

DAC Overview – Business Service Applications and Benefits

A Technical Paper prepared for the Society of Cable Telecommunications Engineers By

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Introduction

Carrier Ethernet business services have become a growing revenue source for Cable MSOs, and this growth is projected to increase in the coming years.

- Ethernet business service revenues to top \$81 Billion worldwide by 2016 – *Infonetics Research*
- U.S. MSO Business Services revenue exceeds \$5 billion, with a Compound Aggregate Growth Rate of 31% over the next five years – *Pike Fischer*
- Cable MSOs own nearly 25% of the U.S. Ethernet market, which will grow to 30% as large MSOs increase Ethernet sales – *Heavy Reading*

The key to this sustained growth is gaining market share in medium and large businesses. Cable MSOs have had success with small businesses within the HFC plant footprint, but the HFC network and DOCSIS do not provide the bandwidth and the Service OAM fault management and performance monitoring required for Carrier Ethernet business services.

The EPON network architecture delivers dedicated, high-speed, symmetrical bandwidth, but the provisioning and management of EPON networks is not standardized. DOCSIS Provisioning of EPON (DPoE™) Networks enables the delivery of Carrier Ethernet services over EPON with DOCSIS management and provisioning.

This paper will review the business benefits of DPoE Networks, and the added benefits of demarcation device (DEMARC) Auto-Configuration with Pluggable ONUs and Network Interface Devices (NIDs):

- DEMARC Auto-Configuration (DAC) simplifies auto provisioning of Carrier Ethernet services to reduce operating costs and speed service turn up.
- The Pluggable ONU enables the DAC process with the added business benefits of streamlining customer equipment deployments on DPoE Networks.
- The Carrier Ethernet DEMARC, or Network Interface Device, enables Carrier Ethernet fault management and performance monitoring to provide Service Level Agreements.

This paper concludes with a report on a Time Warner Cable lab trial of DEMARC Auto-Configuration in a DPoE environment with Pluggable ONUs and DEMARCs. The equipment configuration, the lab trial results and the projected OPEX savings are reviewed.

Business Case for DOCSIS Provisioning

One of the key benefits of DOCSIS[®] service provisioning is the automated configuration of the cable modem (CM) when installed at the customer premise. Traditionally, a newly installed CM is automatically provisioned by the Cable Modem Termination System (CMTS) and the DOCSIS Operations and Support Systems (OSS), providing a seamless plug-and-play experience from the perspective of the installer (which in many cases is the subscriber).

The CM and CMTS operate on HFC networks, which have limited support for Carrier Ethernet mobile backhaul and business services that require enforceable Service Level Agreements (SLAs). SLAs guarantee the Ethernet service with dedicated throughput/bandwidth and multiple Classes of Service (CoS). These services are assured with performance attributes such as frame delay, frame delay variation and frame loss. In addition, HFC networks are not typically located in areas that reach business locations.

Because of the growing demand for Carrier Ethernet services, and the lucrative revenue from the business services market, MSOs are turning to alternative access networks to address the limitations of HFC. One of these alternative solutions is Ethernet Passive Optical Network (EPON). Similar to HFC, EPON uses a point to multi-point topology, where a head-end hub services multiple subscriber endpoints. But unlike HFC, EPON can be provisioned to provide dedicated symmetrical throughput for a specific subscriber, while also offering multiple CoS for the subscriber.

But EPON is designed for the telecommunications market and EPON systems typically use a proprietary management interface. Conventional EPON systems force MSOs to maintain a proprietary OSS in addition to the DOCSIS OSS. The addition of proprietary management increases the complexity of the network, which in turn increases back office OPEX.

As a solution to this management system disparity, CableLabs introduced the DPoE specifications, which allows the EPON system to be transparently managed and provisioned by the DOCSIS OSS. The DPoE specifications define the DPoE System, which is analogous to the CMTS, and together with a virtual cable modem (vCM) and DPoE ONU (D-ONU) mimic the actions of a traditional DOCSIS cable modem. The resulting management scheme allows MSOs to leverage the existing DOCSIS OSS to provision Ethernet services, and automatically configure the EPON ONU.

Typically, the customer-facing interface on the ONU is attached to a DEMARC which provides a demarcation point connecting the operator and the subscriber network. The DEMARC is a device that is owned by the operator and provides specific functions to deliver Carrier Ethernet services – providing a testing and monitoring point to measure the performance attributes.

DEMARC Auto-Configuration (DAC)

The concept of automatically provisioning Ethernet services is further extended to the DEMARC with the release of the CableLabs DPoE DEMARC specification. The DEMARC specification defines the DAC process that automatically provisions the DEMARC after installation, requiring little or no interaction from the installer; similar to the installation of a Cable Modem. The automation provided by the DAC process accelerates Ethernet service delivery.

The following DAC process example is based on a pluggable D-ONU, which is an SFP (Small Form-factor Pluggable) transceiver with an EPON ONU built to the DPoE specifications, and a DEMARC that is compliant with the DEMARC specification. Stage 1 is only applicable for the pluggable D-ONU, but the subsequent stages are the same for both the pluggable D-ONU and the standalone D-ONU.

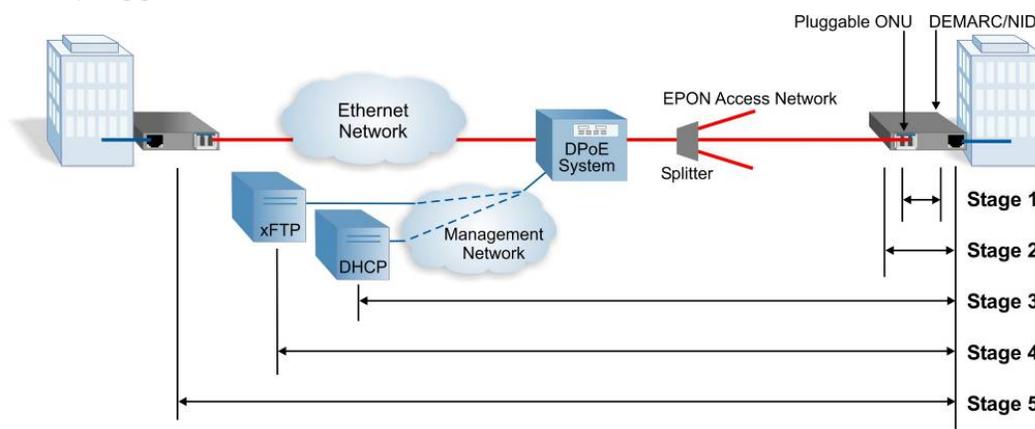


Figure 1 - STAGES OF THE DAC PROCESS

Stage 1: Detect DAC Capabilities of Pluggable ONU

When the pluggable D-ONU is installed in the DEMARC, it identifies itself to the DEMARC through the SFP diagnostic interface. This identification process informs the DEMARC that the pluggable D-ONU supports the DAC process.

Stage 2: Link Layer Discovery Protocol (LLDP)

The D-ONU sends information provided by the DPoE System to the DEMARC using the IEEE Link Layer Discovery Protocol (LLDP). Information sent through the LLDP includes management path (the DEMARC acquires the VLAN ID to establish management communication) and authentication information.

Stage 3: DEMARC Acquires IP Address and Location of File Server via DHCP

The DEMARC connects to the DHCP server and is identified by its MAC address. The DHCP server assigns an IP address to the DEMARC, and provides the location of the file server where the configuration file for the DEMARC is located.

Stage 4: DEMARC Downloads Configuration File from the File Server

Once the DEMARC has the location and IP address, it can download the configuration file from the file server.

Stage 5: DEMARC Automatic Provisioning

The DEMARC automatically configures itself based on the configuration file and turns up the Ethernet Virtual Connection (EVC). At this point the DAC process is complete.

The service is then tested and validated for SLA assurance. Once validated, the service is ready to be handed over to a customer.

The Benefits of the Pluggable ONU vs. the Standalone ONU

The D-ONU is typically a standalone modem-like box, with a network-facing port and a customer-facing port. The network-facing port connects to the fiber line and the customer-facing port connects to the subscriber's network, usually as an Ethernet interface.

When the standalone D-ONU is deployed in conjunction with a DEMARC to provide Carrier Ethernet services over the DPoE Network, the two-box configuration requires extra mounting space, cabling and power source at the customer premise. This bulky configuration adds cost and additional points of failure to the network.

An alternative to DEMARC with a standalone D-ONU is to integrate the D-ONU into the circuitry of the DEMARC (an EPON-specific DEMARC). If an EPON-specific DEMARC is being deployed, the MSO must inventory an EPON-specific DEMARC in addition to

DEMARC with pluggable ports for point-to-point Gigabit Ethernet (GE) and Wavelength-Division Multiplexing (xWDM) connections.

A better alternative to the two-box configuration and EPON-specific DEMARC is to use a pluggable D-ONU. A pluggable D-ONU is an EPON SFP transceiver with a standalone ONU chip/capability built-in according to the DPoE specifications. When installed directly into the SFP port of a DEMARC, the pluggable D-ONU is powered by the DEMARC through the SFP interface. The pluggable D-ONU eliminates the requirement for additional space, cabling, and power source.

By using a pluggable D-ONU instead of an EPON-specific DEMARC, the transport decision is decoupled from the DEMARC decision. The MSO can now deploy the same DEMARC for point-to-point GE, xWDM and EPON connections. One DEMARC can be used for all transport types by just replacing the pluggable interface to match the transport required. The MSO does not need to inventory two different DEMARCs – a DEMARC for point-to-point and xWDM connections, and an EPON-specific DEMARC. Using only one type of DEMARC for all transports reduces the complexity of spare parts inventories, field logistics, and personnel training.

Lastly, the DAC process that specifies the DEMARC can automatically detect the pluggable D-ONU during stage 1, a function not supported by the standalone D-ONU. This automatic detection process can allow the DEMARC to automatically enable DAC specific features that are normally dormant in a point-to-point Ethernet network deployment.

The Ethernet Network Interface Device as DEMARC

The DEMARC functions as a Network Interface Device (NID) for Carrier Ethernet business services. The NID provides a User to Network Interface (UNI) as defined by the Metro Ethernet Forum (MEF). A UNI manages one or more “flows” of traffic coming from the subscriber’s network and applies rate-limiting, traffic classification, and then forwards the traffic destined for another UNI on the service for delivery across the operator’s network. This service is known as an Ethernet Virtual Connection, or EVC.

The NID also provides a performance monitoring point, also known as maintenance point (MP). Service performance indicators are measured between two MPs along the path, most commonly from the Maintenance End Point (MEP) on one NID, to another MEP located on the NID at the other end of the service. The performance indicators

tracked by the operators include frame delay, frame delay variations, frame loss and availability.

Throughput performance is also tested and throughput usage is measured by the NID, by means of RFC 2544 and ITU-T Y.1564 for the former, and RMON statistics for the latter.

Ethernet Service Activation Testing

Ethernet business services, mobile backhaul and wholesale services can deliver a variety of applications, including voice, video and business-critical data. These applications can be assured with SLAs, and each application will likely have unique guaranteed performance parameters.

Y.1564 is a standardized methodology for testing these Ethernet Services and validating the associated Ethernet SLAs in a single test. Y.1564 tests the throughput, loss, delay, delay variation for each EVC or Class of Service.

RFC 2544 is also commonly used for testing Ethernet services. The Internet Engineering Task Force created RFC 2544 in 1999. It was intended to be used for testing new network equipment. It does not support testing of Ethernet services with multiple Classes of Service.

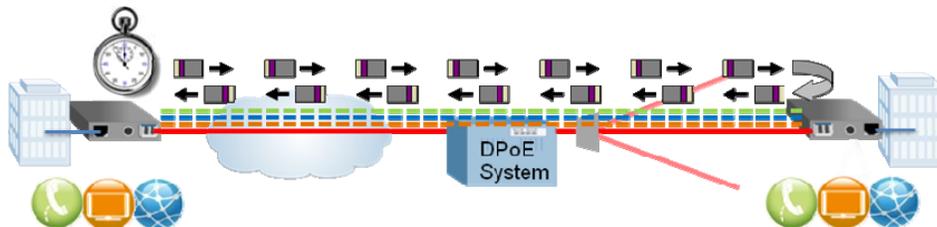


Figure 2 - Y.1564 ETHERNET SERVICE TESTING

Y.1564 does support testing Carrier Ethernet services with multiple CoS and multiple streams. NIDs that support Y.1564 can be remotely controlled to initiate and perform Y.1564 testing, and can run multiple tests across multiple flows simultaneously. For example, when turning up multiple applications (with multiple flows), Y.1564 can ensure that data applications do not affect voice traffic. Operators who deploy NIDs that support Y.1564 can speed time to market and reduce operating costs by turning up services with fewer truck rolls and having less test equipment in the field.

IEEE 802.1ag Connectivity Fault Management

IEEE 802.1ag Connectivity Fault Management (CFM) is the foundation for Service OAM. 802.1ag. It is referred to as Connectivity Fault Management because it has the capability to proactively monitor and provide fault detection of the entire EVC.

802.1ag contains three important mechanisms:

- Continuity Check Message (continuous monitoring)
- Loopback (provider-initiated fault detection)
- Linktrace (provider-initiated fault isolation)

The CCM mechanism provides a means to proactively and constantly monitor the EVC for connectivity failures between end points (NIDs). The CCMs exchanged between NIDs are analogous to “heartbeat” messages.

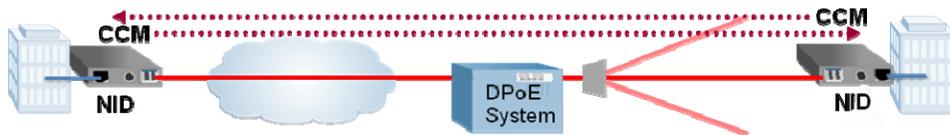


Figure 3 - 802.1ag CONTINUITY CHECK MESSAGES

As long as each NID receives a consistent flow of CCMs, the EVC has end-to-end continuity. If a NID stops receiving CCMs, it can send an alarm notification to alert the Network Management System that the EVC connection to the other NID has been lost.

The benefit of Continuity Check Messages is that network faults are proactively detected with an automatic mechanism. This enables instant notification of loss of service and gives MSOs a head start verifying and restoring service as soon as possible.

Once it has been established that there is a network fault, the MSO may choose to verify the loss of service by initiating an 802.1ag Loopback test. With Loopback, one NID sends a Loopback Messages (LBM) to the other NID, which returns a Loopback Response (LBR). LBMs/LBRs are used to validate faults along an EVC.

Once the MSO has confirmed there is a network fault, the Linktrace tool can be used to isolate the specific location of the fault. When a Linktrace Message (LTM) is initiated by a NID, it follows the service hop-by-hop to the other NID along intermediate points in the network. At each intermediate point, the LTM is propagated to the next point, and a Linktrace Response (LTR) is sent back down the service path to the initiating NID.

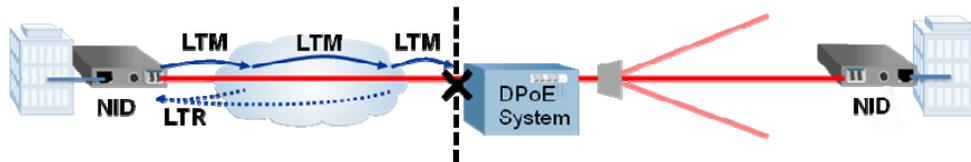


Figure 4 - 802.1ag LINKTRACE

In this example, the last point to respond with an LTM is used to isolate the location of the fault to the network.

Linktrace provides the ability to quickly isolate the problem from any remote management location without deploying costly truck rolls. This capability improves subscriber satisfaction by reducing down time and reduces loss of revenue from SLA enforcement.

ITU-T Y.1731 Performance Monitoring

ITU-T Y.1731 Performance Monitoring measures the performance of different services like Voice, Video and Data on a per EVC basis or per Class of Service basis. SLAs with comprehensive monitoring and reporting via service portals enable value-added revenue and improve customer satisfaction.

ITU-T Y.1731 expands upon the concepts of 802.1ag and adds performance measurement and monitoring, giving service providers the tools needed for SLA guarantees and assurance.

Y.1731 provides the measurement of the following performance parameters:

- Frame Loss Measurement
- Delay Measurement
- Delay Variation Measurement
- Service Availability

Frame loss is the difference between the number of frames transmitted by the NID at one end of the EVC and the number of frames received by the NID at the other end of the EVC. Frame Loss Ratio is the ratio of frames lost to total frames sent.

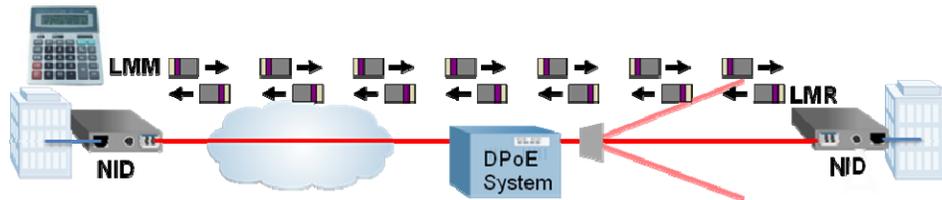


Figure 5 - Y.1731 FRAME LOSS MEASUREMENT

Frame loss is calculated between NIDs by exchanging frame counters through Loss Measurement Messages (LMM) and Loss Measurement Responses (LMR). The NIDs compare frame counters and determine the number of frames lost.

Frame delay is the time to deliver a frame from the source NID to the destination NID. Delay measurement is accomplished by NIDs exchanging Delay Measurement Message (DMM) and Delay Measurement Response (DMR) frames.

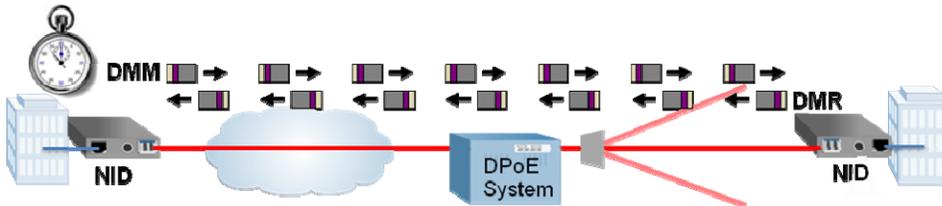


Figure 6 - Y.1731 FRAME DELAY MEASUREMENT

Frame Delay Variation is defined as the variation in delay between two delay measurements. Having a consistent delay (i.e. minimal Frame Delay Variation) is important for mobile backhaul applications and business services such as voice and video.

Some NIDs can capture and collect the data from performance monitoring and present it periodically to the service provider's network management system or a Service Portal. This data can be processed and presented in numerical or graphical form for proof of SLA conformance.

Time Warner Cable DAC Lab Trial

The first revision of the DPoE DEMARC specification was released in April 2012. Though several vendors participated in the development effort, no early versions of the DEMARC Auto-Configuration protocol had been implemented. So that the feasibility of the specification could be tested, a trial of the DEMARC auto-configuration was executed at Time Warner Cable. In addition to demonstrating the feasibility of the DAC Methods and Architecture, the trial was designed to also highlight potential improvements for the DAC specification, and to explore the operational impact of DAC.

Trial Participants

The DPoE DEMARC specification identifies several elements that are key to the implementation of the DAC protocol. In addition to the requirements placed on the DPoE System and the D-ONU, the specification also defines the DEMARC device as a new DPoE element. The requirements placed on these elements do not specify methods that are outside the scope of those used in currently available proprietary auto-configuration systems. However, since none of the available implementations were DPoE DEMARC compliant, it was necessary to solicit vendors to implement the DEMARC specification.

Time Warner Cable approached several vendors regarding the possibility of a DAC trial. Ultimately, Omnitron Systems, Broadcom Corp and Finisar were able to commit to providing the necessary equipment and development efforts. Omnitron Systems offered the iConverter GM4 Network Interface Device (NID) as the DEMARC device. This device continues to be the only known implementation of the DEMARC device.

As no DPoE System vendor has implemented the DEMARC specification, Broadcom volunteered to implement a limited version of the specification on their DPoE Reference Kit. Components used in this trial to represent the DPoE System are the Broadcom TK3723 OLT Reference Kit and the Broadcom DOCSIS Mediation Layer. The Broadcom TK3714 Reference ONU was also used to represent the standalone D-ONU. At the time of this writing, these are the only known implementations of the DAC requirements for the D-ONU and the DPoE System.

Caveats

During the development efforts leading toward the trial it was necessary to define the scope of the effort. As a result, certain features and requirements defined in the DPoE DEMARC specification were left out of the trial effort. Specifically, only the TFTP file

transfer method was implemented in the DEMARC, and no bandwidth profiles were implemented for the DAC-configured management flows. The latter of these implies that the management channel for the DEMARC receives unrestricted access to the PON's capacity and does so on a Best Effort basis. These caveats would be unacceptable in a production network, but are acceptable in the effort to meet the trial objectives.

Testbed Configuration

The functional requirements for the DAC testbed are relatively simple. These requirements are designed to simulate a real-world network supporting Ethernet services such as Ethernet Private Line (EPL) and DEMARC management traffic.

The following is a summary of the testbed requirements:

- R1 – The testbed must allow connection of a DEMARC device to a DPoE Network.
- R2 – The testbed must allow connection of a DEMARC device to the network outside the DPoE Network.
- R3 – The DEMARC must be connected to the DPoE Network through an SFP-ONU or through a standalone D-ONU.
- R4 – The DPoE Network must process 802.1Q S and C VLAN tags using TPID=0x88a8 per the IEEE 802.1Q-2011 specification.
- R5 – The testbed must provide the necessary DHCP services to support DPoE-based provisioning and DEMARC Auto-Configuration.
- R6 – The testbed must provide the necessary TFTP services to support DPoE-based provisioning and DEMARC Auto-Configuration.
- R7 – The testbed must provide IP connectivity between the DPoE Network and the DPoE provisioning services.
- R8 – The testbed must transport S+C tagged user frames between the PON-attached DEMARC and the non-PON DEMARC.

The physical configuration of the testbed is pictured in Figure 7. The Layer 2/3 switch is the core of the network. Two DEMARCs are used to create the EPL connection. The laptops, the non-PON DEMARC, and the DPoE System are connected to the switch. A D-ONU is connected to the DPoE System via an 8-way optical power splitter. The other PON-attached DEMARC is connected to the ONU via the 1000Base-T port or SFP slot. Each traffic generator is connected to a DEMARC.

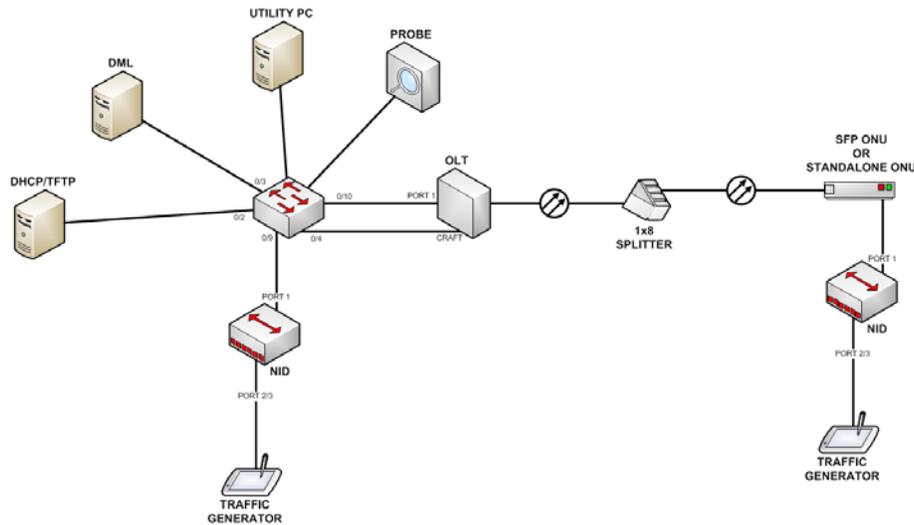


Figure 7 - TESTBED PHYSICAL CONFIGURATION

In addition to the DPoE Network elements listed above, the equipment chosen to fulfill these requirements are:

1. Layer 2/3 Switch with 10 10/100/1000Base-T ports.
2. Intel-based laptop PC running CentOS 5 with the ISC DHCP server and TFTP server.
3. Intel-based laptop PC running CentOS 5 with the Broadcom DML software.
4. Two Ethernet traffic generators.

The logical configuration of the testbed is pictured in Figure 8 and Figure 9. The testbed network needs to provide IP connectivity between all the provisioning servers, the DPoE System, and the management interfaces of each DEMARC device. In addition the testbed network needs to provide Layer-2 connectivity between the UNI ports of DEMARC devices.

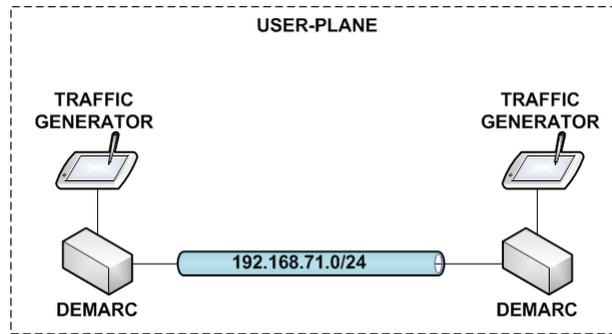


Figure 8 - TESTBED USER-PLANE CONFIGURATION

The network is configured to use S-VID=601 + C-VID range [1...4096] to segregate PON-attached DEMARC management traffic. S-VID 602 segregates direct-attached DEMARC management. VLAN 2 is the attachment domain for the provisioning and DML servers. S-VID=701 segregates user traffic from control plane traffic.

The L2/3 switch is configured to be a router, creating IP-layer connectivity between VLANs as needed in each phase of testing. In addition the switch is configured to tunnel user traffic (S-VID=701) between the DPoE System MN interface and the direct-attached DEMARC. This tunnel completes the transport segment of an Ethernet Private Line (EPL) between the DEMARC UNI ports. No IP-layer connectivity is configured between VLAN 701 and other VLANs in the network.

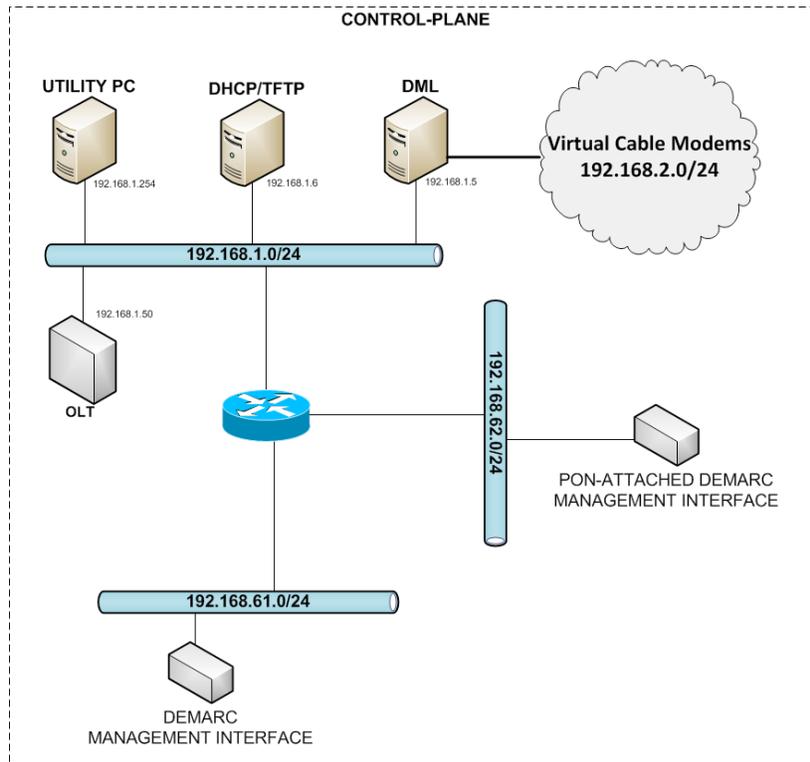


Figure 9 - TESTBED CONTROL-PLANE CONFIGURATION

Per the DPoE specification for DOCSIS-based provisioning, the vCMs receive their key IP-network and bootstrap parameters (IP address, configuration filename, file server, etc.) from the DHCP server and follow through to receive their operating parameters in a file (vCM configuration file) downloaded from the TFTP server. Similarly, the switch-attached DEMARC device receives its IP parameters from the DHCP server and operating configuration from the TFTP server following the proprietary procedures defined by manufacturer. The PON-attached DEMARC receives its IP parameters via DHCP and operating configuration from TFTP according to the DAC procedures.

The vCM configuration file was created using a DOCSIS configuration file editor. A non-DAC and a DAC-enabled configuration file were created to facilitate the phases of testing. Both configuration files contain a set of classifiers and service flows to handle user traffic. These classifiers match the S-VID for user traffic (VID=701) and direct traffic into service flows configured for a committed rate of 15Mbps and Real-Time Polling.

The non-DAC configuration file also contains a set of classifiers and service flows to handle the DEMARC management traffic on S-VID=601. The DAC-enabled configuration file removes these classifiers and adds the DAC-Enabled TLV to the DPoE Vendor-Specific Extensions section of the configuration file.

Figure 10, Figure 11, and Figure 12 are excerpts from the DAC-enabled configuration file (see the DAC-related TLVs in Figure 12).

```
3,NetworkAccess,1,1
24,UsServiceFlow,43
    6,QosParamSetType,1,07
    1,ServiceFlowRef,2,1
    10,MinReservedRate,4,15000000
    8,MaxRateSustained,4,15000000
    15,SchedulingType,1,4
    17,NominalPollInterval,4,5000
    43,VendorSpecificParams,13
        8,VendorIdentifier,3,FF FF FF
        5,L2VPNEncoding,6
        1,L2VPNIdentifier,4,000a
22,UsPacketClassifier,13
    3,ServiceFlowRef,2,1
    1,ClassifierRef,1,1
    14,IEEE802.1ad Classifier,4
        2,SVlanVid,2,02 BD
```

Figure 10 - vCM Upstream Configuration

```

25,DsServiceFlow,19
    6,QosParamSetType,1,07
    1,ServiceFlowRef,2,2
    10,MinReservedRate,4,15000000
    8,MaxRateSustained,4,15000000
23,DsPacketClassifier,28
    3,ServiceFlowRef,2,2
    1,ClassifierRef,1,2
    14,IEEE802.1adClassifier,4
        2,SvlanVid,2,02 BD
43,VendorSpecificParams,13
    8,VendorIdentifier,3,FF FF FF
    5,L2VPNEncoding,6
    1,L2VPNIdentifier,4,000a
    
```

Figure 11 - vCM Downstream Configuration

```

43,GeneralExtensionInformation,25
    8,VendorIdentifier,3,FF FF FF
    5,L2VPNEncoding,18
        1,L2VPNIdentifier,4,000a
        4,CM Interface Mask (CMIM),4,40 00 00 00
        13,L2VPNMode,1,1
        16,DACEnabled,1,01
    
```

Figure 12 - vCM Top Level Vendor Extensions for DPoE Specification

Testing Approach

A methodical approach from building the testbed through the end-to-end DAC-enabled tests is important. To facilitate such an approach, the test procedures followed a three-phase plan.

In Phase 1, the testbed was built and each element in the network was unit-tested. This phase allowed verification that the network was configured to:

1. Bootstrap an ONU/vCM using a non-DAC configuration;
2. Bootstrap a direct-attached DEMARC device using DHCP and TFTP;
3. Deliver LLDP messages and verify that LLDP messages are received and acted upon in the DEMARC device;
4. Deliver user traffic over the configured Ethernet Private Line.

In Phase 2, the testbed was modified to support testing of:

1. A DEMARC provisioned manually (via console);
2. A DEMARC provisioned using manufacturer-specific automation methods;

Making these changes allowed the test team to verify:

1. That management access to both DEMARC devices is functional;
2. The vCM configuration and L2/L3 switch configuration work together to build an EPL between the DEMARC devices;
3. Customer traffic traverses the EPL.

In Phase 3, the testbed received the DAC firmware for the ONU, an implementation of DAC functionality in the DML, and DAC agents in the DEMARC devices. The supporting testbed elements were re-configured to support the new DAC functionality, specifically to test:

1. The DAC Serving Group functions – auto-assigned management VIDs, classifiers and service flows;
2. That the DEMARC receives its configuration via DHCP and TFTP using the DAC-compliant procedures.

Success or failure was determined by verifying:

1. The management interface of the DEMARC devices could be accessed over the IP network;
2. The vCM configuration builds the classifiers and service flows necessary to build the EPL between the PON-attached DEMARC and the switch-attached DEMARC;
3. Customer traffic (generated by the Ethernet testers) traverses the EPL.

Results and Conclusions

In the final measure all the test cases that were executed yielded successful results. This supports the conclusion that the DEMARC specification is technically feasible. It is more important to recognize that the development effort occurred over a 6 week period and consumed only a small portion of the resources available in the participants' development teams. This suggests that developing a DAC implementation is economically viable and is easily justified by the savings found by an operator that would deploy DAC.

The trial also revealed that portions of the DAC specification should be clarified. Specific improvements would allow the specification:

- to remove possible race conditions between ONU bootup and DEMARC bootup;
- to avoid misalignment between DAC auto-assigned VLANS and the VLANS defined in the DEMARC's downloaded configuration file;
- to eliminate inconsistent or inconvenient use of DHCP options.

Further, optimizations should be considered that would allow implementation in limited memory environments such as the ONU.

The Impact of DEMARC Auto-Configuration

During the technical trial, a parallel effort was undertaken to explore the potential operational impacts and savings offered by DAC.

Service Level Metrics

There are many ways to measure how well a service provider is performing for its customers. However, all service providers ultimately evaluate success by revenue (gross and net) and by customer satisfaction. Further, net revenue is directly dependent on customer satisfaction due to the fact that the service provider is bound to the terms of a Service Level Agreement (SLA). The SLA defines the performance standards to which a service provider is held and typically provides recourse in the form of financial penalties if the service provider fails to meet those standards.

The typical SLA gauges customer satisfaction using metrics that indicate the performance of the service to which the customer is subscribing. In addition, the SLA will usually place performance goals on the service provider's processes.

The typical metrics defined in an SLA are:

- Bandwidth/Throughput – The rate at which the customer can reasonably expect to transmit data across the subscribed circuit, usually measured in bits-per-second.
- Latency or Frame Delay – The time required for a customer's data unit (frame, packet, etc.) to traverse the subscribed circuit, usually measured in milliseconds.
- Jitter or Frame Delay Variation – The variability of the latency of experienced by packets traversing the subscribed circuit, usually measured in milliseconds.
- Frame Loss Rate – The acceptable rate at which subscriber frames entering the network are not delivered to the destination, usually measured as a percentage of packets transmitted.
- Network/Service Availability – The amount of time that the subscribed circuit is operating and available for the customer to transmit data through the circuit. Availability is usually measured as a percentage.
- Circuit Delivery Schedule – The amount of time between the service provider receiving the customer's order and the delivery of the circuit for the customer's use.

- Trouble Response Time – The amount of time between a customer submitting a request for help trouble notification and the initial response from the service provider's support team, usually measured in minutes.
- Mean Time to Restore/Repair (MMTR) – The amount of time between initial notification of a problem with the customer's service and the time at which the customer's service is restored, usually measure in hours.
- Excessive Outage Time – The amount of time that a customer's service is unavailable that does not meet the agreed upon service availability SLA. This is usually measured in hours.
- Excessive Outage Recurrences – The number of times exceeding the SLA that a customer's service is interrupted. This is measured in occurrences.

Upon reflection, it is easy to see that only 4 of the 10 metrics listed here are directly related to the performance of the network. Those are Throughput, Delay, Jitter, and Frame Loss.

The Impact of Automation

The other 6 metrics are business-level metrics. They are measures of the service provider's processes and conformance to those processes. DAC has no effect on the performance of the network. It is necessary, then, to ask what impact DAC might have on the service provider's processes such that those process-related metrics are improved. It is important to note, also, that DAC is only one portion of a larger automated provisioning architecture defined inside DOCSIS and DPoE specifications.

Consider the sample process in Figure 13 as a basis for analyzing the effect of DPoE-based automation. This process begins with the receipt, by a field engineer, of an Installation Request (assuming any required construction is complete).

- IP Address database – Each DEMARC device requires an IP address so that it can be managed remotely. IP addresses must be unique on the network, so it is necessary for the engineer to retrieve an available IP address and the associated IP-layer parameters to be assigned to the DEMARC device.
- Wavelength Availability – In cases where the customer circuit traverses a wavelength-multiplexed fiber, the engineer will need to consult the construction teams or a list of available wavelengths to choose the wavelength to be assigned to the customer location.

This list does not exhaust the possible data elements. Many other data elements might be required to build an Ethernet service across the provider's network. Various tools exist to track these items. Most are simple spreadsheets or rudimentary databases. Others are highly complex network and circuit inventory systems with extensive operations teams of their own.

It is the authors' experience, supported by information collected from many deployment-engineering teams, that most of the tools available are limited in scope and uniformity. Most require that the service provider use a particular vendor's equipment and others lack the ability to scale to large deployments. Estimates vary widely, but generally it may take several hours per customer site to retrieve the required information to build the DEMARC configuration and the DPoE Network configuration.

Continuing the process, once the engineer has collected the required information, he is able to retrieve the required DEMARC equipment from inventory, write and install the configurations and deliver the equipment for installation at the customer sites. After installation, it is necessary to execute Ethernet qualification tests to verify circuit operation. The test results and final configurations must then be recorded in a circuit inventory system after which time the circuit would enter into normal monitoring and maintenance processes.

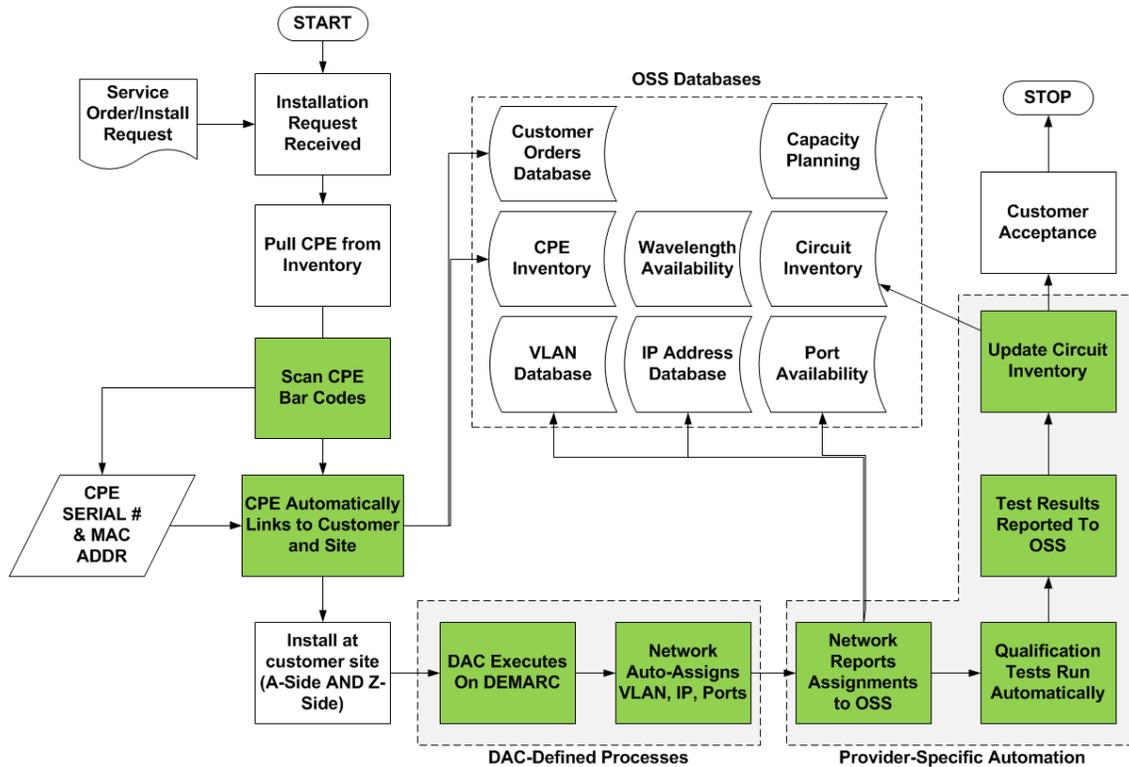


Figure 14 - Circuit Fulfillment Process with Automation

Contrast this manual process with the automated process shown in Figure 14. Each colored box in Figure 14 indicates a procedure that can be automated or a procedure that feeds data into an automated step. Note in this process, there is no need for a human to query the OSS databases to retrieve information required to configure the DEMARC or the DPoE Network.

Automating the provisioning and circuit turn-up processes has a positive direct impact on the customer's satisfaction and the service provider's bottom line. The benefits are found in:

- Shorter time to delivery – leading to fewer resources required for circuit installation (lowering OPEX), more time spent on revenue generating tasks and increased installation volume (increasing revenue);
- Shortened equipment replacement times – leading to lower Mean Time To Repair, shortened outage times, less frequent outages, and lower impact on service availability;

The indirect benefits of DPoE-based automation are found by reducing human interaction with the functions of the network. Where humans can be removed from the processes, the service provider will achieve improved process and standards compliance, lower network failure rates and more reliable execution of best practices.

Summary

The DPoE specification enables Carrier Ethernet services to be delivered over EPON with DOCSIS management and provisioning. The DAC process with Pluggable ONUs further streamlines deployments by automating provisioning of the DEMARC.

Cable MSOs can now leverage the existing DOCSIS OSS, the scalability of EPON, and the Service OAM functionality of the DEMARC to accelerate revenue growth from Carrier Ethernet services with SLA assurances.

The Time Warner Cable DPoE DAC process lab trial demonstrated the viability of the DPoE System, Pluggable ONUs and DEMARCs. The automation of provisioning DEMARCs shortens deployment time, reduces human error, improves customer satisfaction and provides tangible operational cost savings.