma**	**1.0**
0013.7186.9996	C1/0/U0	87	43.20	36.12	1514	-	3.30	40.10	**atdma**	**1.1**
0012.c9c9.8024	C1/0/U0	88	42.20	36.12	1506	-	1.80	39.30	atdma	1.1

One very useful column in this command is the per-CM SNR readings, which can be used to indicate potential linear impairments at or near a specific household. This could lead to activating US equalization-coefficient (Pre-EQ) to help alleviate group delay and micro-reflection issues.

Note: some of these parameters must be obtained via snmp from the modem and may not be populated unless a feature called remote-query is configured. This allows the CMTS to act as an snmp agent and query the modems for their DS MER(SNR), DS Rx level, and US Tx level. Some CMs also have an internal url to assist with troubleshooting, which can be accessed by using an internet browser like Internet Explorer on a PC connected to the specific modem and typing in 192.168.100.1. This can help with troubleshooting by displaying modem DS Rx level, US Tx levels and much more. Some modems may have been blocked from allowing this, though.

During cable modem registration, there are many points of failure. The CMTS “show cable modem” command status provides a list of “Modem States” which will help the user diagnose exactly what point a cable modem has failed during registration. A list of these states is as follows:

offline - CM considered offline

init(r1) - CM sent initial ranging (contention time for initial maintenance burst)

init(r2) - CM is ranging (unicast, station maintenance burst)

init(rc) – CM ranging complete

init(d) – CM has broadcast a dhcp discover packet

init(io) - DHCP server has sent back dhcp offer and CMTS has relayed it to CM

init(dr) - CM has broadcast dhcp request packet back to dhcp server

init(i) - DHCP server replied with ack to grant CM lease & IP address assigned

init(t) - ToD request received

init(o) - TFTP request was received for DOCSIS config file

online - CM registered, enabled for data

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online(d) - CM registered, but network access for the CM is disabled

online(pk) - CM registered, BPI enabled and KEK assigned (not yet done)

online(pt) - CM registered, BPI enabled and TEK assigned (finally done)

reject(m) - CM attempted to register; reg refused due to bad MIC

reject(c) - CM attempted to register; reg refused due to bad CoS (bad config file)

reject(pk) - KEK CM key assignment rejected

reject(pt) - TEK CM key assignment rejected (could be bad date and time)

reject(na) - Rejected because no acknowledgement

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A very useful command for tracking correctable and uncorrectable FEC (dropped packets) is the “show cable hop” command. By running the command a few times, you can see if uncorrectable FEC is incrementing, which indicates dropped packets and may point to impulse noise issues. If correctable FEC is incrementing more than uncorrectable, then FEC is working to fix problems and may be indicative of AWGN, CPD or some steady-state noise source.

```
Show cable hop

US          Port      Poll Missed Min    Missed Hop   Hop    Corr   Uncorr
Port        Status    Rate Poll   Poll   Poll   Thres Period FEC    FEC
                      (ms) Count  Sample Pcnt   Pcnt  (sec)  Errors Errors
Cable1/0/U0 18.0 MHz   1000 * * * set to fixed freq  * * *   443648 11844
Cable1/0/U1 22.0 MHz   1000 * * * set to fixed freq  * * *   0      1
Cable1/0/U2 admindown 1000 * * * interface down     * * *   0      0
Cable1/0/U3 admindown 1000 * * * interface down    * * *    0      0
Cable1/1/U0 26.0 MHz   1000 * * * set to fixed freq * * *    0      2
Cable1/1/U1 30.0 MHz   1000 * * * set to fixed freq * * *    0      0
Cable1/1/U2 down       1000 * * * freq not set     * * *    0      0
Cable1/1/U3 admindown 1000 * * * interface down    * * *    0      0
```

The primary information here is US frequency, number of correctable and uncorrectable FEC errors, and interface status. The poll rate / 1000 * total modems in a DS interface = polls/sec per modem. Typically a station maintenance poll is sent every 20 seconds to each modem.

Hop Threshold and Period are used for Spectrum Management if intending to assign spectrum groups and allow frequency hopping or dynamic modulation changes.

Note: "Clear cable hop", "clear interface cable x/y" or "clear counters" can be used to clear the counters. Also, use "show controller c1/0 | inc UnCorFECBlks" for the total amount of FEC blocks if intending to do your own math to calculate a percentage.

```
Show controller c1/0 | inc UnCorFECBlks
```

```
FECBlks 13699993 UnCorFECBlks 15 CorFECBlks 1
```

What is the Flap List?

Flap list is a feature that lists "flaky" CMs. The list is maintained in the CMTS and focuses primarily on US issues. Most cable companies like this so much that Cablelabs has gotten the permission from Cisco to include it in the DOCSIS 3.0 specification and is known as the modem diagnostics log. The flap list is populated from data obtained when each modem goes through station maintenance (usually every 20 seconds).

A CM is added to flap list when:

- CM fails the registration process
- Keep alive messaging between CMTS and CM is impacted by communication errors
- CM US transmit power is adjusted beyond user-specified threshold

The following parameters are settable using CLI:

- Max size of flap list
- Age threshold
- Insertion time threshold
- Power adjustment threshold

A sample output of Cable Flap List:

```
Show cable flap
```

```
MAC Address     Upstream       Ins    Hit    Miss   CRC    P-Adj Flap   Time
```

```
0012.c9dc.4908 Cable1/0/U0    *** No data available ***        Apr 23 19:58:50
0013.7115.db7e Cable1/0/U0    *** No data available ***        Apr 23 19:58:48
0013.7186.51c2 Cable1/1/U1    0      12519 15     0      0     1   Apr 24 17:11:06
0013.7184.850c Cable1/1/U1    0      12517 15     0      0     1   Apr 24 17:11:04
```

This can be sorted by time, flap, or interface. Technically a modem should receive a hit every 20 seconds, but US impairments could cause a dropped range response. This leads to a miss in the flap list and typically a T3 timeout on the CM. It's not unusual to have a 2-4 misses for every hit, but when it becomes excessive, then the modem will be added to the flap list since this could affect VoIP services.

- Insertion is the number of times in 180 seconds that the CM re-starts initial ranging.
- Hit is the number of times the CMTS sent a Station Maintenance message and received a response.
- Miss is the number of times the CMTS sent a Station Maintenance message and didn't receive a response.
- Power adjust is the number of times the CMTS told a CM to adjust its Tx power > 3 dB.
- A flap is an algorithm based on Power-Adjusts and Insertions.
- The time is the most recent time that the CM dropped off the CMTS.

Note: The cyclic redundancy check (CRC) is a 4 byte ethernet word (layer 2), but difficult to determine if a CRC error occurs if the physical layer (layer 1) is corrupted.

Besides show commands on a CMTS, there are also some higher layer troubleshooting aids like "ping", but ping could have some drawbacks.

Ping Drawbacks

Ping can increase network load, especially if a flood ping is used or if the ping packet size has been increased from its default. Some devices refuse to process packets that are too large, which are called "giants".

Ping uses the time-to-live (TTL) field differently depending on implementation. Most stacks will set the TTL to the maximum of 255 (this is common in BSD-based stacks and on Cisco devices). Because of this, you might be able to ping a device, but cannot connect to it on a high layer service (such as telnet or HTTP). Note: BSD uses 64 for a telnet TTL, IOS uses 248, and Windows uses 128.

There have been outbreaks of ICMP-based denial of service (DoS) attacks. Because of this, many gateways and hosts throttle or deny ICMP. Therefore, ping might not reliably tell you if a host is up or not.

Ping only checks the network layer. It does not verify that services on a particular host are running. For instance, just because you can ping your web server does not mean that it is serving out web pages.

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Ping cannot pinpoint a problem in the network. It merely tells you if two hosts' IP stacks can communicate using ICMP. Another tool must be used to further narrow down connectivity of performance problems.

If pinging a modem does not work, the next logical step is ping docsis. This feature, if available, allows the CMTS to send a station maintenance ping (layer 1-2 of the OSI model). This allows the user to verify physical connectivity even if the layer 3 ping does not work.

DOCSIS Ping

- Quickly diagnoses connection between CM and CMTS
- Even works with CMs that don't complete registration or which may have "crashed"

```
ubr10k#ping docsis 001a.c3ff.d4ee 10 ver

Queueing 10 MAC-layer station maintenance intervals, timeout is 25 msec:

Reply from 001a.c3ff.d4ee: 46 ms, tadj=1, padj=0.75, fadj=-54

Reply from 001a.c3ff.d4ee: 50 ms, tadj=0, padj=0.75, fadj=-35

Reply from 001a.c3ff.d4ee: 50 ms, tadj=0, padj=0.75, fadj=-44

Reply from 001a.c3ff.d4ee: 50 ms, tadj=0, padj=0.75, fadj=-40

Reply from 001a.c3ff.d4ee: 50 ms, tadj=1, padj=0.75, fadj=-54

Reply from 001a.c3ff.d4ee: 50 ms, tadj=1, padj=0.75, fadj=-49

Reply from 001a.c3ff.d4ee: 50 ms, tadj=0, padj=0.75, fadj=-35

Reply from 001a.c3ff.d4ee: 50 ms, tadj=0, padj=0.75, fadj=-44

Reply from 001a.c3ff.d4ee: 50 ms, tadj=1, padj=0.75, fadj=-44

Reply from 001a.c3ff.d4ee: 50 ms, tadj=1, padj=0.75, fadj=-49

Success rate is 100 percent (10/10)
```

Not every vendor has this technology. It uses 1/64th the bandwidth of IP ping. It relies on the SM burst for a physical layer connectivity test.

Unlike IP Ping, it works with modems that don't have an IP address; such as modems which don't complete registration for any reason, modems which have internal bugs, or are partially "crashed" etc.

This allows a real time view and plot of requested power adjustments. The cable system can quickly diagnose the health of the RF channel between the CMTS and a specific CM by soliciting a configurable number of periodic ranging requests from the CM.

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Note: be careful when comparing a ping, which may use the long burst and ping docsis, which may use a different modulation for the SM burst.

SECTION 7: SUMMARY AND CONCLUSIONS

Troubleshooting in a DOCSIS network extends beyond brute force, poke-and-hope methods. Today's subscribers using high-end services demand quick resolutions to any impairment which may impact their lifestyle. In order to be effective solution providers, cable operators and their technicians must first understand the requirements to sustain a DOCSIS network and the impairments which impact it, then they must be versed on the techniques to quickly conquer and divide the network to rapidly identify the root cause of any problem.

The paradigm of rolling a truck for every trouble ticket must be broken. Within every headend and hubsite exists the capability to dissect the network into RF and IP. From the headend/hubsite, a great deal of cable modem diagnostics can be determined before the truck is ever rolled, possibly determining that the problem is actually IP-related. If and when a truck is rolled, the technician should be sent with the knowledge of what the problem is that he/she is going to resolve, i.e. low receive power at the modem or too much loss in the upstream. Blind troubleshooting is still prevalent in our industry, but it is not necessary.

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