Modernizing Subscriber Management on the Road to 10G

A Technical Paper prepared for SCTE by

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1. Introduction

Network device provisioning (NDP) is a key component of the end-to-end system for service order fulfillment and activation. NDP is responsible for the configuration and service provisioning of subscriber's network devices. The DOCSIS network devices are the D2.0, D3.0, D3.1 and soon D4.0 modems, and their derivatives, such as set-top-box (STB) with embedded cable modem, media terminal adaptor with embedded cable modem (eMTA), eRouter, and more.

The number of device types, along with the number of available services applies a multiplication factor in the number of configuration files needed to provision. In the process of supporting tens of millions of individual devices and hundreds of services, the NDP of today is managing millions of DOCSIS configuration files. As network operators continue to invest in the roadmap to 10G, expanded network capabilities will add to the number of permutations of service and the number of device types involved. In addition, customers are expecting greater service agility in terms of faster development, deployment, and support for these innovative products and services offerings.

Although the DOCSIS subscriber management term is used extensively, currently the provisioning and management are done at the device level. This paper discusses an approach to modernizing today's device management and introduces new management systems with the goal of maintaining backward compatibility, employing network automation with dynamic service assurance, and increasing service activation velocity in support of the 10G technology roadmap. Use cases for current and possible future services are also covered towards a real subscriber management system.

2. Current Service Fulfillment Architecture

The service fulfillment architecture features a number of components that are vital to providing and implementing the customer's desired services (Figure 1).

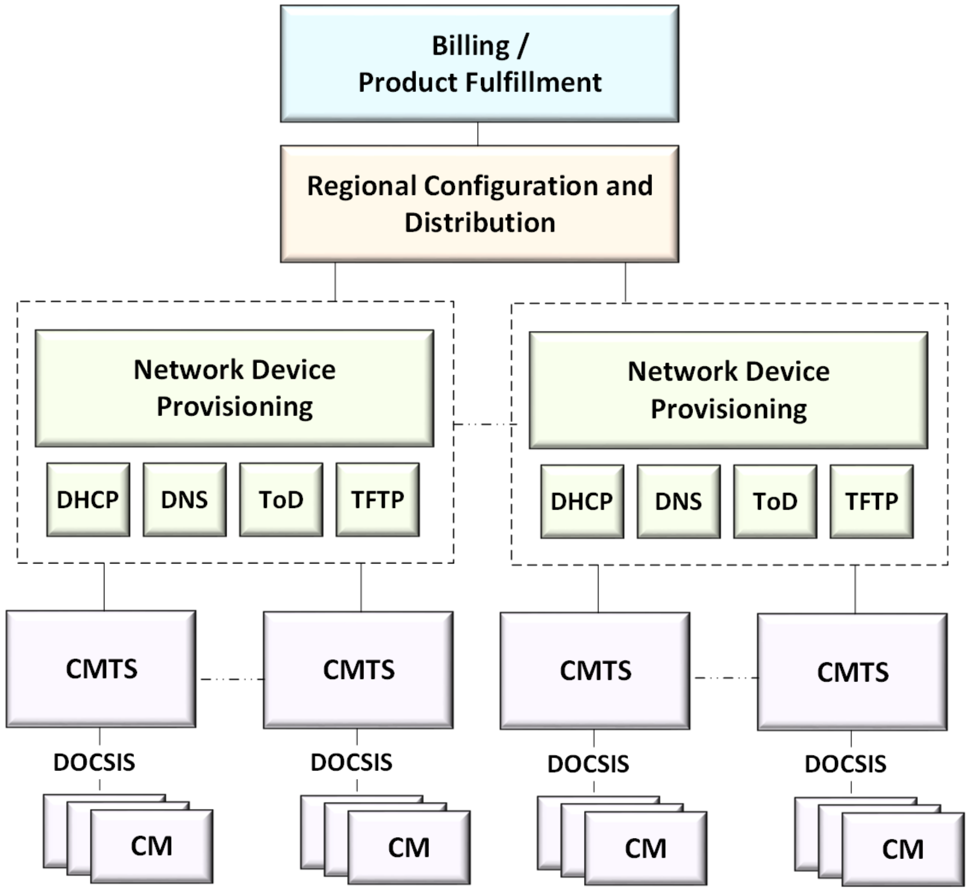

Figure 1 - Cable Service Fulfillment Architecture

As shown in Figure 1, a central provisioning and distribution system configures the servers and routers and distributes Dynamic Host Configuration Protocol (DHCP) instructions and device configuration files to the Device Provisioning Servers. These servers are integrated with the Network Registrar DHCP server to control the assignment of IP addresses for each device.

The devices supported by this architecture are the DOCSIS cable modems (CM) and embedded devices such as set-top-box (STB), media terminal adaptor (eMTA), eRouter, and more. The modem establishes DOCSIS data link layer connection to the cable modem termination system (CMTS), which in turn provides the L2 or L3 path to reach the NDP for its service provision and device configuration.

Figure 2 illustrates the main steps for CM initialization and registration. After ranging with CMTS and optional early authentication and encryption initialization, the IP initialization step takes place. The CM acquires an IP address in the cable operator address space, the current time-of-day, and a binary configuration file. The configuration files are delivered to the devices via the Trivial File Transfer Protocol (TFTP) server whose address is provided through DHCP information. During the registration step, the CMTS validates the configuration file contents sent by the CM, activates Medium Access Control (MAC) layer resources accordingly and sends MAC layer identities to the CM, as described in detail in CableLabs MULPI specifications. Services are defined statically in the configuration file except for dynamic services that support eMTA voice service configuration file. Different service flows (SF) including High Speed Data, Voice Signal, Video data and signal, Community Wi-Fi and Business Services over DOCSIS (BSoD) services are defined with corresponding classifiers and QoS settings. Operators often use Service Class Names (SCN) that are defined in the CMTS and mapped to SFs in the configuration files but may include explicit service definition TLVs as well. A variety of other service attributes such as number of IP addresses, packet classifiers, and even diplexer settings maybe included in the configuration files further expanding the unique sets of service attributes.

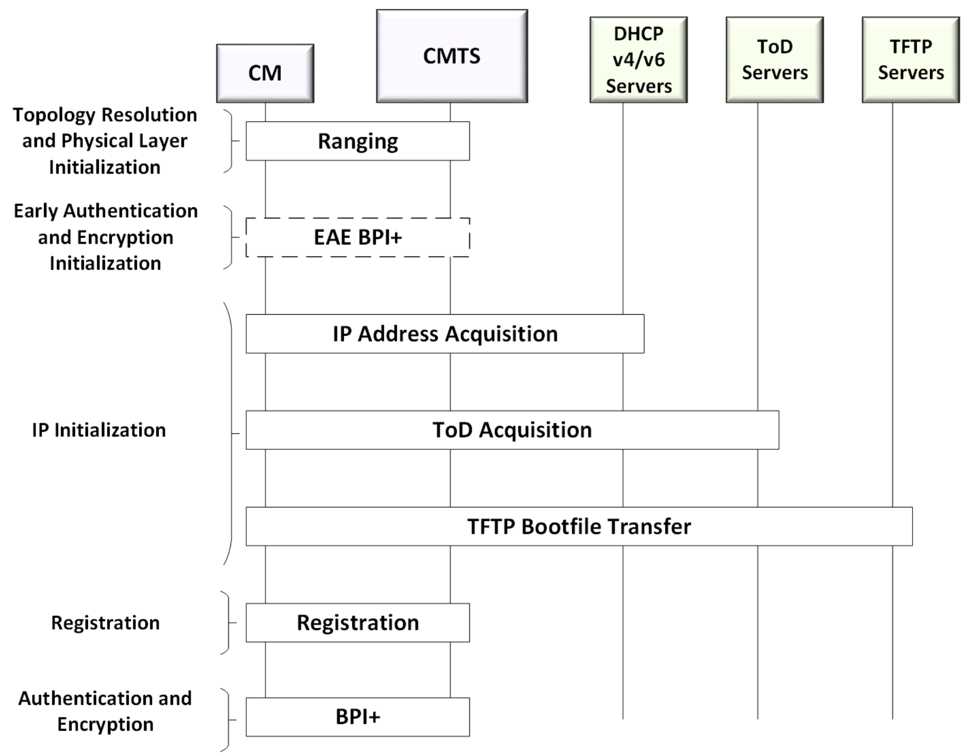

Figure 2 - Cable Modem Initialization and Provisioning

An SCN provides a set of Quality of Service (QoS) parameters for the SFs associated with it. At least two default SFs known as Primary Service Flows must be defined. As described in detail in the CableLabs OSSI specifications, the SCN also identifies the SF service characteristics to billing or customer service systems. Therefore, both SF identifier (SFID) and SCNs are used by the billing system. For most operators, the creation and integration of SCNs is a manual process.

Voice calls are established using PacketCable MultiMedia (PCMM) as shown in Figure 3. For eMTA voice calls, the SIP messages are delivered to P-CSCF that provides the reservation information to Policy Server (PS) for CMTS gate instructions. The Gate settings include classifiers and QoS settings defined for Upstream Unsolicited grant service (US UGS) and Downstream Best Effort (DS BE) calls. The PCMM architecture can also be used for non-voice SFs such as HSD SFs. All HSD dynamic SFs must be created using an SCN defined in the CMTS if the service is processed by the billing system with the current architecture. The details on the PCMM architecture and OpenDayLight implementation of a Policy Server can be found in [6].

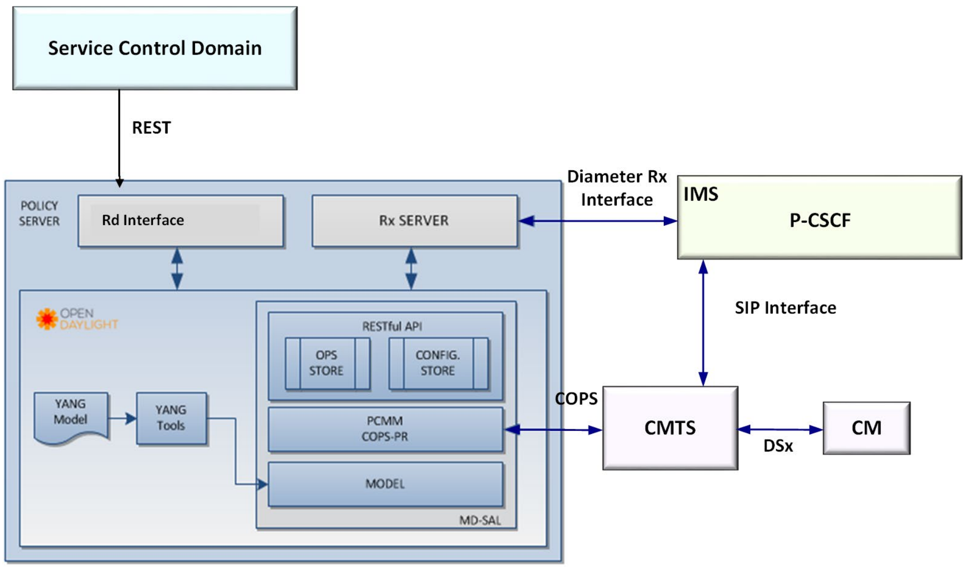

Figure 3 - PacketCable MultiMedia Architecture

2.1. Challenges

This section covers the challenges operators face with traditional network provisioning systems with the focus on DOCSIS CM and service provisioning.

2.1.1. Scaling

New configuration files are introduced for new speed tier rates and CM models and versions. Different number of CPE IP addresses and security attributes also require new configuration files. Furthermore EOL devices that are not swapped but required to support additional speed tier rates increase this number. If the configuration file management is not effective, e.g. not fully automated, many unused configuration files may exist within the operator's active database. In the process of supporting tens of millions of individual devices and hundreds of services, the NDP of today may be required to manage millions of DOCSIS configuration files.

Manual processing steps in the creation, update and deletion of a high number of configuration files may create issues in the existing deployments and new service launch.

2.1.2. Service Agility

Service agility for the 4As to have "Any content, Anywhere, Anytime and on Any device" is the ultimate goal for the ISPs. The key points of service agility are:

- Fast development of innovative products and services
- Configuring the services according to changing customer behaviors and requests
- Deploying new products and services without breaking existing systems and creating new issues
- Operating the services and underlying networks through proactive management techniques

A survey conducted by the TM Forum in October 2018 [1] shows that legacy Operations and Business Support Systems (OSS/BSS) remain the biggest challenge to network transformation causing slow progress. However, more recent TM Forum research [2] shows that 80% of ISPs have started to implement or benefit from digital transformation programs during the Covid-19 pandemic, which shifted the focus to customer experience and operations digitalization. Modular and configurable BSS are being adopted to reduce customization costs.

To achieve optimized service lifecycle management [3], some existing MSO systems, which have not been changed for more than two decades, must be replaced by a new design with automated service workflows and microservices. Today, the workflows for a new service and subscriber activation include manual steps for device and resource provisioning. The system is prone to human error, not suitable for fast activation and deployment and hard to operate and provide service assurance. These systems require customer equipment to be staged and configured initially in the warehouse and then shipped to the customer premises for installation. It also creates more need for dispatching technicians to activate services.

In these systems, initial estimations of the service group size and traffic load are used to project current and future scaling requirements. Therefore, service to resource mapping is not adaptable to more granular service and network changes. Traditional polling-based monitoring of data and manual troubleshooting create obstacles for automation and scaling.

To mitigate these issues, operators have started to automate the workflows gradually. A critical workflow that needs automation is the network infrastructure and device configuration.

2.1.3. Network Programmability

Service agility requires dynamic mapping of services to underlying network resources and automated provisioning based on traffic characteristics and service policies. The network resources may be physical or virtual function components and can be located in customer premises, the field, edge network, core network or in the cloud. The same network functionality may be distributed in different locations and scales.

Today, MSO networks consist of different access networks such as HFC, PON, Carrier Ethernet and Wireless. Redundant access networks and multi-path technologies are also being deployed with new service requirements. Although access networks have different resources and functionalities, the service to resource mapping and automated provisioning of workflows must be unified for effective service deployments and operations [3,4]. This can be achieved through microservices that can be reused by different technologies. In this case, the services may be defined without requiring specific knowledge on the underlying technology. Such abstraction is crucial for both service agility and network programmability.

As an example of the current obstacles, today in most Cable operators' networks, configuration file TLV settings and SCN settings are provisioned separately. This creates an obstacle to change the network and device settings for customer needs without requiring a reset and interruption of the services. If a combination of SCN and explicit TLVs is used for modem provisioning, having a TLV value to be optimized based on an SCN parameter may not be feasible in this case. Optimization may require a vendor or the operator to introduce a new firmware code. This approach also makes network functionality upgrades impossible or very hard for early versions of the network components. For instance, a new optimization defined in the specifications can be applicable for both D3.0 and D3.1 modems but the operator may choose to apply it only for D3.1 since the code upgrades by the vendor for D3.0 may not be active.

Another example is the introduction of new speed tiers in the upstream direction. Mid-split and High-Split Enablement use cases involve CMs to range to OFDMA channels. This process has the following issues:

- It requires reconciliation among different tools and settings (SCNs and per CM Configuration file CoS)
- Backward compatible solutions must exist for iCMTS/iOLT but allow for more flexible solutions for vCMTS/vOLT
- Some of the new systems like FDX and PON do not use diplexers, requiring different provisioning
- Each new system must support different new modem models which require new configuration files

Not having programmable systems, e.g. requiring more configuration files also has direct scaling consequences.

One gradual step MSOs may take is to use PCMM based Dynamic Service Flow management for non-voice services. The current deployments are mostly for voice calls that are based on RSVP type resource allocation and management. This system may not be optimal for general dynamic service flow management and many ISPs have to pay license to a third party due to implementation and management complexities. Gradually, open source and APIs should be developed and adopted for all SF types.

2.1.4. Operations

Today manual and siloed workflows and resource management systems create obstacles for lighter operations and automated processes. Functionalities common to multiple access technologies such as subscriber management filters are implemented and managed differently depending on the access network. Therefore, multiple components with the same functionality are configured and operated for different implementations and APIs.

Services and network components are intertwined. Service definitions still include access network attributes, and they are not access technology agnostic. The billing system must know the SCNs defined in the access network provisioning system. The lack of abstraction is a challenge on the road to automated service operations. Therefore, a unified service chaining over digitized network components cannot be deployed over multiple access technologies.

Having operational parameters of a CM provisioned using configuration files creates obstacles for a self-optimizing system without service disruption.

Therefore, there is a need for new network provisioning and subscriber management systems. The next section describes a solution that can be implemented as a first step towards completely agile service and automated network management.

3. Proposed Solution

3.1. Device Management Application

The proposed solution must be backward compatible, interoperable, and incremental because the existing back-end system is vast and impossible to replace as a single unit. Backward compatibility and interoperability are required for the front-end facing interfaces to cable modems and backend facing interfaces to the existing Billing-Production Fulfillments and NDP components.

The proposed solution is to introduce the device management application (DMA) component to proxy the interfaces between NDP, CMTS and modem devices. The DMA provides a light-weight API interface as an alternative, programmatic provisioning interface that enables a path toward modernizing the backend systems. Figure 4 illustrates the end-to-end (E2E) system model view.

The DMA has the following components (Figure 5):

- TFTP Client for downloading modem configuration file from NDP on behalf of modem devices,
- TFTP Server for modem devices to download their configuration file,
- Configuration File Manager (CFM) for managing the DOCSIS modem configuration file,
- API server for external orchestration application to programmatically managing modem devices provisioning,
- Device Database for modem devices configuration and provisioning attributes

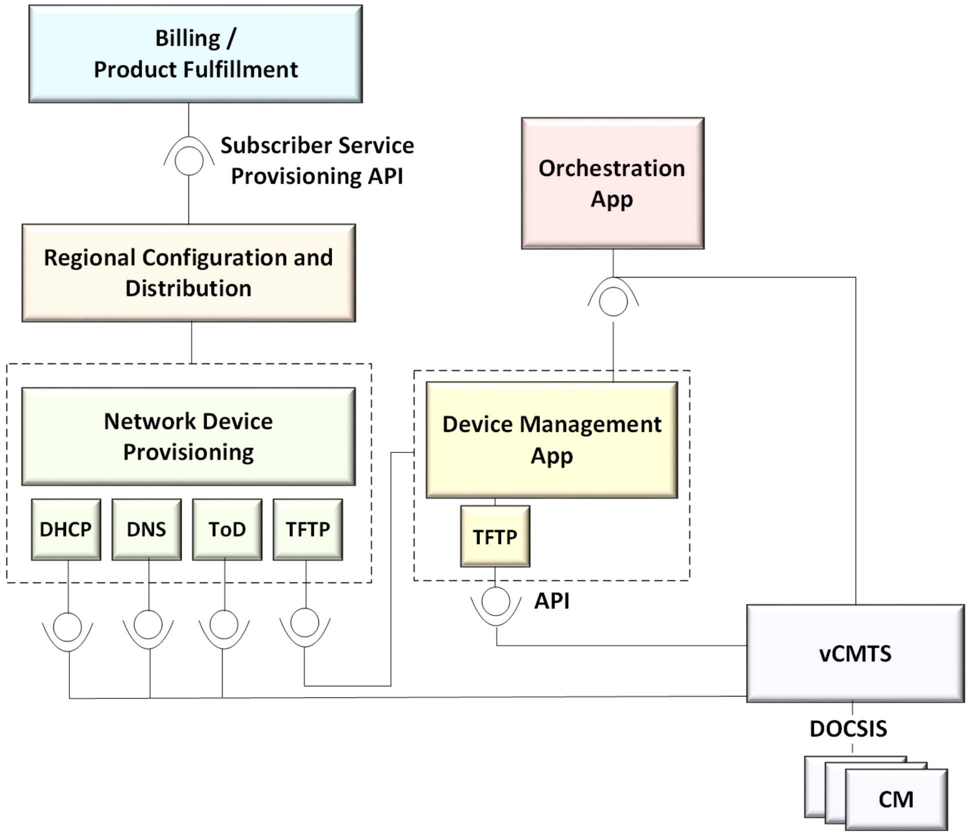

Figure 4 - E2E System Model

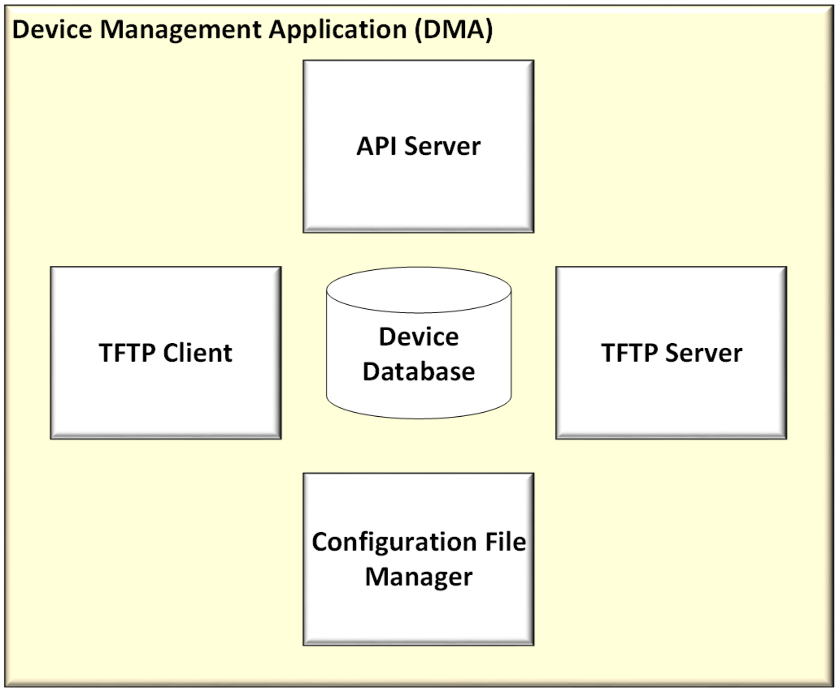

Figure 5 - DMA Component View

In the following subsections, the key functions and concepts are described.

3.2. Device Database

The device database must be persistent and highly available. Its database schema must support all objects and attributes in the DOCSIS modem configuration file. The schema must be extensible to support devices such as ONU for PON. The schema could support classifiers, policy rules and intent objects.

Automated database management without manual processes is needed to reduce errors and increase the speed of introducing new devices and services. Otherwise, increased number of device configurations may not be manageable and create scale and maintenance issues.

3.3. TFTP Proxy

DMA is the TFTP proxy server, consisting of TFTP client, TFTP server and configuration file manager (CFM) components. The configuration file manager downloads the configuration file on behalf of the cable modem. The configuration file is parsed, and the provisioned objects and their attributes are stored in the device database. At a high level, the sequence of events is:

- When modem sends DHCP request, CMTS DHCP relay agent would replace DHCP options 66 (TFTP server name) and 150 (TFTP server IP address) to DMA's internal TFTP server FQDN and IP address.
- CMTS then notifies the CFM.
- CFM initiates the TFTP client to download the modem configuration file from the NDP on behalf of the cable modems.
- CFM parses, validates, and updates the device database.
- CFM finally regenerates a new configuration file for the modem to TFTP download.

The DMA enables the combination of NDP provided configuration file and locally inserted device configuration attributes by regenerating a new configuration file and offering it to the cable modem.

3.4. Ligthweight REST API

As an alternative to NDP, the API server provides REST interface for other orchestration applications to programmatically provision a modem. The API provides access to the provisioned objects and the attributes in the device database.

As described earlier, the device database schema is extensible to support objects such as:

- Policy, Rules, and Intents
- Device Classifiers
- New Service Offerings

These objects will be newly defined, beyond the scope of the existing DOCSIS configuration file. The objects are meant to be consumed by the CMTS or OLT at the core side for the active management of the device devices.

3.5. Deployment

The distributed access architecture (DAA) specification was introduced to evolve and modernize access network performance. This split allowed the core functions to run on a cloud computing platform. As such, virtualized CMTS (vCMTS) is a collection of software applications for the core functions. It is built upon a microservice architectural pattern and targeted for cloud computing platforms.

Here, vCMTS as platform is referring to the deployment of vCMTS core function software in MSO private cloud. In contrast, the integrated CMTS (iCMTS) represents the traditional custom hardware CMTS platform.

During the MSO roll out of the vCMTS platform, the production environment will have a mix of vCMTS and iCMTS components. It is essential for DMA to support new service offering across all iCMTS and vCMTS systems in the footprint. With that in mind, the DMA application can be deployed either in the MSO regional data center or public clouds.

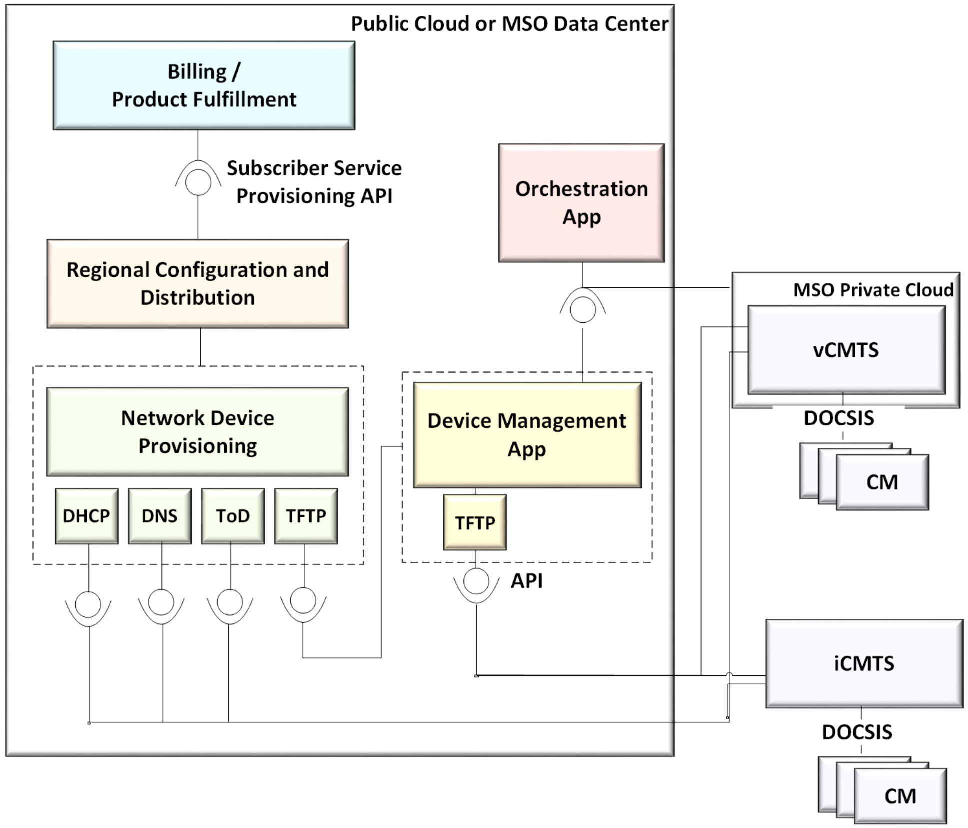

Figure 6 - DMA Deployment Diagram

4. Use Cases

4.1. Mid-Split Enablement

The benefits and challenges to Mid-split deployment are well documented in [5]. The obvious benefit is that a mid-split plant doubles the upstream bandwidth of the standard-split (aka low-split) plant. The challenges are:

- Coexistence of Mid-split (MS) and Standard-split (SS) CPE, where the MS-CPE and SS-CPE share the cable feed through a splitter. With imperfect isolation, the MS-CPE's upstream OFDMA signal may leak into the SS-CPE's downstream RF front end.
- Old infrastructure components such as drop-amps and splitter that makes MS-CPE inoperable on the OFDMA channel.

A detection and mitigation mechanism is proposed in [5] to address the above challenges. The mitigation mechanism is to steer the modem via the configuration file or DBC. Customizing modem configuration file at per device level is operationally challenging. The mechanism to DBC the modem requires external application to be developed, CMTS to expose its DBC API, and re-apply whenever the modem re-registers.

The management and mitigation mechanism can be simplified by utilizing the device management application. The interference detection tool would invoke the DMA API to update modem having SS-CPE interference or drop-amp. CMTS queries the DMA during modem registration. If the device database has the interference attributes set, then the CMTS would enforce the OFDMA channel exclusion as part of the transmit channel set assignment process. Reports of modems having these types of interference can be easily obtained by querying the device database.

4.2. New Service Offerings

Operators are interested in providing personalized solutions for their subscribers without the need to have custom solutions for their network and service platforms. For example, services to support low latency applications, speed boost and continuation of speed rates over wireless (home and on-the go use cases) can be supported per subscriber's status and preference.

These services can be turned on and off by the subscriber or service options may be available to subscribers. In this case, an agile service platform can support runtime changes without interruption and resets. An example is provided in Figure 7 where Low Latency and Speed-Boost requests can be fulfilled dynamically using a PCMM based system. A REST API may provide the request to the PCMM that in turn opens or deletes gates for the vCMTS. As an alternative, PCMM gates may be integrated with Device Management App to facilitate future architectures (Figure 7).

Current PCMM specifications, at the time of publishing this paper, do not include Aggregate SF cases as defined in Low Latency DOCSIS specifications. However there is an increasing interest to extend PCMM SF definitions and have Policy Server implementations that are based on open source code and standard APIs.

This architecture can be further extended to use DMA only at the first initialization of subscriber devices and services or to remove it completely. In the former case, a basic common configuration file may be used to initialize the CM with primary SFs. Then, actual SFs can be dynamically provisioned using Orchestration app and PCMM. When backward compatibility is not needed and standard APIs may be used directly to configure the CMs, DMA may be replaced. This architecture is also a first step to have automated subscriber management by provisioning network and device components per subscriber service status and preferences.

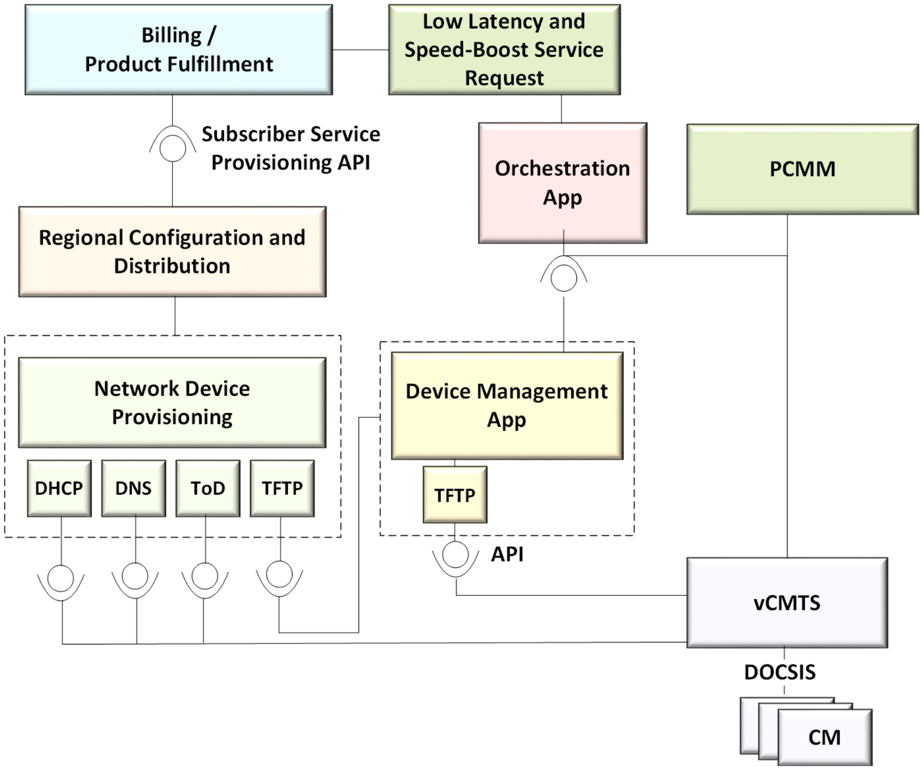

Figure 7 - New Service Use Cases

4.3. vBNG

CabeLabs' DOCSIS Provisioning of EPON (DPoE) specification enables MSO to deploy EPON technology using the existing DOCSIS based backend systems. As shown in Figure 8 the ONU is emulated as virtual cable modem (vCM).

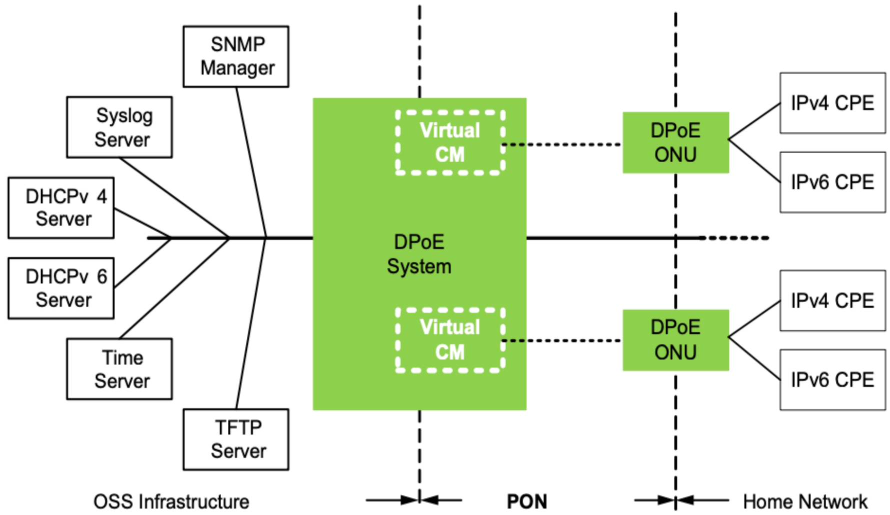

Figure 8 - DPoE-SP-MULPIv2.0 vCM Model

As MSOs are rolling out vCMTS platforms, the same private cloud can host virtual broadband network gateway (vBNG) [4] application to support EPON technology.

vBNG can be developed to utilize DOCSIS based NDP. In this case, vBNG invokes DMA provided API to initiate the download of the vCM configuration file and to query for the ONU device and service provisioning objects as shown in Figure 9.

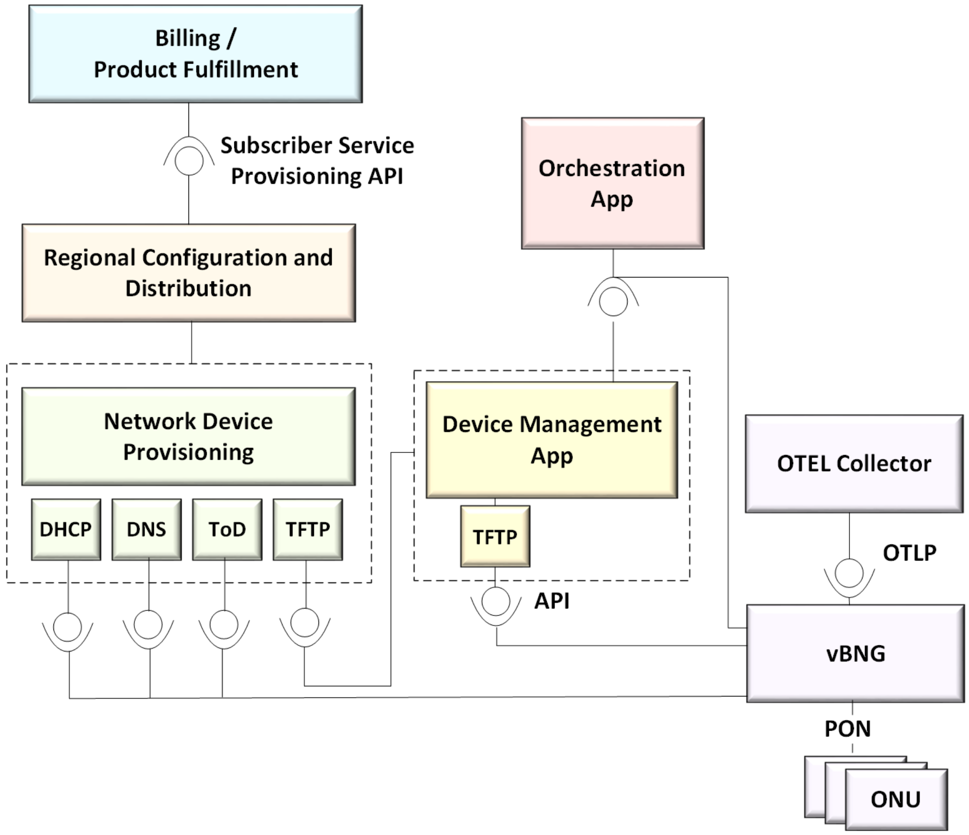

Figure 9 - vBNG System Components Utilizing DOCSIS Based NDP

The observability aspect of the operational support systems (OSS) for vBNG can be modernized by utilizing vendor-neutral open-source observability framework such as OpenTelemetry (OTEL).

5. Conclusion

The proposed DMA provides a path forward for modernizing the device management systems. It maintains backward compatibility and interoperability with the existing NDP systems. At the same time, it enables steps toward agile service deployments with programmable and automated networks. The DMA provides a programmatic interface to external applications to access the device database. The external application can be a CMTS, utilizing the DMA for the active management of subscriber services.

The proposed device management systems enable the operator to meet the goals of maintaining backward compatibility, employing network automation with dynamic service assurance, and increasing service activation velocity in support of the scalable 10G technology roadmap. The solution can be extended to unify management of access networks and introduce dynamic services with low latency and speed-boost support. These new services can be personalized based on the subscriber's status and preferences using dynamic SF provisioning. This architecture enables MSOs to integrate device, subscriber and service management as a unified system.

This is a crucial step to achieve optimized service lifecycle management. Operators started to transition to automated service workflows and microservices and have been deploying SDN, NFV and cloud enabled access networks [3]. The new system supports existing services while being upgraded for new services such as Gig Symmetric (Mid-Split, High-Split and FDX), MVNO and Low Latency services. As more services are being introduced at a faster pace and service personalization is becoming more crucial, a fully automated system as illustrated in Figure 10 is needed. The orchestrator and controllers use telemetry data and system knowledge to map services to resources, instantiate and manage the service and network microflows, and program and configure resource components. Once such a system is adopted, it can support dynamic changes to support customer runtime requests or network needs. Abstraction between services and resources can help to support multiple access technologies in a harmonized way, either as single or simultaneous technologies serving the same subscriber.

The following list describes the steps needed for modernizing device, service and subscriber management systems:

- Abstracted service and digitized resource management independent of underlying technologies
- Data and knowledge center based on cloud-enabled and push-based telemetry with standard APIs
- Data-driven orchestration for self-optimizing and scaling systems
- Microservices instead of monolithic functionalities and meshed service chains
- Containerized SW for faster initiation, efficient execution, and better isolation
- Automated inventory and topology management
- Zero touch installation and self-activation systems
- Customer centric personalization without requiring customized designs and operations

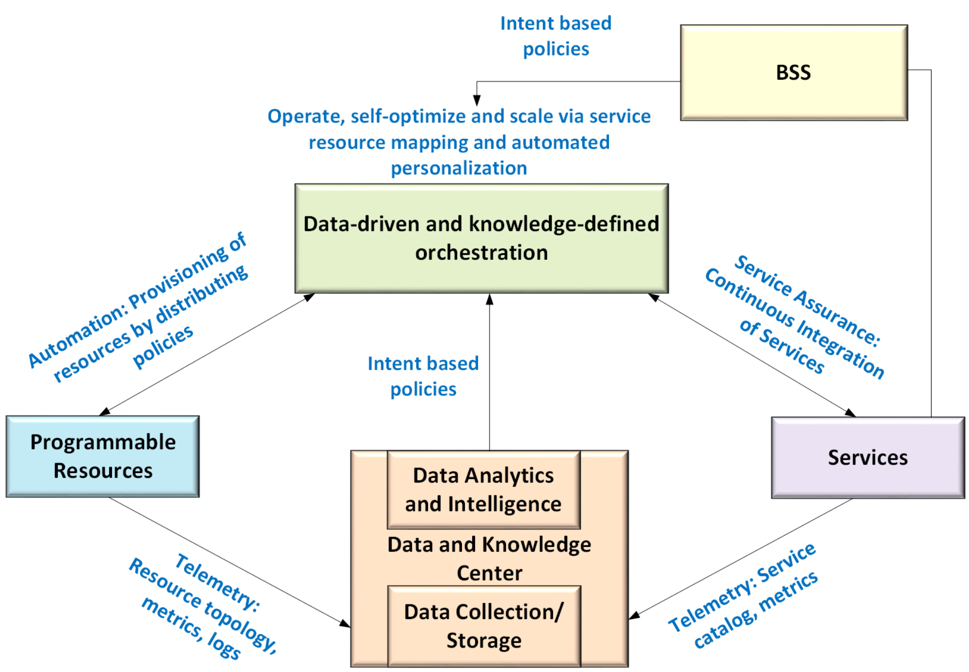

Figure 10 - Data-driven and Knowledge-based Systems

Abbreviations

API	Application Programming Interface
BSoD	Business Services over DOCSIS
BSS	Business Support System
CM	Cable Modem
CMTS	Cable Modem Termination System
DHCP	Dynamic Host Configuration Protocol
DMA	Device Management App
DNS	Domain Name System
DPoE	DOCSIS Provisioning over EPON
eMTA	Embedded Media Terminal Adaptor
HFC	Hybrid Fiber Coaxial
HSD	High Speed Data
MAC	Medium Access Control
MSO	Multiple System Operators
NDP	Network Device Provisioning
OSS	Operations Support System
OTEL	Open Telemetry
PCMM	PacketCable MultiMedia
PON	Passive Optical Network
QoS	Quality of Service
REST	Representational State Transfer
SCN	Service Class Name
SFID	Service Slow Identifier
STB	Set-top Box
TFTP	Trivial File Transfer Protocol
ToD	Time of Day
vBNG	Virtual Broadband Network Gateway

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