R-PHY with Remote Upstream Scheduler

Introduction

The cable access network is radically transforming from the traditional integrated Converged Cable Access Platform (CCAP) architecture to a Distributed Access Architecture (DAA), driven by growing capacity crunches and cost pressures to deliver gigabit broadband services. With DAA, cable operators can push fiber deeper and replace legacy fiber nodes with DAA devices, achieving higher capacity with both better signal quality and reduced service-group sizes.

Depending on how the CCAP Media Access Control (MAC) and Physical (PHY) functions are separated, there are two basic architectural options to DAA: Remote PHY (R-PHY) and Flexible MAC Architecture (FMA).

In the R-PHY architecture, the PHY element is removed from the CCAP core and added to the fiber node as a Remote PHY Device (RPD). The basic design philosophy is to put the least amount of hardware and software at the endpoints and keep the complexity centralized. It also allows operators to leverage existing CCAP functions for a fast and seamless transition to DAA with both integrated PHY and R-PHY potentially connected to the same CCAP core.

Contents

Flexible MAC Architecture is a small-scale Cable Modem Termination System

The FMA, on the other hand, moves both the CCAP MAC and PHY elements to the node, either as an integrated Remote MAC-PHY Device (RMD) or a combination of Remote MAC Core (RMC) and RPD. Essentially, an FMA DAA device is a small-scale Cable Modem Termination System (CMTS) without the routing and management functions. Compared to R-PHY, the DAA device requires significantly more hardware and software functions, and inevitably imposes design and deployment challenges when the device is constrained by power and cost. Moreover, given the complexity of the DOCSIS MAC layer, FMA requires a fairly comprehensive standard interface for the upper network layer and management applications to talk to the DAA devices.

From the latency point of view, one architectural difference between FMA and the R-PHY today is the location of the upstream (US) scheduler. With all the MAC layer functions centralized at the CCAP core, R-PHY uses a centralized US scheduling scheme that requires the request (REQ) and grant (GNT) information to be exchanged across the Converged Interconnect Network (CIN). CIN delay has no impact on the US scheduling latency provided it is not the dominating factor, which is the case when GNTs are carried in the de facto two millisecond (ms) MAPs, and the CIN distance is within the normal 100-mile (160 km) DOCSIS operational range assumed for I-CMTS deployment.

As the network keeps transitioning to DAA, there are reported cases where the CIN is stretched beyond the 100-mile mark for reasons such as hub-side consolidation that relocates a CCAP core to the central headend or a regional data center. Meanwhile, driven by new low latency applications like cloud gaming and mobile xHaul[2], the DOCSIS REQ-GNT protocol is being tightened to shorter MAPs, such as one millisecond MAPs, on DOCSIS 3.1 OFDMA channels[3]. In such circumstances, the CIN delay could be exposed as a significant factor in the REQ-GNT latency equation.

The reason why FMA is immune to CIN delay is because the US scheduler, the MAC element that handles REQ-GNT, is co-located with the PHY where the REQ is received, while in the R-PHY case, the US scheduler is at the core and separated from the RPD across the CIN. This realization leads to the central question of this paper: Is it possible to put a remote US scheduler at the RPD to help with the latency sensitive REQ-GNT processing?

The remote US scheduler idea was considered at the beginning of the R-PHY design and development and is mentioned as an option in the current R-PHY specification. However, since the initial R-PHY deployment goal was to replace I-CMTS, it was deferred as a future enhancement. Now the time has come to move forward with the remote US scheduler design to provide the low-latency scheduling (LLS) needed for long-distance R-PHY deployment.

R-PHY with a remote US scheduler adds a new DAA scenario as shown in Figure 1. It is equivalent to FMA in latency, but with much less cost and complexity. It offers FMA-lite functionalities with R-PHY's efficiency and simplicity.

Since the remote US scheduler is internal to the RPD, it can leverage the RPD hardware and software platform and the established forwarding, control, and management plane interfaces such as R-UEPI, R- DEPI and GCP. The remote US scheduler APIs will be based on the Yang data model and able to take advantage of the new control plane infrastructure proposed for R-PHY2.0[4].

R-PHY US scheduler location options

Since the beginning of the R-PHY architecture, there has been a technical debate as to where the US scheduler should be placed. Should it be in the CCAP core with the rest of the software, or should it be in the RPD with the US PHY? To answer this question, there are both business and technical reasons to consider when choosing one location over the other.

From a technical standpoint, latency is the main consideration when comparing the two location options. In this perspective, R-PHY with a centralized US scheduler is equivalent to I-CCAP when operating at 2ms MAPs over a 100-mile plant. R-PHY, with a remote US scheduler, is expected to provide better latency when operating at shorter MAPs and across a longer CIN distance.

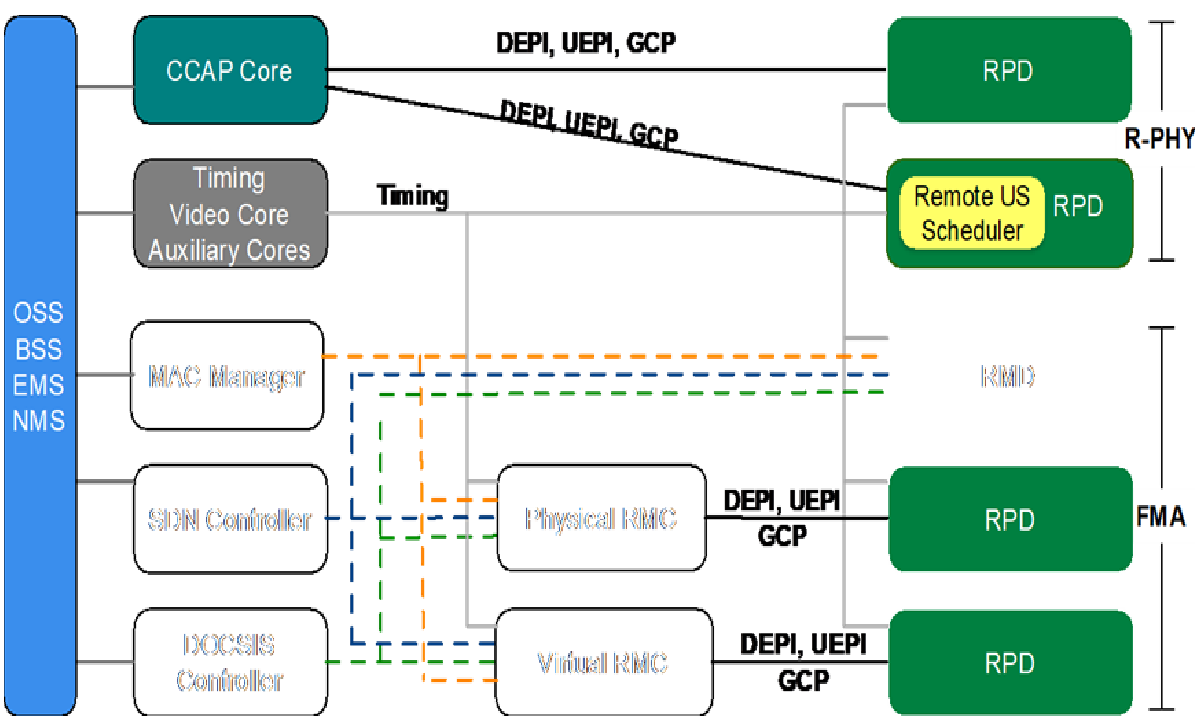

Figure 1 - DAA Options including R-PHY with Remote US Scheduler

US scheduling

The essence of split US scheduling with the remote US scheduler at the RPD is to enable system-wide locality optimization.

By co-locating the reactive granting portion of the scheduling with the PHY where the REQ is received, latency is reduced by avoiding the CIN delay in the REQ-GNT process.

The case for a centralized US scheduler

The basis of the R-PHY architecture is to move the PHY and replace the analog optical link between the CCAP and the node with a digital link. Just with this initial step, cable operators can expect better SNR performance, pull the fiber deeper, rebuild the plant, and cut a large N+M service group into much smaller ones.

All of these can be achieved by simply moving the PHY element out of the CCAP core, while keeping all MAC elements including the DOCSIS US scheduler centralized. This also allows operators to leverage the existing CCAP MAC functions to simultaneously support both integrated PHY and remote PHY for a seamless transition to DAA.

Locality optimization with remote US scheduling

The essence of split US scheduling with the remote US scheduler at the RPD is to enable system-wide locality optimization. By co-locating the reactive granting portion of the scheduling with the PHY where the REQ is received, latency is reduced by avoiding the CIN delay in the REQ-GNT process. By keeping the latency-tolerant and computation-intensive part of the scheduling centralized at the core, efficiency is maximized by positioning the core as the common computation platform accessible to all RPDs.

This scheduling model is different from the decentralized scheduling model used in FMA that has no centralized control from the CCAP core. The core US scheduler in the R-PHY case provides a unique value for global locality optimization that takes into consideration the per-service flow latency requirement, RPD capabilities/constraints, and the CCAP core real-time processing capacity. In this perspective, the ability to perform remote scheduling with centralized control gives R-PHY the architecture advantages to achieve low-latency and high efficiency and remain backwards compatible with legacy R- PHY deployments.

Conclusion

Cable networks are going through a radical transformation in changing from bandwidth-limited and latency-tolerant networks to a high-capacity, low-latency, multi-service edge access network. Adapting to the change by enabling low-latency US scheduling in R-PHY is one step in accelerating this transformation and preparing cable networks for the future.

R-PHY low-latency US scheduling involves moving the latency-sensitive scheduling tasks such as REQ- GNT handling to the RPD, while keeping the latency-tolerant scheduling tasks centralized to retain the centralized MAC advantages. For the US scheduling service, the core

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This is a short summary and the complete white paper by Tong Liu, PHD Principal Engineer Cisco and John T Chapman CTO Cable Access and Cisco Fellow can be found at the NCTA Technical Papers Hub: https://www.nctatechnicalpapers.com/Paper/2019/2019-r-phy-with-remote-upstream-scheduler

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and RPD form a client-server relationship, where the RPD remote US scheduler provides services to REQ-GNT low-latency service flows, builds MAPs for both core and the remote schedulers, and replicates MAP UCDs to the proper DS channels. Such services can be precisely defined using data model-based APIs, which can be autogenerated based on published Yang data models.

The RPD remote US scheduler can be built on top of an existing R-RPY platform, which contains the basic MAC and PHY building blocks and the glue logic. The addition of the remote US scheduler has no impact on the US PHY or DS PHY silicon and can be readily supported by the R-UEPI and R-DEPI architecture, as the only change needed is the endpoint location of the UEPI and DEPI PWs on the MAC side.

The addition of the remote US scheduler to the R-PHY US scheduling scheme enables a distributed model where the core optimizes the scheduling locations and conducts the vertical load balancing between the core and the RPD. This scheduling model is unique to the R-PHY architecture, being able to achieve system-wide optimization in both latency and efficiency, and simultaneously maintaining backwards compatibility with legacy RPDs.

References:

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