DOCSIS® EoC for EPON in China

Driven by increasing competitive pressure and market evolution toward triple-play services in China, Chinese cable operators are seeking standards-based solutions for economical and future-proof final-100-meter access technologies. Much of the demand is driven by the need to provide higher bandwidth packet transport for Internet connectivity, video and voice services. Current solutions involve various technologies generally referred to as Ethernet over Coax or EoC. These solutions are vendor-specific and consequently provide no interoperability between equipment vendors and no standardized method of implementing Quality of Service (QoS) for isochronous services such as voice. DOCSIS® provides a standardized technology for services over cable and thus has strong interoperability between system providers and robust QoS methods, ensuring packet delivery during periods of network congestion.

This paper presents an overview of using DOCSIS as an EoC solution for China-based cable operators. The solution presented leverages properties of Ethernet Passive Optical Network (EPON) networks to provide QoS continuity across the fiber/coax boundary, as well as to enable the economics of the solution to be competitive with current EoC offerings.

Table of Contents

Market Drivers

China's cable operators are undergoing a significant structural shift toward provincial consolidation and service expansion. The Chinese government recently designated twelve cities as trial sites for triple-play services and next-generation architectures as part of China's Next Generation Broadcast [NGB] initiative. This initiative's goal is to create state-of-the-art broadcast networks in China and will facilitate the convergence of the telecommunication, Internet, and CATV networks.

This program is expected to cause cable operators to significantly increase their capital expenditures over the next several years as they rush to upgrade their networks. The focus on capital spending will require innovative network architectures as cable operators build their networks to reach Chinese consumers in a cost-effective manner.

In the large cities of China, most triple-play consumers live in multitenant buildings (referred to as Multi Dwelling Units or MDU) with the number of residents usually being less than 500 residents per building or cluster. These buildings are typically served by fiber with one of several "final 100 meter" technologies installed in the buildings' risers. These technologies include fiber, twisted pair, Ethernet, and coax as shown in Final 100-Meter Options in Multidwelling Units. Cable operators typically have access to the cable in the risers and would prefer to use this cable for their services.

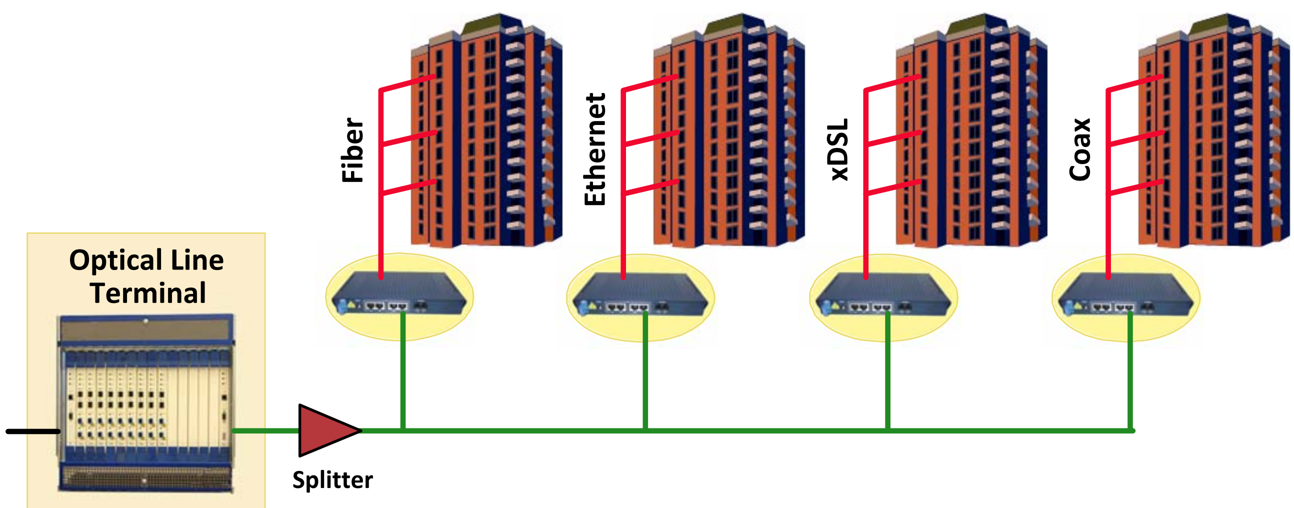


Figure 1: Final 100-Meter Options in Multidwelling Units

Several technologies exist for enabling two-way services over cable. These include a number of proprietary and vendor-specific methods generally referred to as Ethernet over Coax or EoC. However, a standards-based approach to using cable is typically preferred by operators, since this ensures vendor interoperability and provides lower costs as suppliers take advantage of the economies of scale in building their products. DOCSIS (Data Over Cable Systems Interface Standard) and EuroDOCSIS are standards that define two-way operation over a cable network. DOCSIS also provides the necessary Quality of Service (QoS) tools for ensuring voice call connectivity during periods of network congestion that are anticipated in triple-play networks. Millions of DOCSIS modems have been shipped worldwide over the last 12 years, proving DOCSIS to be a robust and mature technology for voice, video, and IP video services.

DOCSIS, however, was engineered to support an unknown RF environment with limited bandwidth in a network that usually consists of thousands of subscribers. The management and arbitration of subscribers on the shared cable is performed by the Cable Modem Termination System or CMTS. While a CMTS can be quite cost-effective for offering two-way services on cable, its costs must be spread across thousands of users to be at parity with those costs associated with existing EoC solutions. The use of a traditional and commercially available CMTS to serve a MDU facility with only 200 users or fewer would be cost-prohibitive.

This paper will discuss a new and innovative approach called DOCSIS EoC that can be used to deploy DOCSIS in MDUs in China. The approach will leverage existing EPON Optical Line Terminal (OLT) equipment to enable two-way services over cable at cost points competitive with proprietary EoC solutions, while providing speeds up to 400 Mbps.

DOCSIS EoC proposes a unique solution for China. It leverages China-developed EPON standards and customizes DOCSIS as a “final 100 meter” solution specific to the infrastructure requirements of China and China’s next-generation convergence requirements.

DOCSIS EoC Solution and Technical Overview

The DOCSIS EoC architecture utilizes the DOCSIS MAC/PHY layer technology and EPON network elements to implement an economical solution for utilizing DOCSIS CPE in China’s MDUs. The main network elements are shown in DOCSIS EoC for EPON Network Architecture.

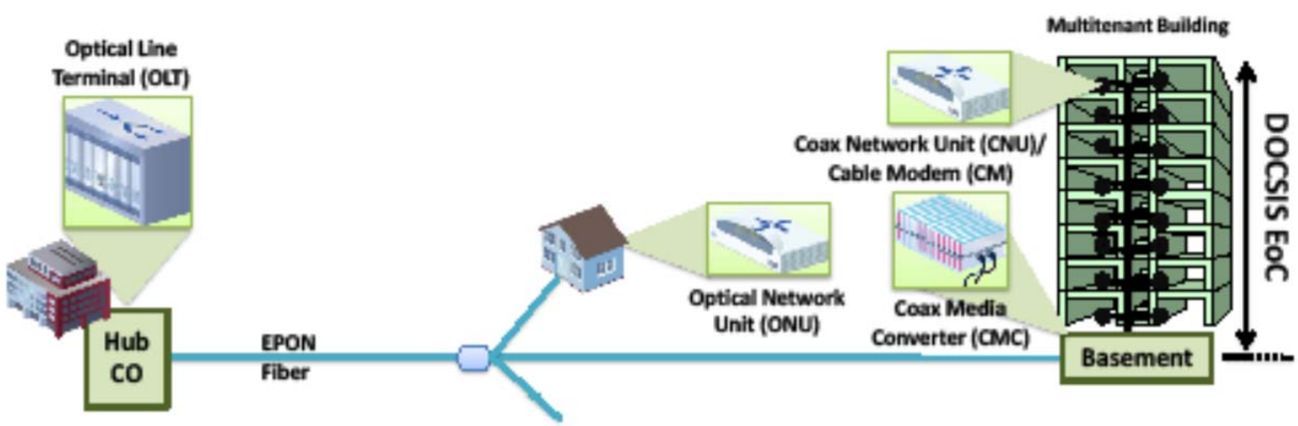


Figure 2: DOCSIS EoC for EPON Network Architecture

The fiber and cable protocols stacks are summarized in DOCSIS EoC for EPON Protocol Summary. The EPON OLT provides packet ingress/egress on the WAN side of the broadband network and serves the fiber leading to the MDU with the EPON protocol stack shown over the blue “Fiber” portion of the diagram. At the MDU facility the Coaxial Media Converter (CMC) provides the bridging function from EPON to the DOCSIS domain for Radio Frequency (RF) transmission over the coaxial risers in the building. The DOCSIS protocol is terminated at the subscriber location with standard off-the-shelf DOCSIS certified cable modems (CMs), Embedded Multimedia Terminal Adapters, (EMTA), or set-top boxes (STB) with embedded DOCSIS modems that utilize the DOCSIS Set-top Gateway protocol (DSG).

Figure 3: DOCSIS EoC for EPON Protocol Summary

The CMC equipment is responsible for terminating the EPON protocol with an embedded Optical Network Unit (ONU) and originating the DOCSIS protocol using DOCSIS MAC and PHY layer technology found in CMTS equipment. In order to achieve the economic targets for the CMC, it is necessary to leverage existing OLT functions and to select only the most advanced DOCSIS functions necessary to guarantee proper operation of certified DOCSIS CPE modems and STBs. Specific capabilities leveraged in the OLT include packet classification and switching functions that tag packets with their order of priority and direct which port at the CMC the packet should be sent to.

The elements can be deployed and managed using third-party China Operations, Administration, and Management (OAM)-compliant network management systems (NMS) or, conversely, using DOCSIS Command Line Interface (CLI) instructions.

The CMC supports DOCSIS 3.0 and DOCSIS 2.0 operation, minus the following functions that are not included to reduce costs:

MAC Layer

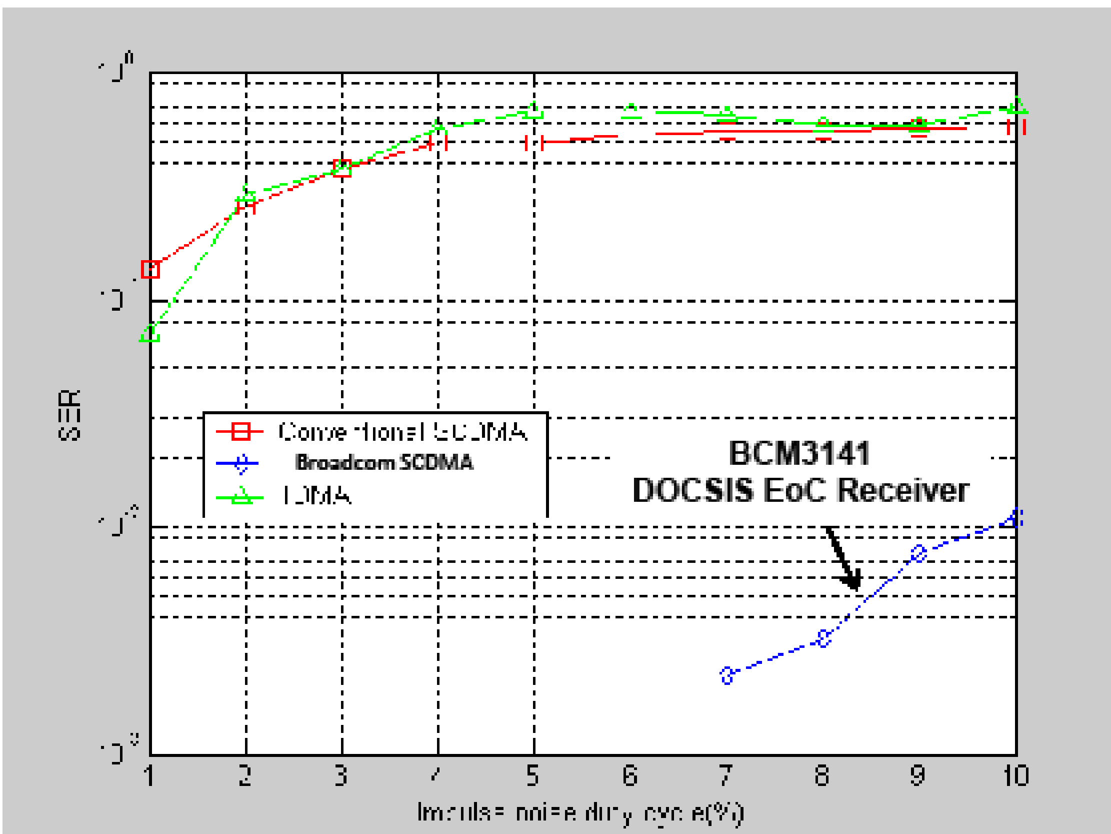
1. **Payload Header Suppression (PHS)**: PHS is used to increase network efficiency by suppressing fields in the TCP portion of an IP packet and then reinserting these items at the receiver. PHS was created in DOCSIS 1.0, which was engineered to serve networks that may have limited upstream and downstream bandwidth. With improved plant conditions and increased bandwidth with DOCSIS 2.0 and DOCSIS 3.0, the benefits of PHS are minimized. In addition, PHS is only useful for operator-managed services where the operator explicitly sets up a separate service. Today this basically means voice, and voice is occupying a smaller percentage of the total bandwidth, so the efficiency gain is less valuable.
2. **Baseline Privacy Interface using Advanced Encryption Standard (AES)**: AES is a cipher that was added in DOCSIS 3.0 for BPI. DOCSIS 2.0 uses the DES cipher for BPI and the CMC will utilize DES in order to reduce costs at the MAC layer.
3. **Logical Channel**: DOCSIS 2.0 added logical channel operation to enable ATDMA and SCDMA PHY operation over the same physical channel. The DOCSIS EoC CMC only supports SCDMA operation, eliminating the need for logical channels.

DOCSIS EoC RF Transmission

Upstream PHY

DOCSIS EoC utilizes SCDMA, the most advanced PHY-layer technology found in DOCSIS. DOCSIS EoC SCDMA also supports 256 QAM operation in the upstream, which provides a 40 Mbps line rate in a 6 MHz channel, a 33% improvement over 64 QAM operation. In addition, SCDMA uses orthogonal codes to provide a robust transmission method for cable modems.

Today's burst receivers utilize powerful DSPs to implement complex algorithms that leverage the orthogonal codes of SCDMA to mitigate burst and impulse noise on cable plants. SCDMA Operation in the Presence of Impulse Noise shows the noise mitigation properties of Broadcom's BCM3141 DOCSIS EoC burst receiver compared to ATDMA receivers, as well as conventional SCDMA receivers operating without sufficient DSP power to leverage SCDMA codes for noise mitigation.

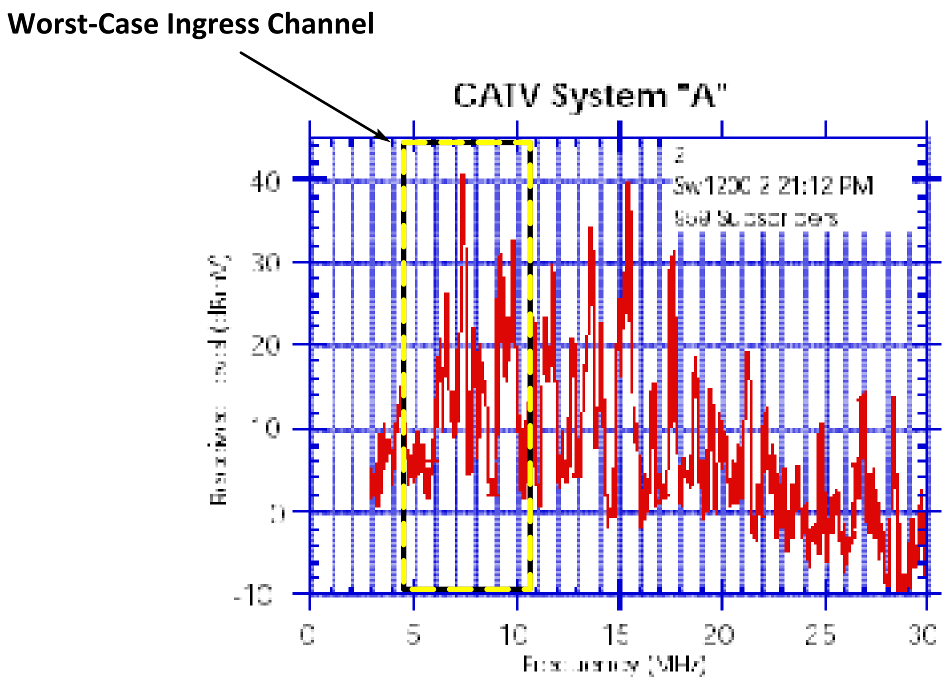


Chip Rate = 5.12 Mcps, Impulse Noise = 1 Microsec, +20 dBc
K=32, L=32, QPSK, SNR=25 dB

Figure 4: SCDMA Operation in the Presence of Impulse Noise

SCDMA's orthogonal codes also allow it to operate in the presence of strong ingress noise. By selectively using only certain codes, SCDMA can detect and avoid both narrowband and wideband ingress. This technology is called Selectable Active Codes (SAC) and is a standard in DOCSIS CPE, allowing equipment from multiple vendors to operate in the presence of ingress.

As a example of this technology, Ingress on Cable Plant shows a spectrum analyzer capture from a real cable plant with the worst-case ingress outlined by the dotted rectangle.

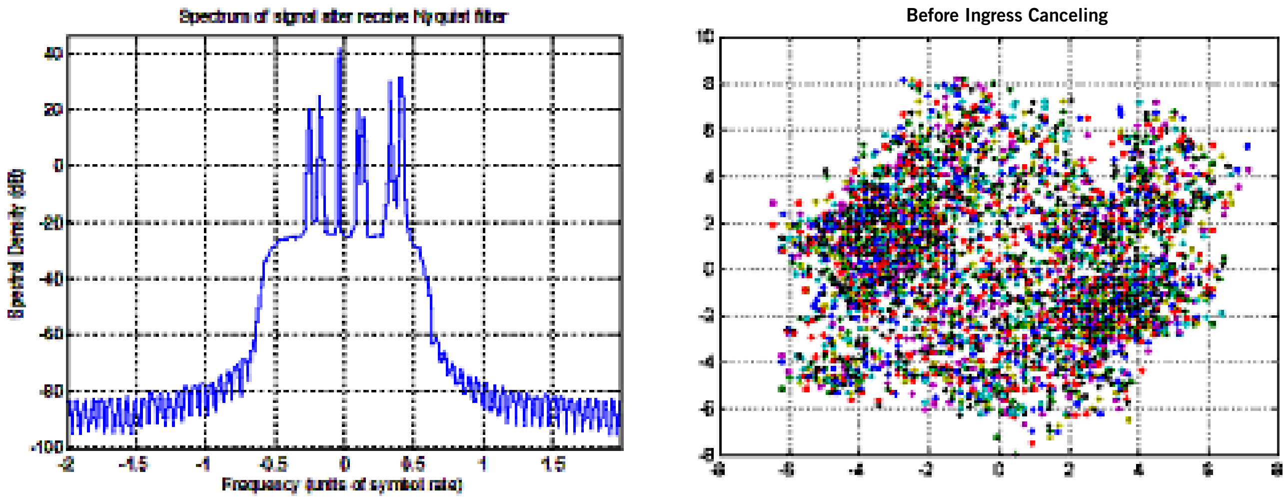


AWGN SNR = 30 dB for 64 QAM and 24 dB for 16 QAM
Chip rate = 5.12 Mcps, Ingress to Carrier Power Ratio Is Varied in dBc.

Source of Ingress Channel: Network Reliability Council: Reliability Issues•–Changing Technologies Focus Group, New Wireline Access Technologies Subteam Final Report, Appendix B

Figure 5: Ingress on Cable Plant

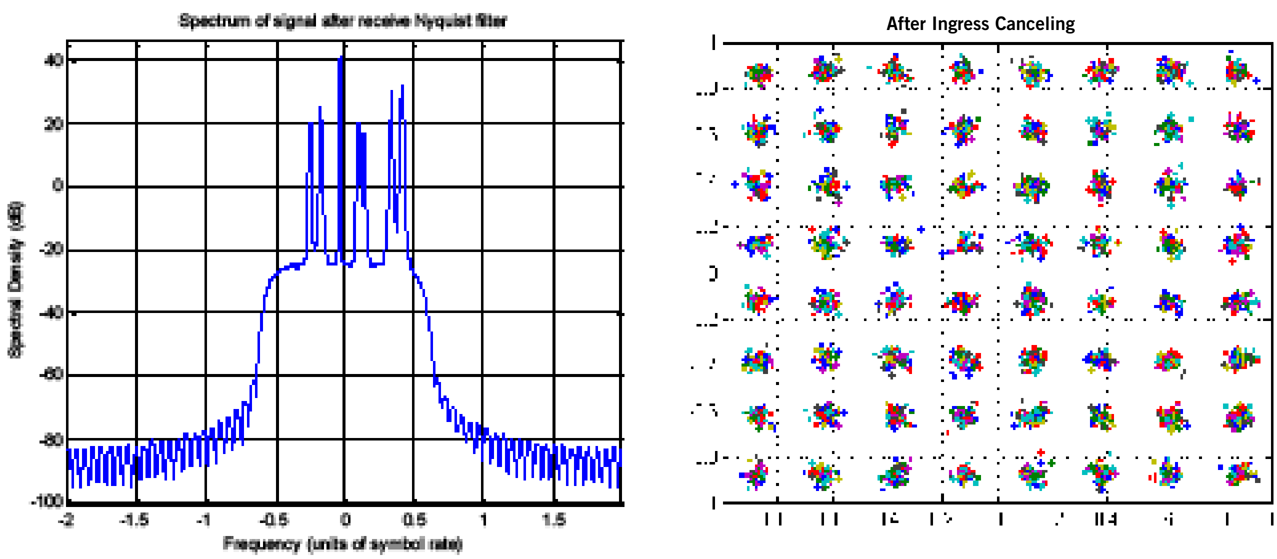
This ingress noise was applied to the BCM3141 DOCSIS EoC Burst Receiver and allowed to interfere with a 64 QAM, 5 Msym/sec modem transmission. Without SAC the constellation is unrecoverable, as shown on the right in Conventional SCDMA with Ingress.



Chip Rate = 5.12 Mcps, K = 32, L = 32, 64 QAM, SNR = 30 dB, Ingress Level = 15 dBc

Figure 6: Conventional SCDMA with Ingress

However, with SAC enabled on the receiver, the ingress is mitigated and the 64 QAM constellation is recovered with sufficient SNR for error-free operation, as shown in DOCSIS EoC SCDMA Operation with Ingress.



Chip Rate = 5.12 Mcps, K = 32, L = 32, 64 QAM, SNR = 30 dB, Ingress Level = 15 dBc

Figure 7: DOCSIS EoC SCDMA Operation with Ingress

Downstream PHY

DOCSIS EoC also supports an advanced downstream transmission mode with 1024 QAM operation. This mode of transmission provides a 50 Mbps line rate in a 6 MHz downstream channel, a 25% improvement over 256 QAM operation. The 1024 QAM constellation is shown in DOCSIS EoC 1024 QAM Downstream Constellation.

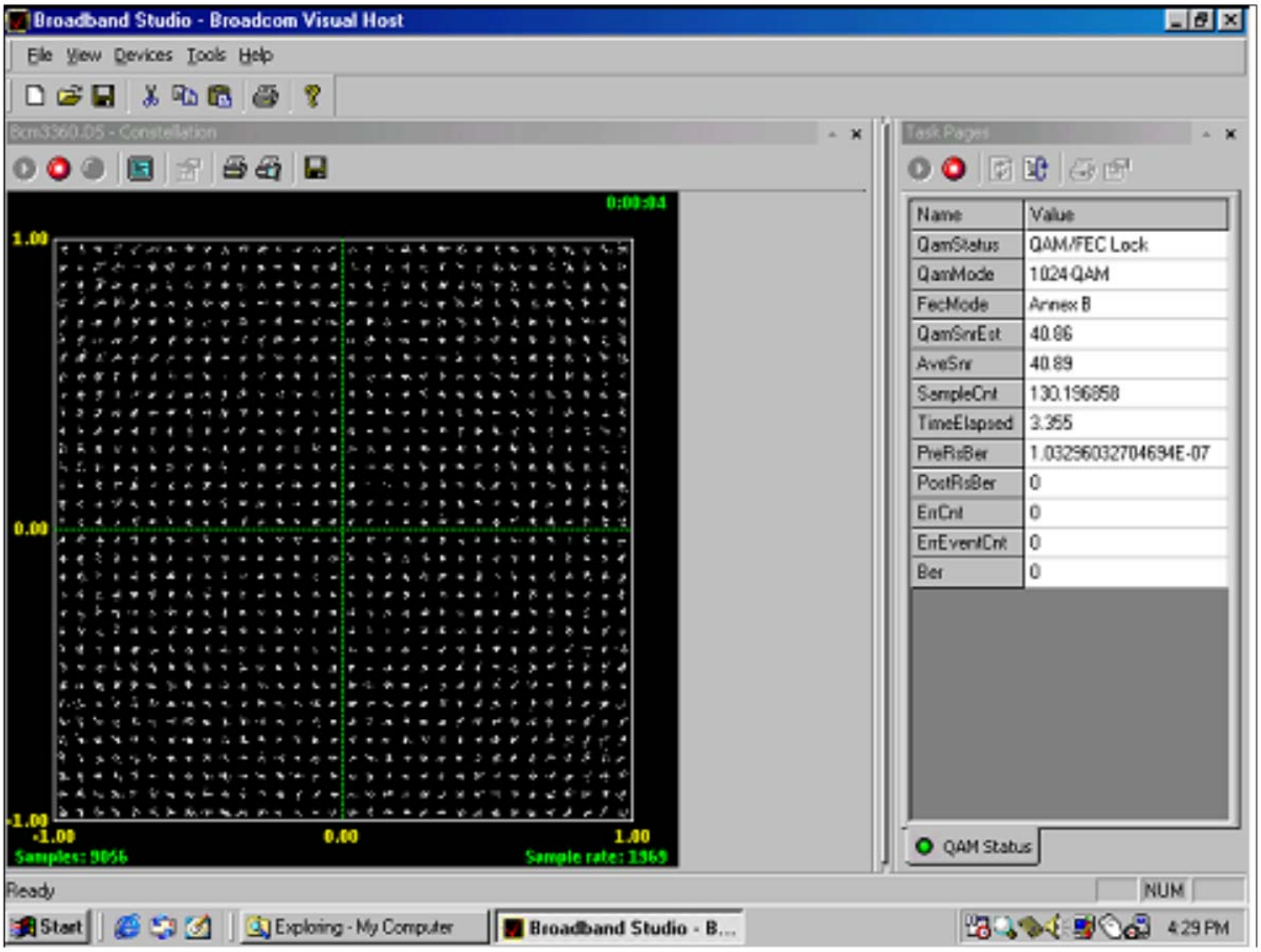


Figure 8: DOCSIS EoC 1024 QAM Downstream Constellation

MAC-Layer QoS Technology

The DOCSIS EoC provides a two-stage solution for end-to-end QoS. The DOCSIS MAC provides per-customer, per-service scheduling and shaping for both upstream and downstream direction. By individually controlling and monitoring the customer services, operators can provide value-added connections beyond internet access for a variety of uses such as video conferencing, virtual private networks, and network backup. On the Passive Optical Network (PON), the customer services are grouped with guaranteed bandwidth and delay parameters over the PON. DOCSIS EoC and the CMC provide the bridge between the two QoS domains, as illustrated in EPON to DOCSIS QoS Mapping.

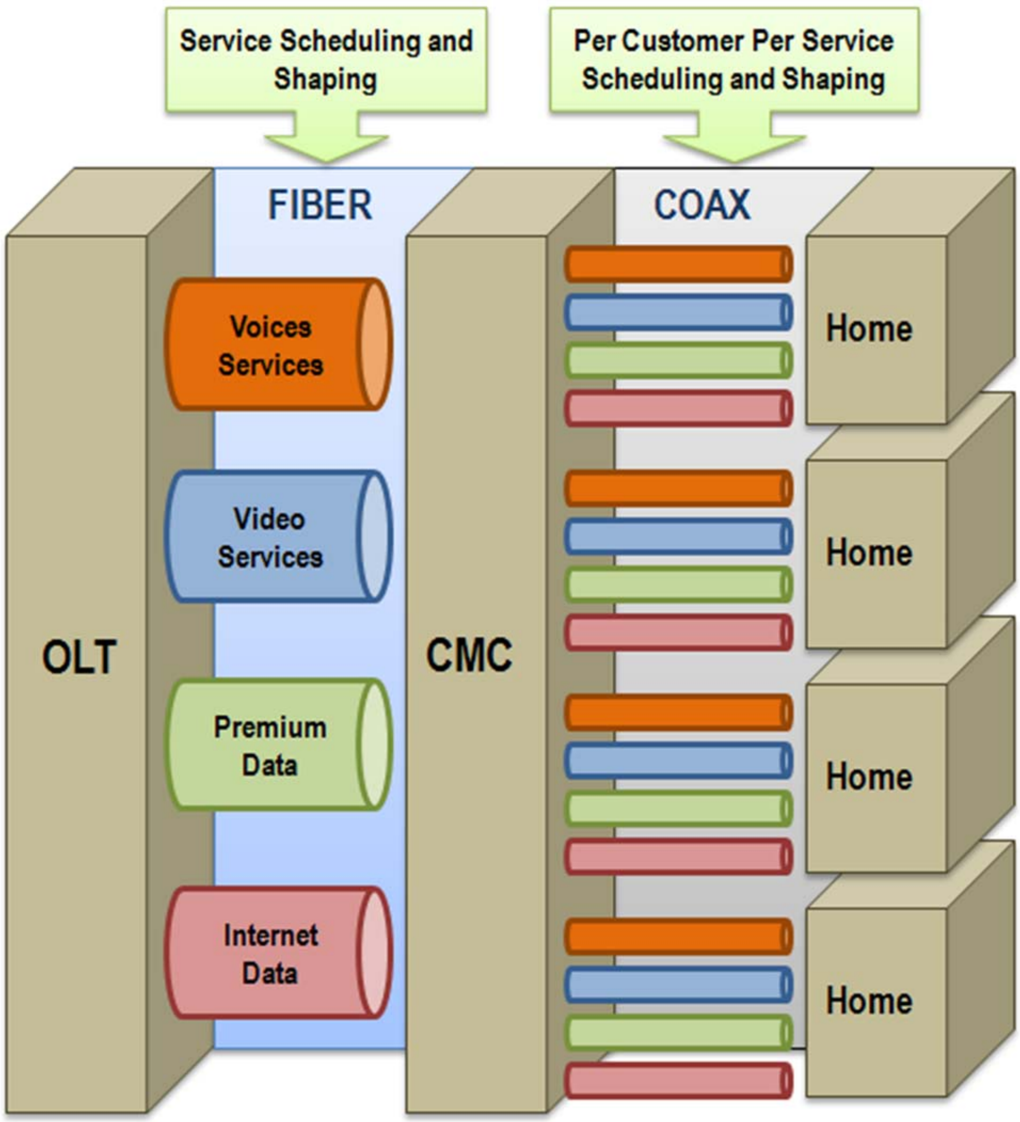


Figure 9: EPON to DOCSIS QoS Mapping

DOCSIS Quality of Service

The DOCSIS standard defines a proven QoS methodology, using service flow Identifiers to separately schedule packets per customer and per service. Using the QoS methods available in DOCSIS, the CMC can provide per-service and per-customer service level agreements. The CMC can monitor the performance for any user on a per-service basis. Services can be established via static provisioning or dynamically based on operator demand. Once established, the service flow will have a minimum bandwidth guarantee and maximum bandwidth limit, along with delay bounds for both the upstream and downstream directions. The CMC provides accurate shaping that alleviates the need for expensive traffic management devices in the network. With multiple service flows and embedded traffic management, operators can provide high-quality triple-play services on lightly loaded or oversubscribed networks.

Because DOCSIS uses Frequency Division Multiplexing (FDM) between the upstream and downstream directions, it is possible to provide video services over standard QAMs or via DOCSIS IP video. The uninterrupted downstream of FDM along with an isolated service flow for the video-on-demand, multicast video, or unicast video allows for high-quality video to the home. Half-duplex EoC systems will struggle to provide high-quality video to the home because of the contention delay with multiple transmitters.

EPON Quality of Service

Ethernet PON allows for multiple logical links to provide isolation of services in the upstream and downstream direction. The DOCSIS EoC system uses multiple Logical Links Identifiers (LLIDs) to isolate the services provided on the coax network. The service contracts on the logical link can be set to guarantee the bandwidth and delay requirements of service flows on the CMC. Because the EPON scheduler is work-conserving, unused bandwidth on guaranteed services will be redistributed for other services.

DOCSIS EoC Specification Summary

Table 1: DOCSIS EoC Specification Summary

DOCSIS EoC Coax Media Converter Item	Specification
DOCSIS CPE supported	DOCSIS 2.0/3.0
Number of subscribers (per ONU)	≤200
Number of subscribers per EPON OLT Port	≤1000
Number of service flows per CMC	≤1024
Upstream modulation	SCDMA
Upstream modulation order	QPSK, 16, 32, 64, 128, and 256 QAM
Upstream symbol rate	1.28, 2.56 & 5.12 Msymbols/sec
Upstream bit rate per channel	≤40 Mbit/sec
Number of bonded upstream channels	≤4
Upstream aggregate bit rate	≤160 Mbit/Sec
Upstream receiver power (four bonded channels)	1.280 Msymbols/sec: -13 to +17dBmV 2.560 Msymbols/sec: -10 to +20 dBmV 5.120 Msymbols/sec: -7 to +23 dBmV
Upstream frequency range	5 to 65 MHz
Downstream modulation order	64, 256, and 1024 QAM
Downstream channel bandwidth	Annex A (QAM 64 and 256) Annex B (QAM 64, 256, 512, and 1024)
Downstream bit rate per channel	≤69 Mbit/sec
Number of bonded downstream channels	≤16
Downstream aggregate bit rate	≤1 Gbits/sec
Downstream power (eight bonded channels)	+50 dBmV per channel
Downstream frequency range	50 to 1 GHz

Summary

DOCSIS EoC for EPON enables China's cable operators to deploy DOCSIS-based networks at cost parity to proprietary EoC technologies while obtaining all of the benefits of using standards-based equipment. These benefits include multivendor interoperability, standardized and proven QoS for voice services, lowest cost, and wide availability of both cable modem and set-top box systems.

Complete reference designs to realize a DOCSIS EoC for EPON solution—including schematics, software, and hardware components—are available from Broadcom Corporation.