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In this issue

From Broadcasting to Communicating

The good old cable TV that till now was supposed to only provide us with TV channels only through a one way system is now becoming more modern. Technologies today are converging or intermixing to provide fast and easy communication.

By using a technology called, DOCSIS, we are now able to access internet through cable network.

What is DOCSIS?

DOCSIS stands for Data Over Cable System Interface Specification. It basically is a set of rules to define the interface specifications for cable modems that are involved in high speed data (MPEG and IP) transfer over existing cable infrastructure.

It is an international standard developed by CableLabs and contributing companies that include: ARRIS, Harmonic, BigBand Networks, Broadcom, Cisco, Conexant, Correlant, Intel, Motorola, Netgear, Terayon, and Texas Instruments.

DOCSIS defines the communications and operation support interface requirements for a data over cable system. It is currently employed by many cable television operators in US, Europe and elsewhere to provide Internet access over their existing hybrid fibre coaxial (HFC) infrastructure.

A DOCSIS network provides bi-directional flow of IP data between cable modem and CMTS over hybrid-fiber/coax cable systems

There are two major components in this system:

(1) **CM or the cable modem** is located at subscriber end. Various devices like PC, laptop, phone etc can be connected to it. (It is similar to the DSL modem in the traditional wire line broadband system.)

(2) **CMTS** stands for **cable modem termination system** and it is located at the cable operators end (also known as head-end) and connected to Internet. (It can be compared to a DSLAM in the wire line broadband architecture.)

The basic DOCSIS architecture

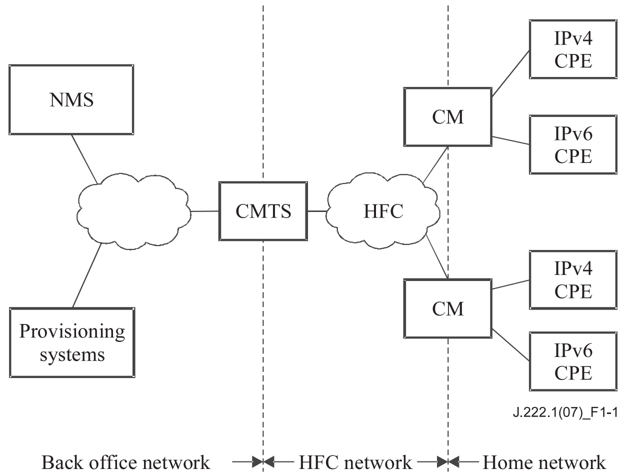

Figure 1 : The Basic Docsis Architecture

The basic DOCSIS architecture contains:

- A cable modem termination system (CMTS) at the cable operator end (also known as head-end).
- Cable modem (CM) which is located at the subscribers end.
- Devices connected to cable modem
- Internet and other servers connectivity to CMTS
- CM and CMTS communication over HFC cables.

This architecture supports Bi-directional data flow between the CM and CMTS. The path from CM to CMTS is known as **Upstream** channel while path from CMTS to CM is known as **Downstream** channel.

In upstream TDMA technology is used for multiple accesses as several CMs are using same upstream channel to send data.

Since most of the data flow is assumed to be in downstream direction, the downstream bandwidth is high as compared to upstream. But, with the growing trends such as on-line gaming etc, the upstream bandwidth is fast catching up with the downstream bandwidth. CMTS provides services like Dynamic Host Configuration Protocol (DHCP), Time of the day (TOD) etc to the CM.

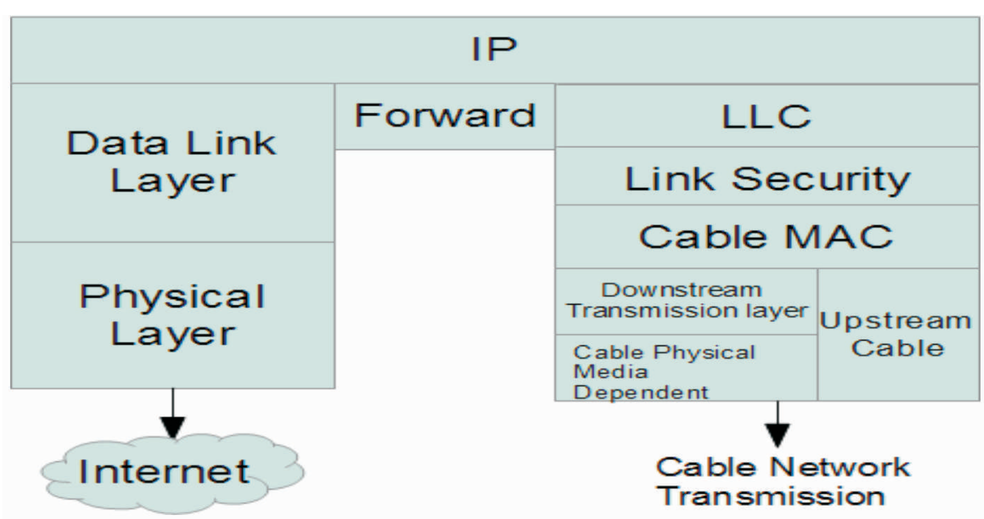

Figure 2 : CM/CMTS protocol stack

Figure 2 shows only the CMTS portion of the stack. CM and CMTS both can act as end hosts and forwarding agents. While sharing some controlling information the packets are destined to CM and CMTS only so in that case they act as end-hosts while in case a device connected to CM is interacting with some other host on Internet then in that case the CM and CMTS are only acting as forwarding agents.

Since CM-CMTS can act both as end-host and as forwarding agents so different protocol stacks exist in CM/CMTS for each role (as shown in the figure). CM-CMTS interaction holds the key to smooth bidirectional IP data flow on the existing cable infrastructure. To achieve this in DOCSIS network, the IP packet goes through a completely different protocol stack (as shown in the figure).

How does it work?

The CMTS sends data to the cable modems by transmitting a 6 MHz wide band of digital information in an FDM mode. The digital information (1's and 0's) is actually converted to Quadrature Amplitude Modulation (QAM) and RF-upconverted.

Due to present applicability of cable wires, we might think that they transfer data only in one direction. Actually, cable plants transmit RF signals in two directions.

In the figure 3, the forward (or downstream) path is from the cable operator's head-end to the subscriber and is generally from 54 MHz to as high as 1000 MHz, while the upstream is what is from 5 MHz to 42 MHz. Now the cable modems can send their data back to the CMTS using FDM in the upstream sending 1's and 0's which are also converted to QPSK or QAM and RF-upconverted.

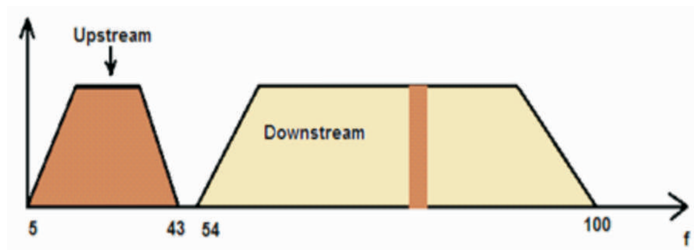

Figure 3

DOCSIS communications work in Quadrature Amplitude Modulation (QAM) framework. This is because it needs high-speed conditions for its working.

QAM transmits data by changing the amplitude of two carriers simultaneously. Since the two carriers are 90 degree out of phase, the sum of resulting signals has both level and phase variations. This provides for a large variation of data transition points, adding to the data throughput of a QAM signal. The mathematical formula for a QAM signal is as follows:

$s(t) = I(t) * sin(2 * pi * f_0 * t) + Q(t) * cos(2 * pi * f_0 * t)$

A representation of an 8-QAM signal is shown in the following figure.

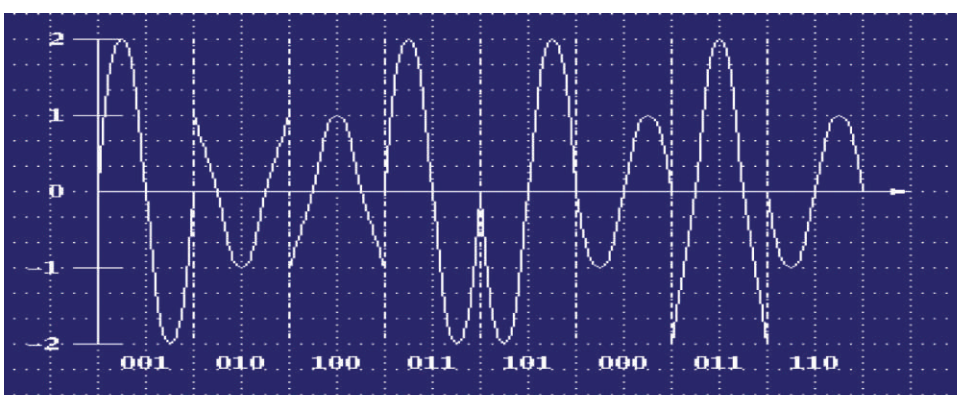

Figure 4

Quadrature Amplitude Modulation (QAM)

There are two modulations identified in the DOCSIS specification for downstream data transmission: 64-QAM and 256-QAM.

64-QAM has six (6) bits per symbol, while the 256-QAM has eight bits per symbol. 64-QAM is able to transmit about 30 mega-bits-per second (Mbps) and 256-QAM can transmit about 40 Mbps.

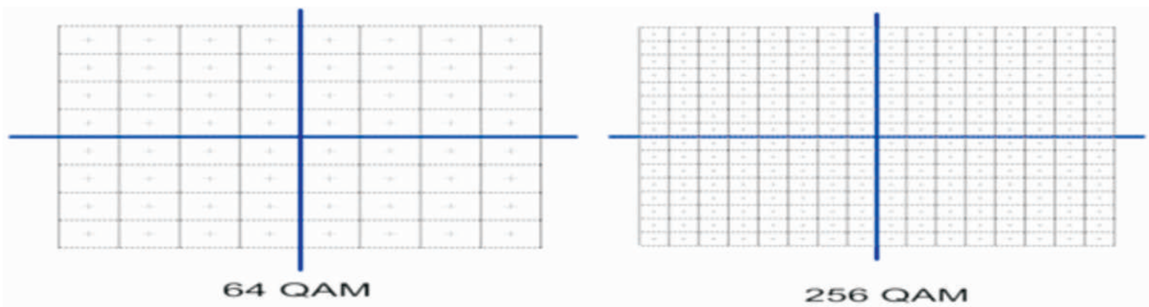

Figure 5

The DOCSIS 1.0 and 1.1 specifications are provided for two upstream modulation profiles; QPSK and 16-QAM.

As per the DOCSIS 1.0 and 1.1 specifications, the allowable symbol rates for upstream data transmission are 160, 320, 640, 1,280 and 2,560 ksym/sec.

DOCSIS 2.0 added higher order modulations including 8-QAM, 32-QAM and 64-QAM. In addition a higher symbol rate was added at 5120 ksym/sec; therefore, at 64-QAM and 5120 ksym/sec one can achieve a theoretic limit of 30.72 Mbits/sec in the upstream or ~27 Mbits/sec of user PDU after overhead. DOCSIS 2.0 also added some other advanced features.

DOCSIS 3.0 has added another feature called "channel bonding", both in the downstream and in the upstream. Channel bonding essentially allows one to take up to four upstream DOCSIS channels and transmit data over them as if they were one single channel.

When DOCSIS was first launched, most subscribers were downloading web pages, but today peer-to-peer file sharing, Voice-over-IP (VoIP), and many emerging applications are enabling symmetrical data utilization rather than the previous model of asymmetrical-dominant downstream traffic models.

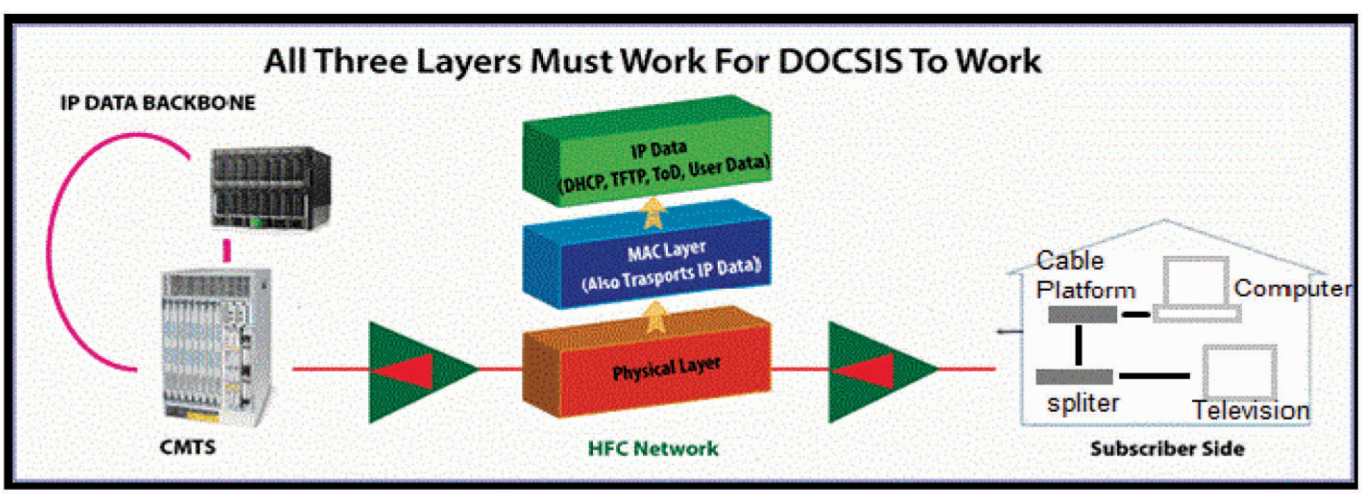

Figure 6 : DOCSIS in an HFC Network

DOCSIS in an HFC Network

In the above figure, on the left is a Cable Modem Termination System (CMTS) that is connected to an Internet back bone. To the CMTS is also connected a number of servers which run a Dynamic Host Configuration Protocol (DHCP) server, a Trivial File Transfer Protocol (TFTP) server, and a Time of Day (ToD) server. The CMTS transmits downstream data via 64- or 256-QAM signals over the RF Plant to the subscriber's home cable modem. The cable modem transmits data to the CMTS on the upstream over the RF Plant via QPSK, 8-, 16-, 32, or 64-QAM modulation. The RF Plant (essentially coaxial cable, fiber optic cable, RF amplifiers, a fiber optic node, Erbium-doped fiber optic amplifiers and countless RF passive devices) is capable of supporting the RF modulations being transmitted by the DOCSIS devices without significant degradation to stop higher layer communications.

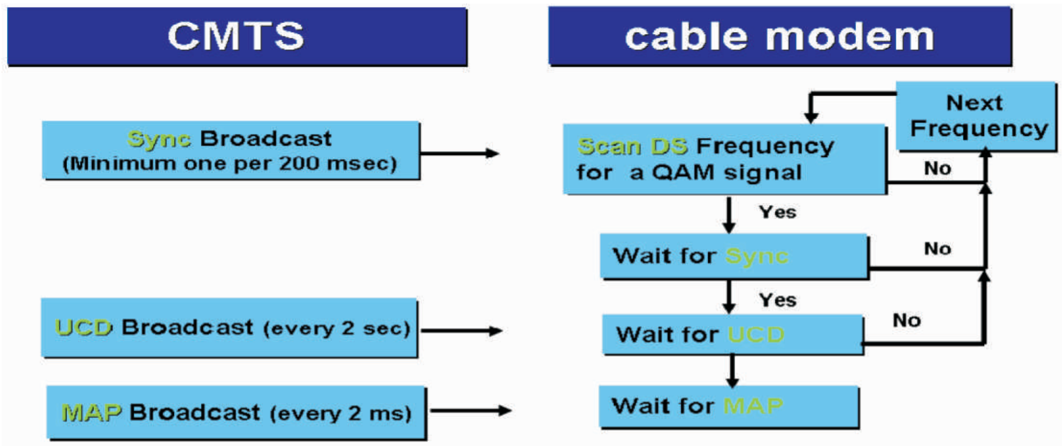

Figure 7 : Downstream DOCSIS Channel Lock

Downstream DOCSIS Channel Lock

The CMTS sends a "Sync" broadcast at least every 200 msec, which is used for system timing. In addition, the CMTS sends out an Upstream Channel Descriptor (UCD) every two seconds, which tells modems the upstream frequency to transmit on along with symbol rate, modulation profile, and other parameters necessary to communicate on the network. Finally the CMTS sends out Media Access Protocol (MAP) messages to allocate "talk time" to each cable modem. Since there are many cable modems and only one upstream frequency, the cable modems must "time-share" the upstream channel, which is called Time Division Multiple Access (TDMA).

Once a cable modem is powered on and connected to the RF cable of a CATV network, it will begin a "hunt" for a valid downstream DOCSIS channel. First the cable modem looks for and locks to any 64- or 256-QAM digital channel. When the cable modem successfully locks to a QAM channel, it looks for the Sync, UCD and MAP messages from the CMTS. If it finds these messages, it knows it is on an active DOCSIS channel. If they are not present, the cable modem assumes the DOCSIS channel is offline or it is on a video QAM channel and continues its search.

Assuming a successful lock above, the cable modem is now ready to begin ranging with the CMTS. The ranging process begins with Initial Ranging, which is a process in which the cable modem begins by sending a Range-Request at a power of 8 dBmV (very low power). If it does not receive a Range-Response from the CMTS the cable modem retransmits the Range-Requests at a 3 dB higher power level and continues the process until a Range-Response is received.

The following diagram shows this process:

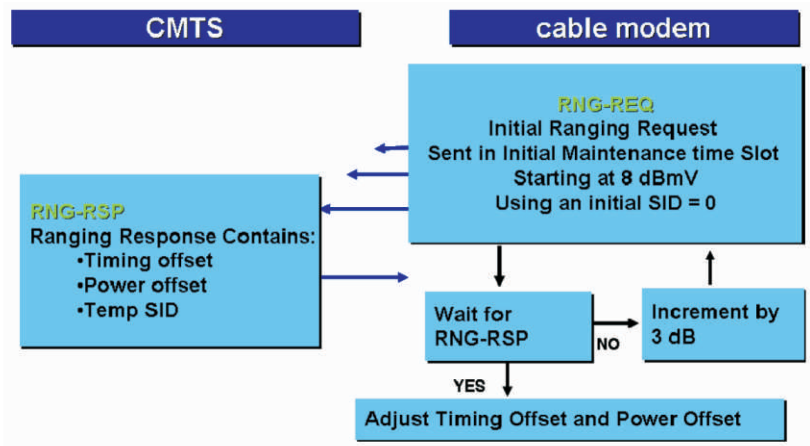

Figure 8 : Ranging with CMTS

Ranging with CMTS

All initial ranging occurs during a "contention" window, which means that the CMTS does not have prior knowledge of the cable modems existence. Therefore it is possible that when multiple cable modems are attempting to register during the contention window that they could interfere with each other and cause collisions. DOCSIS has a built-in back-off window for just such an occurrence which will help alleviate collisions in the contention window. This is most prevalent when there is a system outage and many cable modems are trying to come back online at the same time. Once the modem has received its first Range-Response from the CMTS it will moved from Initial Ranging to Station Maintenance. The cable modem will also be instructed by the CMTS to make adjustments to its transmitting frequency, amplitude, timing offset and optionally pre-equalization. Station Maintenance (Ranging) will occur at least once in every 30 seconds for each cable modem on the DOCSIS network to continue making these adjustments. This will also help the CMTS to get the details of the modems which are online.

Next the cable modem is ready to move from DOCSIS protocol communications to IP layer communication and perform DHCP to get an IP address and the addresses of other devices in the network. Now that the cable modem is operating within its TDMA parameters, it must first ask for permission to transmit data to the CMTS by sending a bandwidth REQUEST. The CMTS will prioritize the request in its queue and issue a MAP for the specific cable modem. When the cable modem's time slot comes up, it can transmit a DHCP discover to find a DHCP server. The DHCP server on the network will respond and offer an IP address to the cable modem along with a number of other network addresses, gateways and parameters for proper network operation. A DHCP Request and Acknowledgement are required to complete and confirm the transactions.

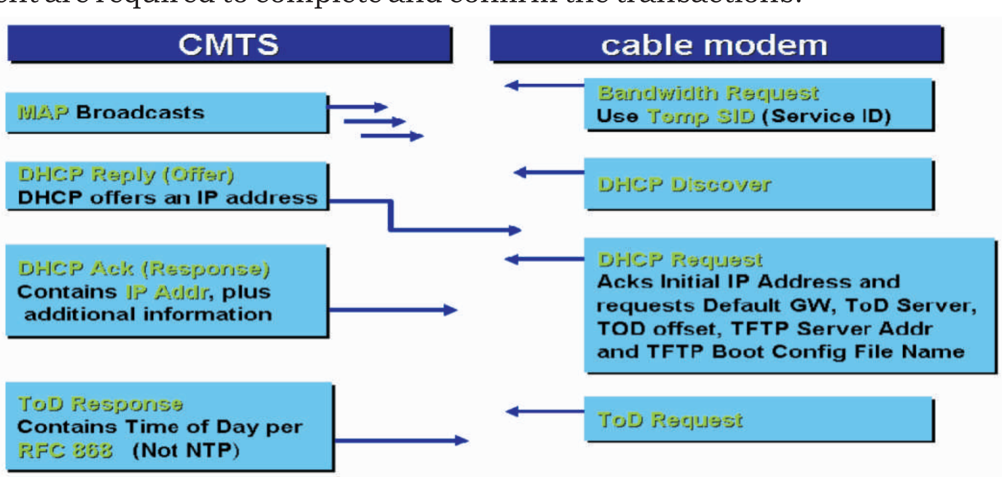

Figure 9 : DHCP and ToD

DHCP and ToD

Next the cable modem will request the Time of Day from the ToD server. This is a simple transaction that was a requirement in DOCSIS 1.0, but has now become an option in later release of the specification. In DOCSIS 3.0, more emphasis is placed upon the critical nature of over-all network timing accuracy.

Now the cable modem is ready to download a file called a configuration file from the TFTP server. The configuration file contains all of the parameters the cable modems needs for network access speeds, quality of service, advanced service features such as voice-over-IP and much more. The following diagram illustrates the flow of procuring the configuration file.

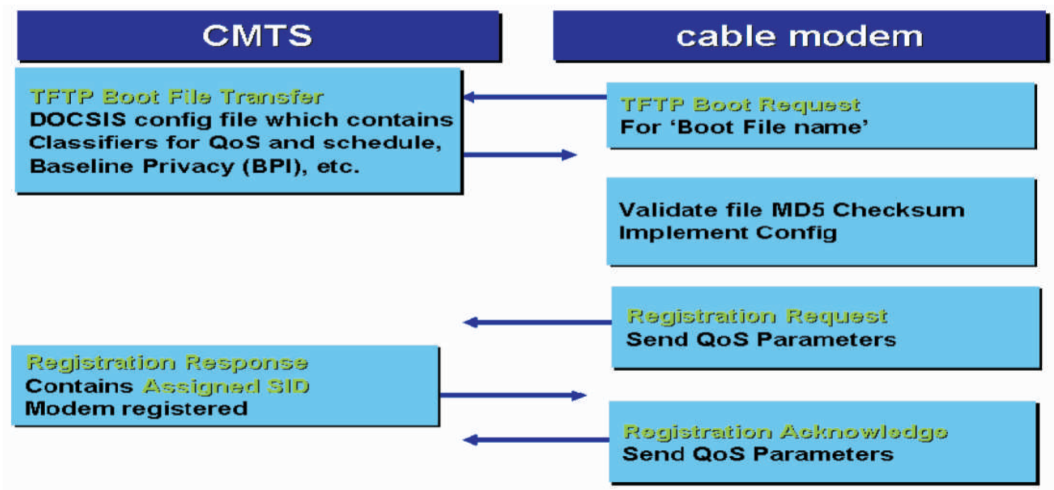

Figure 10 : TFTP Download and Registration

TFTP Download and Registration

Upon validating the MD5 check-sum to ensure the TFTP file was properly downloaded, the cable modem is now ready to perform the most important step – registration. The cable will send a Registration Request to the CMTS along with a list of TLV (Type Length Value) parameters that tell the CMTS how the cable modem has been told it is to operate on the network. The CMTS reviews this information against the parameters it has been programmed with by the system administrator. Unless data has been corrupted or there is an interoperability issue, the CMTS will send a Registration Response "Okay" message and assign the cable modem a Service IDentifier (SID). The cable modem will respond back with a Registration Acknowledgment notifying the CMTS that it has received confirmation of registration and it is now online and ready for subscribers to transmit Internet data.

After registration a cable modem could next enter an encryption mode called Baseline Privacy Interface (BPI) protocol.

As the cable modems share the upstream channel by using Time Division Multiple Access (TDMA), when a cable modem is not transmitting data its RF transmitter is turned off. In order to transmit data it must transmit a burst of data which contains a REQUEST to the CMTS. The REQUEST relays the cable modem's Service IDentifier and the number of bytes of information the modem has to transmit in its buffer. The CMTS prioritizes all incoming REQUESTS and sends out time slots to each cable modem in MAP messages that contains the information about SID, when the SID (i.e. cable modem) can transmit, and how many bytes to transmit. It is not uncommon that the CMTS may force a cable modem to span its transmission over multiple time slots since it is a shared medium. Speaking of time slots, in DOCSIS lingo, a time slot is actually referred to as a "mini-slot". A mini-slot is made of an integer number of "ticks", depending upon the configuration of the CMTS. One tick is equal to 6.25 micro seconds.

Current Scenario

The ITU Telecommunication Standardization Sector (ITU-T) has approved the various versions of DOCSIS as international standards.

DOCSIS vs. EURO DOCSIS

As frequency allocation bandwidth plans differ between United States and European CATV systems, DOCSIS standards have been modified for use in Europe. These modifications were published under the name EuroDOCSIS. The differences between the bandwidths exist because European cable TV conforms to PAL standards of 8 MHz bandwidth and North American cable TV conforms to ATSC standards which specify 6 MHz. The wider bandwidth in EuroDOCSIS architectures permits more bandwidth to be allocated to the downstream data path (toward the user).

Most cable systems in Japan and Colombia use the North American version of DOCSIS, while some employ a variant of DOCSIS that uses upstream channels that are based on a 9.216 MHz master clock (as opposed to 10.24 MHz used in DOCSIS/EuroDOCSIS) resulting in upstream channel widths that are a power-of-two division of 6 MHz (as opposed to 6.4 MHz in DOCSIS/EuroDOCSIS).

Security Concerns

Security systems in DOCSIS are still under development.

DOCSIS includes MAC layer security services in its Baseline Privacy Interface (BPI) specifications.

DOCSIS 1.0 utilized the initial BPI specification. BPI was later improved with the release of the Baseline Privacy Interface Plus (BPI+) specification used by DOCSIS 1.1 & 2.0. Most recently, a number of enhancements to the BPI were added as part of DOCSIS 3.0, and the specification was renamed "Security" (SEC).

The intent of the BPI/SEC specifications is to describe MAC layer security services for DOCSIS CMTS to cable modem communications. BPI/SEC security goals are twofold:

- provide cable modem users with data privacy across the cable network
- provide cable service operators with service protection; i.e., prevent unauthorized modems and users from gaining access to the network's RF MAC services

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