Leveraging external applications for DOCSIS 3.1 HFC plant optimization.

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Abstract

DOCSIS 3.1 offers a robust upgrade to the physical layer transmission methods by taking advantage of the state-of-art technologies such as OFDM and LDPC. These new techniques allow the DOCSIS networks to better utilize spectrum of HFC network, effectively pushing the efficiency towards the Shannon limits. The improvements come at a price; very complex configuration and the need for constant monitoring and probing processes which generate vast amounts of test metrics and maintenance information.

This information needs to be analyzed and acted upon by the CCAP software in order to adapt to changing network condition in a timely manners. The results are in the form of customized transmission profiles matched to groups of cable modems. However, the analysis of complex and voluminous test data on the CCAP has its limitations which we will explain in the presentation.

This paper presents a case for opening components of the CCAP OFDM phy maintenance sub-system to rely on an ecosystem of external applications and services. In particular, the paper reviews the requirements and compares options for definition of Cable Unique API for increasing the value proposition of DOCSIS. Such external APIs will offload CCAP from HFC optimization tasks and enable implementation of these functions in third party tools and applications. As result, CCAP configuration and operational complexity will be reduced. The set of compared external interface options includes an SDN controller based approach. The paper examines the relevance of such an approach to accelerate software development as well as the economic value for customers who desire to extend the CCAP functions with third party services and applications. Finally, the paper explores the need for multivendor interoperability and prospects for standardization of APIs.

Introduction

The ink is still drying on the recently issued DOCSIS 3.1 specifications. They offer vast improvements to the physical layer techniques and network scaling. The improvements come at a price; a complex channel structure, much higher PHY processing requirements (approx. 3-fold increase in the number of required silicon gates), multiplication in scale of operational and configuration data as well as the need for constant monitoring and probing processes which generate vast amounts of test metrics and maintenance information.

The intended audience

The intended reader of this paper is assumed to have a rudimentary familiarity with DOCSIS 3.1 technology.

What are DOCSIS 3.1 OFDM profiles?

This section provides a brief introduction to OFDM Profiles including a discussion about how a CMTS manages them.

DOCSIS 3.1 introduces Downstream and Upstream channels based on the OFDM technology, which enables effective deployment of higher level modulation orders. An OFDM channel has a complex structure; it consists of large collection of individually modulated sub-carriers, which are processed by FFT and can be individually modulated. DOCSIS 3.1 supports downstream modulation orders up to 4096-QAM (in the future up to 168384-QAM and higher) and upstream modulation of 1024-QAM (in the future up to 4096-QAM and higher).

After much discussion, DOCSIS 3.1 adopted the concept of modulation profiles for OFDM and OFDMA channels. We will refer to them as OFDM Profiles. An OFDM Profile defines modulation order for all active data sub-carriers of a downstream OFDM channel and for the data symbols of a minislot of an upstream OFDMA channel. OFDM Profiles allow for effective optimization of the transmission path to or from the CMs that can tolerate a higher modulation.

Sub-carrier modulation orders in a profile may vary across the frequency range of a channel. For example, the active sub-carriers in the range 100-188 may be configured for 64-QAM modulation; the active sub-carriers in the range 200-399 use 256-QAM modulation and the remaining active sub-carriers of a channel use 1024-QAM modulation order.

DOCSIS protocol primitives allow for unlimited variability of modulation orders where each of the eight thousand sub-carriers of OFDM channel may have a different modulation order from its neighboring sub-carriers. In most cases, the sub-carrier modulation order fluctuation will be more limited; in many cases sets of thousands of adjacent sub-carriers will share the same modulation order.

DOCSIS specifications require that a CM must provide support for 4+1 (four active and one test) profiles for each downstream OFDM channel and two profiles for each upstream OFDMA channel. The CMTS may provide up to 16 profiles for downstream OFDM channels and up to 7 profiles for upstream OFDMA channels.

In the control plane, the CMTS communicates downstream profile configuration to the CM via Downstream Profile Descriptor (DPD) messages. The upstream profile information is sent in UCD messages.

In the dataplane, downstream packets belonging to the same profile are organized into FEC codewords and FEC codewords are mapped by the NCP signaling channel. In the upstream an OFDM profile becomes synonymous with data IUCs; their allocations are signaled by MAP messages.

OFDM Profile Management

CMTS vendors will undoubtedly apply a various techniques and algorithms to effectively manage OFDM Profiles. The paper does not prescribe a specific method for this purpose. However, for background information, in order to appreciate the complexity of OFDM profile management functions we feel we need to examine those functions at high level.

The CMTS profile management involves two distinct, yet interdependent tasks. The first task is the determination of the OFDM profile parameters. For the second task, the CMTS assigns OFDM Profiles to groups of cable modems which receive downstream signal with similar fidelity or from whom the CMTS receives upstream signals with similar fidelity.

In its simplest form, the CMTS could create OFDM profiles based on a static device configuration. By "static device configuration" we understand a mode of operation where the CMTS is provisioned with a persistent set of configuration parameters for OFDM Profiles.

The static method for configuration of OFDM Profiles has a number of inherent limitations. Static profile configuration is difficult to manage and the profile settings are less efficient than dynamically created profiles. A typical CMTS/CCAP can house hundreds of OFDM channels, each with thousands of sub-carriers. The large number of sub-carriers makes the static configuration a difficult task, even if the configuration can be automated and involve only machine-to-machine interactions. Unless the OFDM Profile settings are greatly simplified, with very little variability in modulation levels across the channel's frequency range, any direct human involvement in OFDM profile configuration management tasks will overwhelm even the most patient operators. Furthermore, statically configured OFDM profiles are … static. They cannot be flexibly adapted to changing network conditions, such as occurrence of ingress noise, cable failures, component degradation, etc. Because the profiles are static they must be provisioned with larger error margin therefore have less then optimal efficiency. Static OFDM Profile configuration does not represent an interesting case for an external application and will not be considered further.

Alternatively, the CMTS may create OFDM profiles dynamically. At a high level, the CMTS algorithm includes collection and analysis of signal quality measurements from receivers, sorting of CMs with similar signal quality measurements into groups and determination of per sub-carrier modulation order for the groups. However, after diving into the details, it quickly becomes obvious that the problem has many dimensions.

The volume of signal quality measurement samples can quickly grow to considerable proportions. CMTS algorithms must scrutinize various MAC and PHY level error reports and incorporate elements of root cause analysis. Error reports that communicate the potential for direct impact on the user data must be acted on immediately. In such cases the CMTS will reduce the profile modulation or switch the set of affected CMs to a different, less strenuous profile. The frequency in which the CMTS collects the signal quality measurements has a direct impact on the ability to promptly detect and resolve issues that may be shared by groups of CM or by entire channels. Reduction in the intervals for gathering and analyzing the signal quality metrics helps with the response time, but it also increases the system processing overhead. The goal to maximize the spectral efficiency has to be balanced with other performance criteria, such as the need to minimize latency and overhead. To ensure minimal impact on the users, the newly created OFDM profiles candidates have to be tested before they are enabled to carry user data.

Dynamic OFDM Profile generation functions have the potential to become a complicated and a CPU intensive task because they need to fulfill many, often contradicting requirements and because they operate on large volumes of signal quality and diagnostic data.

Naturally, a hybrid of these two approaches to OFDM Profile management is feasible. For example, the CMTS could use static profile configuration as a starting point and further refine profile parameters through a dynamic process.

A more detailed description of OFDM profiles and a discussion of their management can be found in [01] as well in [03].

Problem Definition

Next, we will examine basic scaling and CPU performance requirements for dynamic management of OFDM profiles. As mentioned earlier, the CMTS periodically collects signal quality metrics from OFDM receivers and based on the analysis of the collected data can progressively build OFDM Profiles. How large is the volume of the signal quality metrics that a CMTS needs to collect and comb through to determine optimal OFDM Profile settings?

For this purpose, we decided to examine a performance metric which has per CM and per sub-carrier scaling multipliers. DOCSIS 3.1 specifications define standard methods for the measurement of a receiver's ability to receive modulated signal known as Modulation Error Ratio (MER). MER values can be effectively represented as 8-bit values using a logarithmic scale (dB). Cable modems measure MER for each active downstream OFDM sub-carrier based on pilot signals inserted in the channel.

The CMTS gathers MER information for each active sub-carrier of upstream and downstream channels. The CMTS requests MER measurements from CMs and collects MER statistics reported by CMs via newly added DOCSIS OFDM Downstream Spectrum (ODS) messages. In the reverse path, the upstream receiver embedded in the CMTS measures upstream sub-carrier MER from OFDMA probe signals.

The MER statistics database size examples have been calculated by taking into account the following parameters. Each downstream OFDM channel may include up to 7680 active sub-carriers. Each upstream OFDMA channel can consist of up to 3840 active sub-carriers. Both upstream and downstream MER stats for each sub-carrier are maintained as 8-bit values. Table 1 displays the MER database size estimates for a few combinations of CMTS Scale and service group compositions.

	SG Composition (OFDM Channels)	
CMTS Scale	2 DS + 1 US	5 DS + 2 US
3 000 CMs	**58 MB**	**138 MB**
10 000 CMs	**196 MB**	**470 MB**
30 000 CMs	**575 MB**	**1.4 GB**
60 000 CMs	**1.2 GB**	**2.8 GB**

Table 1 MER Database Size Examples

These values have been calculated considering the worst case scenario, for systems operating with 25 kHz sub-carrier spacing. The MER database size estimates for systems with 50 kHz sub-carrier spacing should be reduced by half. Nevertheless, Table 1 demonstrates that the MER statistics database size can grow quickly with the CMTS scale and with the increase in spectrum dedicated to OFDM. Considering that numbers in Table 1 represent memory sizing estimates for only one of several possible signal quality measurements, the actual memory requirements for the signal quality measurement database may be much higher. The database size could grow by another factor of magnitude if the processing algorithm includes elements of trend analysis and requires access to multiple generations of MER measurements. While these numbers won't stun readers familiar with modern, general purpose computing platforms, a comparison to the limitation of existing CMTS platforms may give a better perspective. The estimates may be approaching or exceeding the total memory pool size of many currently deployed CMTSs. Jumping a few years forward with Moore's law in mind, the signal quality measurement database, even if partitioned to fit the modularity of CMTS processing components (think cable linecards) will likely consume a significant portion of available memory in currently developed DOCSIS 3.1 compliant CMTSs. Undoubtedly, removing the need to maintain signal quality database from the CMTS will lower CMTS's memory and performance requirements.

Outline of the operation

The main goal of the paper is to examine the case for separation of the majority of the OFDM Profile management functions from the embedded programming environment of a CMTS and moving them to an external application which may be operating in a virtualized environment. We will refer to such application as HFC Profile Manager, or HPM. In this section, we will describe how such distributed system could operate.

The architecture of a system incorporating HPM is shown on Figure 1.

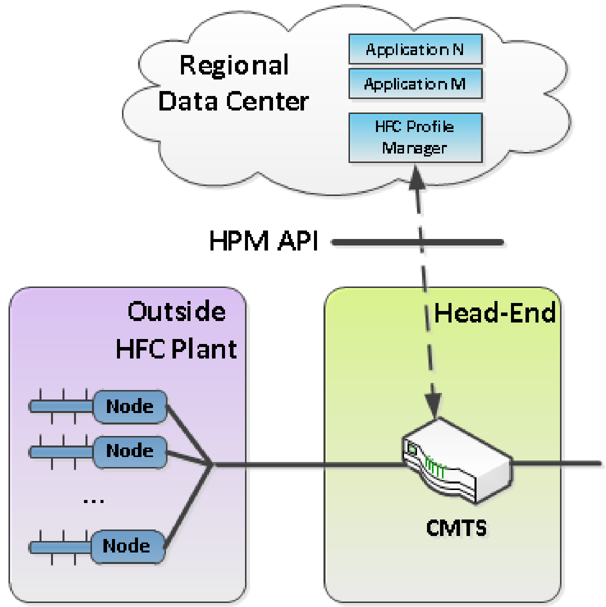

Figure 1 - Proposed architecture

CMTS and HPM

The authors assert that the bulk of non-real time OFDM Profile management functions can be implemented in the HPM. In the proposed functional split the CMTS responsibilities include:

- Periodic and on demand collection of signal quality measurements and error reports from CMs and the CMTS's upstream receiver
- Real-term evaluation of error reports and necessary profile adjustments to address urgent issues, such rapid profile downgrades.
- Initiation of on demand profile test procedures with CMs and collection of test results
- All protocol interaction with Cable Modems

HPM responsibilities include:

- Implementation of complex and CPU intensive functions to analyze signal quality measurement data

- Determination of the optimal set of OFDM profiles, backup OFDM profiles, and the most common denominator profile, referred to a profile “A” in DOCSIS 3.1
- Evaluation of error reports for the purpose of long term profile adjustments

The CMTS and HPM interact through an abstract application programming interface (API). We will refer to this interface as HPM API. The HPM API can be divided into several functional components:

- **The channel registration** component, through which the CMTS registers and unregisters its OFDM channels and their attributes with HPM. This is a process roughly analogous to the resource registration process described in Edge Resource Management Interface [4] (ERMI) specification to manage QAM channels. For each OFDM channel the CMTS communicates to the HPM the channel parameters, current OFDM Profile settings, and dynamic changes to those parameters as well as the channel’s unique identifier and HFC topology information.
- **The device registration** component through which the CMTS informs the HPM about the CMs which are using registered channels and their current OFDM profile assignments.
- **The signal quality analytics** component through which the HPM can request the CMTS to deliver a variety of diagnostic and performance information which may be useful in evaluation of OFDM Profiles. The set of analytical data includes performance metrics defined in DOCSIS specification such as RxMER collected from Cable Modem or CMTS upstream receiver as well as other performance indicators, for example LDPC performance statistics or upstream pre-equalizer coefficient settings. The data flowing through the signal quality analytics interface constitutes the bulk of information exchanged between the HPM and the CMTS. The throughput of the exchanged data can reach the levels of many megabits per second for each CMTS.
- **The test and command** component through which the HPM communicates to the CMTS OFDM Profile candidate parameters, requests from the CMTS to test OFDM Profile candidates and through which the CMTS delivers the results of requested profile tests.

The HPM API with logical partitioning is shown on Figure 2.

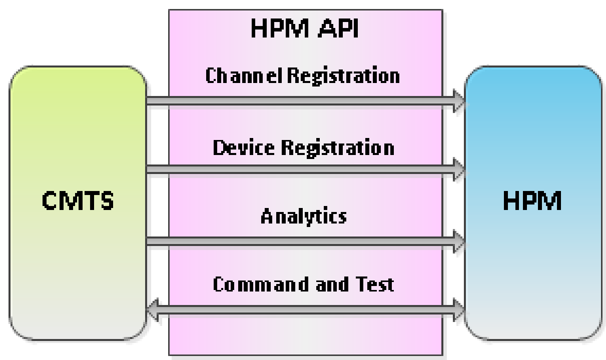

Figure 2 – HPM API

Possible Extensions

HPM application, initially developed for traditional CCAP/CMTS could become a building block of a future, virtualized CMTS. HPM could be integrated and operate in concert with other HFC management applications, such as Proactive Network Maintenance PNM server, explained in [2].

Is HPM suitable for an SDN application?

Next, we'll evaluate whether the OFDM Profile management functionality meets rudimentary criteria for a SDN application. We believe that OFDM Profile management as well as the presented HPM concept fit well into the mold of SDN application.

- OFDM Profile management can be broadly categorized as custom control plane functionality.
- As we discussed throughout the paper, OFDM Profile management involves complex, highly customized SW.
- The HPM application can be efficiently isolated or abstracted from other components of the CMTS system as we have demonstrated earlier, by outlining HPMI.
- There are few real-time processing constraints on OFDM profile management.

Standardization of HPMI

The benefits of standardization of network interfaces cannot be overstated. Virtually all interfaces between components of a modern network, including external interfaces of a CCAP/CMTS are based on industry standards. Open standards cover not only the external interfaces but also selected internal interfaces between components of a CMTS. The majority of Cable Operators networks deploy equipment, including CMTSs from multiple vendors. Interface standardization is rudimentary in enabling multivendor interoperability and reducing deployment costs. Undoubtedly, if HPM is to be developed and adopted as a decoupled cloud application, its interface to the CMTS will be formally defined. HPMI standardization will benefit CMTS vendors, the prospective vendors of HPM application software and ultimately, the Cable Operators.

The benefits of the proposed idea

Finally, let us review the benefits of the proposed approach.

Moving OFDM Profile processing from the embedded environment of a CMTS to the data center provides benefits generic to SDN and virtualization; those include the acceleration of software development and improved feature velocity, shorter test cycles, fewer memory constraints and scalable processing power. Once the data gets into the cloud it is generally easier to manage it, for example to archive it or perform historical analysis on it.

The application specific benefits include elements of CapEx and OpEx reduction:

- The removal of the bulk of OFDM Profile processing functions lessens CMTS processing burden and lowers CMTS memory requirements, resulting in lower equipment cost.
- It leverages the more sophisticated application development environment (eg commercial data bases) and much lower cost of generic processing and storage and available in the virtualized data center.
- Operations can be simplified because HPM as a cloud application makes dynamic OFDM Profile management possible, thus eliminating the need for complex and error prone OFDM Profile configuration settings in the CMTS.
- A decoupled, centralized HPM application will execute a single, consistent set of OFDM Profile processing algorithms and offer a single set of configuration knobs to control them even when serving CMTSs from different vendors. Centralized configuration and unified processing algorithms further help in operational simplification.

- HPM as a cloud application can be directly integrated with other HFC management applications, for example the PNM servers, becoming an integral part of the HFC plant management and service monitoring ecosystem.
- HPM application developed initially for a traditional CMTS/CCAP can be reused as a building block of a future, virtualized CMTS.

Conclusion

In recent years the Cable Industry has embraced two areas for innovation and significant investments: DOCSIS 3.1 and SDN. These areas appear to be completely unrelated. DOCSIS 3.1 aims at the physical network capacity optimization and scaling. DOCSIS 3.1 goals have been accomplished at the cost in increased network complexity. SDN intends to simplify the network by allowing operators to abstract control plane functionality from physical network nodes and implement them in a virtualized environment. Increased complexity of DOCSIS 3.1 represents a new opportunity for application of SDN concepts. The paper presents a cogent case for decoupling one of DOCSIS 3.1 control plane functions, OFDM Profile management and for implementation as an SDN application.

References

[1] DOCSIS 3.1 MAC and Upper Layer Protocols Interface Specification, CM-SP-MULPIv3.1-I02-140320, CableLabs, 2014

[2] DOCSIS 3.1 PHY Physical Layer Specification, CM-SP-PHYv3.1-I02-140320, CableLabs

[3] The Power of DOCSIS 3.1 Downstream Profiles, John T. Chapman, NCTA 2013

[4] DOCSIS Edge Resource Manager Interface Specification, CM-SP-ERMI-I04-110623, CableLabs

List of Acronyms

CM – Cable Modem
CMTS – Cable Modem Termination System
CCAP – Converged Cable Access Platform
DPD – Downstream Profile Descriptor
HPM – HFC Profile Manager
HPMI – HPM Interface
IUC – Interval Usage Code
NCP – Next Codeword Pointer
ODS – OFDM Downstream Spectrum
OFDM – Orthogonal Frequency Division Multiplexing
OFDMA– Orthogonal Frequency Division Multiplexing with Multiple Access
OUDP – OFDM Upstream Data Profile
PNM – Proactive Network Maintenance
SDN – Software Defined Networking
UCD – Upstream Channel Descriptor