Remote PHY for Converged DOCSIS, Video and OOB

John T. Chapman, CTO Cable Access BU & Cisco Fellow
jchapman@cisco.com
Cisco

Abstract

Remote PHY refers to the technique of moving the PHY circuit out of a device such as a CCAP and putting the PHY circuit at the end of a network. Remote PHY builds upon the work started with Modular CMTS (M-CMTS) and Modular Headend Architecture (MHA) at CableLabs.

Remote PHY is an evolving set of specifications and products. This white paper will focus on the expanded definition and the updates to the transport and timing for Remote PHY and how they apply to DOCSIS, MPEG-TS video, and Out-of-Band signaling for STB.

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INTRODUCTION

Disclosure

The ideas described in this paper are being considered to become part of a formal set of public Remote PHY specifications.

The Remote PHY specifications are still under development. The following represents the author's current thoughts on the requirements, form, and functionality of the Remote PHY protocol. Since actual bit positions within the protocol are still being finalized, they are not explicitly specified in this white paper.

However, this white paper should be a fairly accurate guide to what the Remote PHY protocol can accomplish and how it operates.

What is Remote PHY?

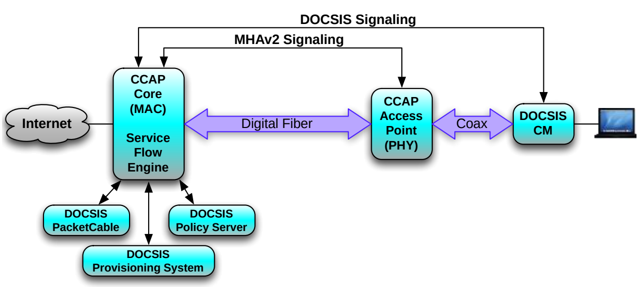


Figure 1 - Remote PHY CCAP Network

Remote PHY is an architectural strategy that removes the PHY element from a product and places that PHY element in a separate access point that is interconnected with an IP network (even simple Metro Ethernet networks or just EPONs qualify as they use IP packets). This is shown in Figure 1 and explained in the white paper [8].

Restated, Remote PHY allows you to put your main chassis at one end of a network and your PHY chip at the other end of the network. This is a useful technique when the PHY chip needs to be close to an access network, but the desire is to put the intelligence and complexity in a central location that has more room and is more serviceable.

Remote PHY infers centralized software. The least amount of complexity is placed remotely; the most amount of complexity is retained centrally.

Remote PHY-like strategies (similar in concept but different in implementation) have been used in adjacent markets such as:

- WiFi access points
- LTE access points
- Ethernet over Coax (EoC)
- EPON over Coax (EPoC)
- xDSL

Remote PHY in this context was applied initially to a DOCSIS CMTS. Remote PHY is also now being applied to traditional MPEG-TS video and to out-of-band (OOB signaling).

Remote PHY Lineage

The first instance of Remote PHY technology was the Modular CMTS (M-CMTS) specifications from CableLabs in 2005. Architecture and tutorial discussions of M-CMTS can be found in white papers [11], [12] and [13].

The specifications included:

- DEPI – DOCSIS External PHY Interface
- DTI – DOCSIS Timing Interface

- ERMI – Edge Resource Management Interface
- M-OSSI – M-CMTS Operations Support System Interface Specification

These specifications where targeted at combining CMTS and Edge QAMs (EQAM) together into one system. While the original intent was to lower the system cost, the real benefit ended up being the ability to greater customize the CMTS for cost and performance.

At the time, another specification was written but was not published, as there was no market application for it. That spec was:

- UEPI – Upstream External PHY Interface

UEPI builds upon the DEPI pseudowire concepts and applied them to the upstream CMTS MAC-PHY interface. In 2006, UEPI was used as a MAC to PHY interface for vendor silicon for I-CMTS applications.

In 2008, a second round of specifications that focused on the EQAM were published. Since the set of specifications now referred to more than just the CMTS, they were renamed as the Modular Headend Architecture (MHA) specifications. These specifications were:

- EQAM-PMI – Edge QAM Provisioning and Management Interface
- EQAM-VSI – Edge QAM Video Stream Interface
- MHA Technical Report

In 2012, the Chinese national regulatory body for the cable industry known as SARFT (State Administration of Radio, Film, and Television) adopted DEPI and UEPI as C-DOCSIS (China DOCSIS) Type III.

Also in 2012, the Remote PHY technology won a China CRTA Scientific and Technological Innovation Award, shown in Figure 2.

Figure 2 - Remote PHY Innovation Award

It is anticipated that the work described in this white paper will evolve into industry specifications as well.

Why is Digital HFC Interesting?

One of the product goals of Remote PHY is to put Remote PHY technology into an Optical Node in an HFC (Hybrid Fiber Coax) Plant. This would allow the fiber portion of the HFC plant to become digital. To date, the HFC forward path has used analog optics and the reverse path has used both analog and digital optics.

The conversion of the HFC plant from a linear optics plant to a digital optics plant would be applicable anytime the plant is to be segmented or upgraded. The most compelling case is deep fiber. Today's plant is typically N+5, which refers to an optical node plus 5 amplifiers deep. A deep fiber plant design would be N+0 or N+1, meaning an optical node plus no or one amplifier.

In a deep fiber plant, there are many more optical nodes, head end optical lasers and receivers, as well as CMTS ports to be purchased. A conversion to digital fiber may yield a better investment decision.

Digital forward and reverse paths are interesting for technical and strategic reasons. The technical reasons are:

- Longer distances (80+ km vs. 40 km)
- More wavelengths (80 vs. 16)
- Lower cost optics (based upon 10G Ethernet)
- Higher throughput (more bits per Hertz) if the DOCSIS 3.1 PHY is located after the coax segment.
- Lower maintenance costs
- Higher Reliability

If the digital fiber is also an IP network (or Metro Ethernet or EPON/GPON network), then there are also additional strategic benefits:

- Compatibility with digital access networks which are now appearing internationally
- Good scaling for deep fiber
- The same IP-based access network can be used for residential and commercial use.
- The same IP-based access network can be used to support DOCSIS (with Remote PHY) and fiber to the home (FTTH).

Review of Comparable Technologies

Table 1 - Technology Comparison

Criteria	BDR, BDF	Remote PHY	Remote MAC	Remote CMTS
IP Network	No	Yes	Yes	Yes
I-CMTS impact	Low	Low	High	Low
Remote SW	0%	5%	50%	100%
Remote HW	5%	10%	40%	100%

There are several ways to address the market need for digital HFC. These methods are shown in Table 1 and they are ranked to several basic criteria that define them. [9]

BDR/BDF

The most basic approach would be to do a baseband digital forward (BDF) in a similar manner to how baseband digital reverse (BDR) was done. This has been too costly to date to do, but may become feasible in the future. The main advantage of this approach is that it is transparent to any modulation or service that goes across it. The main disadvantage is that it maintains a single hop proprietary fiber interface. Even if BDF where to adopt a network packet format, the network traffic would be very high bandwidth and continuously on 100% of the time. It also does not allow the CMTS to Remote PHY path to traverse a generic IP network.

There are three variations on the DOCSIS CMTS theme, all of which support IP networking.

Remote PHY

Remote PHY, the subject of this white paper, puts the bare minimum hardware and software into a remote entity. Remote PHY keeps all the complexity centralized where it can be more easily scaled and maintained. The advantage of Remote PHY is its simplicity. The disadvantage is that the PHY definition has to be committed to and not changed. (Note that an overlay network could deal with changes, but the long term goal is that an overaly network should not be required).

Remote MAC

Remote MAC puts the DOCSIS PHY, the MAC, and a good amount of packet processing and software into the remote entity. Some examples are C-DOCSIS Type II and the PASI interface that was under development in CCAP but was later cancelled.

The advantage of the Remote MAC approach is that the CMTS-Core could be replaced with alternative products such as generic BRAS (Broadband Remote Access Server). The disadvantages of this approach are that there is no compatibility with an I-CMTS and the remote phy entity is more complex.

Further, to prevent truck rolls and upgrades, the remote node has to implement full spectrum DOCSIS MAC processing years before full spectrum DOCSIS is needed. It also requires the millions of lines of DOCSIS specific CMTS code to be decomposed and ported to the BRAS and MAC PHY node. This is a huge code stability concern, and an unnecessary risk.

Remote CMTS

Remote CMTS puts the entire CMTS into the node. The advantage of this approach is that the software model for the CMTS is not split in half, as is the case with Remote MAC. The disadvantages of Remote CMTS are that there are now 1000's of CMTS to configure and the node is not a secure location that was always an assumption for BPI (Baseline Privacy).

Of these choices, this white paper would like to suggest that Remote PHY provides the optimum balance of supporting IP networking and still striving for maximum simplicity and compatibility with existing CCAP devices.

CURRENT MHA TECHNOLOGY

Overview

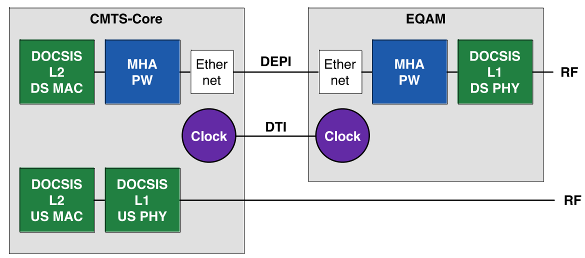


Figure 3 - MHA System Diagram

In a current MHA system, the downstream DOCSIS PHY is located externally in an EQAM while the upstream DOCSIS PHY remains in the CMTS-Core. The interface for the downstream PHY is DEPI.

DEPI

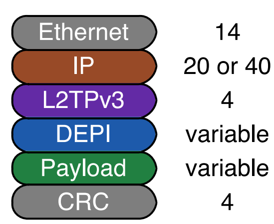


Figure 4 - DEPI Pseudowire Format

DEPI is the Downstream External PHY Interface. In an Integrated CMTS (I-CMTS) system, it can be the interface between the MAC chip and the PHY chip. In a Remote PHY system, it is the protocol interface between the MAC interface in the CCAP-Core and the PHY chip in the Remote PHY entity.

The general pseudowire format for DEPI along with a byte count is shown in Figure 4. The sub-elements of the DEPI packet are as follows:

- Ethernet header
- IPv4 or IPv6 header
- L2TPv3 header
- DEPI header
- DEPI Payload
- CRC

The first three headers are well defined by IEEE and IETF specifications. The published version of DEPI does include an optional UDP header ahead of the L2TPv3 header. This option was not used in practice and will be eliminated from the specification.

This also simplifies the L2TPv3 header. The L2TPv3 header contains a single 32-bit session ID. If the session ID is all zeros, the packet is a control plane packet. If the session ID is non-zero, then it is a data packet. The control plane will associate a session ID with a pseudowire type and sub-type. The base L2TPv3 protocol is in [20].

The format of the DEPI header is specific to DEPI. The DEPI header also specifies the format of the DEPI payload. There are two DEPI pseudowire types.

- D-MPT which is the DOCSIS MPEG Transport pseudowire
- PSP which is the Packet Streaming Protocol pseudowire

Each pseudowire can have a sub-type. Examples of sub-type are “DOCSIS 3.0 Downstream” and “DOCSIS 3.1 Downstream”. The significance is that the pseudowire type is part of the normal L2TPv3 control plane while the pseudowire sub-type is advertised in the DEPI specific extensions.

D-MPT Pseudowire

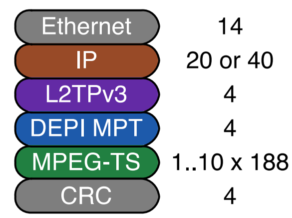


Figure 5 - D-MPT Pseudowire Type

The DOCSIS MPEG-TS pseudowire is the only pseudowire that was deployed in DOCSIS 3.0 based M-CMTS systems. As the name implies, there is a DEPI header followed by a number of 188 byte MPEG-TS packets. For M-CMTS, the DEPI packet size limited the number of MPEG-TS packets to seven.

The D-MPT header is 32 bits in size and contains the basic DEPI header that is used in all the pseudowire types. It contains:

- A V bit to permit L2TPv3 payload multiplexing within an L2TPv3 session.
- A S bit to indicate if the sequence field is valid
- Two H bits that allow DEPI payload multiplexing within a DEPI session. This is used for DLM, the DEPI Latency Measurement packet.

- Three-bit flow ID. Used for indicating the QoS of the payload.
- Segment count for PSP.
- Sequence number for the pseudowire session.

The V bit, S bit, and the sequence number are recommended fields from L2TPv3. All the other fields are DEPI specific.

PSP Pseudowire

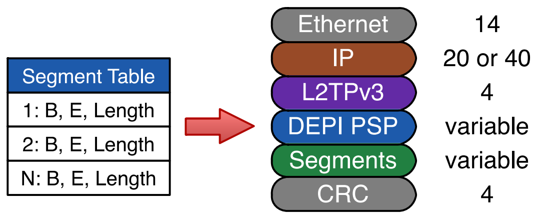


Figure 6 - PSP Pseudowire Type

The PSP Pseudowire has a payload that is divided into one or more segments. Packets are mapped to segments. A segment can contain the beginning, middle, or end of a packet. Payload packets can be split across multiple DEPI packets. Unlike CCF (Continuous Concatenation and Fragmentation) from DOCSIS 3.0, a segment cannot contain the end of one packet and the beginning of the next.

The basic PSP pseudowire sub-type only places packets in the segments. In other sub-types, segments can be used to carry pre-pended or post-pended information that is per packet.

The PSP pseudowire header uses the same 32-bit header from D-MPT, plus it adds a segment table. There is one entry in the segment table for each segment present in the payload. The entries contain:

- Begin bit
- End bit
- Segment length

The “begin” and “end” bits are used for packet reassembly. The segment length is used to find the next segment start byte.

REMOTE PHY TECHNOLOGY

This white paper will focus on the Remote PHY transport. In later white papers, the control protocols and management/OSS protocols will be covered in more detail.

Remote PHY technology builds upon the original DEPI specification.

Overview

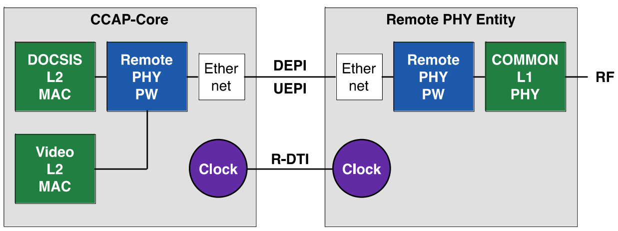


Figure 7 - Remote PHY CCAP System

A CCAP (Converged Cable Access Platform) is a combination of a DOCSIS (Data Over Cable Service Interface Specification) CMTS (Cable Modem Termination System) and an EQAM (Edge QAM).

An I-CCAP (Integrated CCAP) has the CMTS and EQAM in one chassis. In a Remote PHY system, the PHY circuitry from the I-CMTS is removed and put into the Remote PHY Entity (this will get a proper CCAP name later). The remaining parts of the CCAP are called the CCAP Core. This is shown in Figure 7.

Note that hybrid approaches are equally valid. A CCAP system could have both integrated MAC-PHY line cards and MAC-only line card that support Remote PHY.

The Remote PHY protocols use the concept of a pseudowire (PW). A pseudowire is just a cooler and updated name for an IP tunnel between two points in an IP network. Pseudowires can take a specific packet from one point on an IP network and move it to another point. In the case of Remote PHY, pseudowires are used to move MPEG-TS packets and DOCSIS frames between the MAC and the PHY.

One of the significant properties of the Remote PHY Protocols is that it is an IP packet that can traverse any kind of network. It can traverse a layer 2 forwarding network, a layer 3 routed network, an MPLS network, or even a lambda over fiber network.

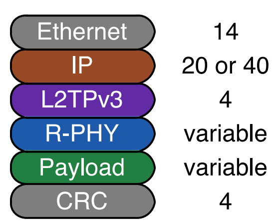
Specifications and Applications

Table 2 - Applications and Transports

Transport	Application		
	DOCSIS	Video	OOB
DEPI	▯	▯	▯
UEPI	▯	▯	▯
R-DTI	▯	▯	▯

Table 2 shows the basic transports and timing used in Remote PHY and how three different applications or higher layer protocols are mapped to these transports. Each of the transports and applications will be described next.

Remote PHY Pseudowire



The generic Remote PHY Pseudowire is the same as the MHA DEPI pseudowire with the exception that there are many more sub-types. In MHA DEPI, there was just the D-

MPT and PSP pseudowire types. There are now a collection of sub-types that add extensions to D-MPT and PSP.

UEPI

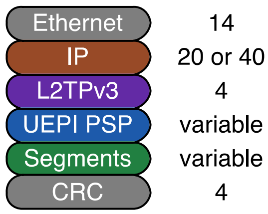


Figure 8 - UEPI Pseudowire

UEPI is the Upstream External PHY Interface. UEPI is new for Remote PHY and was not part of the original M-CMTS and MHA specifications.

UEPI is an extension to L2TPv3. UEPI uses the PSP pseudowire type from DEPI and uses the same control plane as DEPI. UEPI has unique pseudowire types for the upstream direction that are explained in a later section. UEPI for DOCSIS 3.0 is described in [1].

R-DTI

R-DTI is the Remote DOCSIS Timing Interface. The local version, just known as DTI, is part of the M-CMTS specifications. The original DTI protocol defines how a timing server can run timing to a CMTS-Core and an EQAM and how both devices can have the same timestamp. The DTI protocol is described in [10].

R-OOB

R-OOB is Remote Out-of-Band. OOB is the signaling channel in the downstream and upstream that is used to control Set-Top Boxes (STB).

R-OOB use DEPI and UEPI so that the pseudowires can be setup and torn down with the same control plane protocols as rest of the Remote PHY Pseudowires. R-OOB is carried as a separate specification since it is a distinct and potentially separate application.

NEW PROTOCOL EXTENSIONS

Packet Length

DEPI was originally defined with a 1500 byte Ethernet packet. In D-MPT mode, this allows for up to 7 MPEG-TS packets per DEPI packet. In the new Remote PHY specifications, that length will be increased to approximately 2000 bytes. This will allow up to 10 MPEG-TS packets per DEPI packet.

MPLS

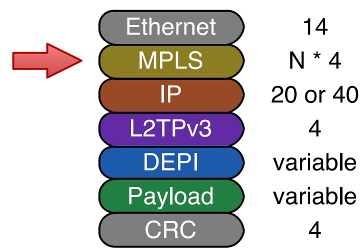


Figure 9 - DEPI over MPLS

MPLS is Multiple Protocol Label Switching, and is a method of moving packets across a network using labels which can be popped on and off at each network forward point. MPLS routes are setup using LDP, the Label Distribution Protocol. MPLS routes are calculated using protocols such as MPLS-TE that is MPLS Traffic Engineering.

Technically, there are two underlying types of pseudowires used in network – MPLS and L2TPv3. The MPLS pseudowire is used for native MPLS networks and the L2TPv3 pseudowire is used for native IP networks. Each protocol has its own control plane. If DEPI had been originally designed as an MPLS pseudowire, it would have added protocol extensions to MPLS-TE.

Since DEPI is just an IP packet, it can be sent over any network, including an MPLS network. Since the DEPI control plane is already well defined and working, the current direction is to not rebuild DEPI with MPLS-TE. Instead, the DEPI forwarding plane and control plane will remain as L2TPv3 and will (optionally) run on top of MPLS. This is shown in Figure 9.

Thus, DEPI does not use an MPLS pseudowire. DEPI uses an L2TPv3 based pseudowire which can be run over an MPLS network.

MCM: Multi-Channel MPT

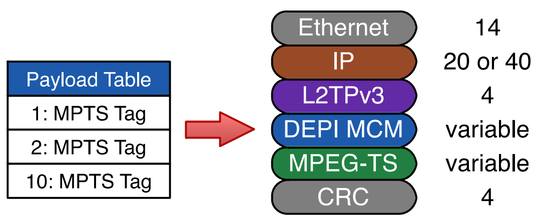


Figure 10 - DEPI MPT/MCM Pseudowire

In the current usage of the MPT pseudowire, there is one pseudowire for each QAM channel in the Remote PHY. The advantage of MPT is that it provides a simple point-to-point connection from a MAC channel to a PHY channel. The disadvantage is that additional latency is incurred in building up MPEG-TS packets into a DEPI packet. The latency of ten MPEG-TS packets at 1 Gbps is 1.6 usec.

While this is not much of an additional delay, MCM also offers an improvement by allowing multiple QAM channels to share the same pseudowire. This also helps with scaling. For example, instead of having 160 pseudowires for 160 QAM channels, technically, there could be one really busy DEPI pseudowire. Typically, there would be a smaller number of DEPI pseudowires with a number of pseudowires.

MCM is a sub-type of the main MPT pseudowire. MCM uses a table in the DEPI header that lists which MPEG-TS packet in the DEPI payload goes to which QAM Channel. A table format in the header is used rather then tagging each MPEG-TS packet so that in implementation, the table can be read and then executed against the rest of the packet. This is shown in Figure 10.

Note that while any number of QAM channels can be supported within a pseudowire, each DEPI packet can only contain up to 10 MPEG-TS packets in one packet at one time.

BFD

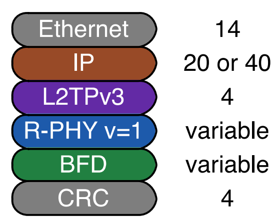


Figure 11 – DEPI or UEPI with BFD

BFD refers to Bi-Directional Forwarding Detection. BFD is essentially a loopback packet that can be used for testing data path integrity. By integrating BFD directly into the packet, the entire transmission path from the DOCSIS MAC channel to Remote PHY QAM channel can be tested.

Note that BFD can also be sent in a stand-alone UDP packet. BFD is an industry standard extension to L2TPv3 and applies to all DEPI and UEPI pseudowires types and sub-types. BFD is described in [17], [18] and [19].

DOCSIS 3.1

DOCSIS 3.1 is a new version of DOCSIS that has recently been released from CableLabs. DOCSIS 3.1 uses a new physical layer based upon OFDM (Orthogonal Frequency Division Multiplexing) and an error correction scheme called LDPC (Low Density Parity Check). The data path consists of one or more OFDM channels. Each OFDM channel has a PLC (PHY link Channel) for initializing CMs (Cable Modems). DOCSIS 3.1 is discussed in more detail in [3], [4] and [5].

In DOCSIS 3.1, the downstream OFDM channel is assigned a list of profiles. The profile lists the modulation to be used for each sub-carrier in an OFDM channel. The profile can be different for each LDPC block and is dependent upon which CM is receiving the OFDM block. This is done to allow the optimization of the transmission path to those CMs that can tolerate a higher modulation. The management of DOCSIS 3.1 profiles is described in [2].

The PLC Channel is composed of message blocks (MB). The following message blocks are defined in DOCSIS 3.1:

- Timestamp MB
- DLS (DOSIS Light Sleep Mode) MB
- Trigger MB
- Message Channel
- Null MB

The timestamp MB is generated locally at the Remote PHY. The other MBs are transparently passed from the CCAP-Core to the Remote PHY Entity.

In DOCSIS 3.1, the downstream and upstream frequency ranges also can be altered to provide more throughput. DOCSIS 3.1 can support 1 to 2.5 Gbps in the upstream, and 5 to 10 Gbps in the downstream. [7]

DS OFDM Channel Pseudowire

Each OFDM Channel is assigned to a PSP pseudowire with a subtype of DOCSIS 3.1 Data Path. The PSP header is extended so that its table contains the OFDM profile number for each packet in the PSP stream.

DS PLC Channel Pseudowire

Each PLC is assigned to a PSP pseudowire with a subtype of PLC. For the DLS MB, Trigger MB and the Null MB, the MBs are placed directly into a PSP segment and referenced by the PSP table. A 32-bit timestamp can optionally be prepended to a segment. This is useful for the trigger MB. The packets in the payload of the message channel are mapped to PSP segments.

D3.1 Upstream Pseudowires

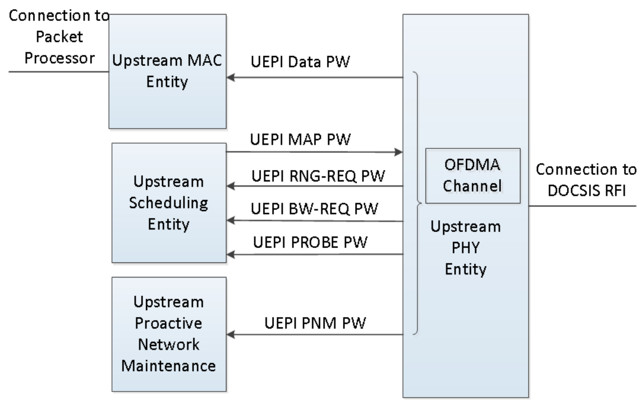


Figure 12 - DOCSIS 3.1 UEPI Pseudowires

There are a number of pseudowires associated with the DOCSIS 3.1 Upstream. All pseudowires have a pseudowire type of PSP and each have a unique sub-type. The DOCSIS 3.1 UEPI pseudowires are similar to the DOCSIS 3.0 UEPI pseudowires, but have differences in formats. The Probe PW is unique to DOCSIS 3.1 Remote PHY.

Video

For video, the same Remote PHY philosophy that was used for a DOCSIS CMTS is applied to a video EQAM. This works extremely well now that both the CMTS and EQAM functionalities are contained in the same CCAP device and use the same PHY chip.

The video in the form of SPTS or MPTS is received by the CCAP-Core from the network. The CCAP core performs all the same EQAM functions that it normally performs. These include a jitter buffer with PCR re-stamping, SPTS assembly into MPTS, Conditional Access, PID remapping, etc.

The resulting fully formatted MPTS stream is then sent over a DEPI pseudowire to the Remote PHY entity. Due to some jitter that will be introduced by the network between the CCAP-Core and the Remote PHY entity, the Remote PHY needs to contain a second smaller video jitter buffer. This jitter buffer will be smaller than the one in the CCAP-Core as it does not need to filter server jitter.

Since video is already in MPEG-TS format, video can be sent using a variant of the MPT/MPT and MPT/MCM pseudowires. The variant is that an MPEG-TS frame counter is added in addition to the L2TPv3 sequence counter. The additional MPEG-TS packet counter helps in error recovery.

OOB

OOB refers to the Out-of-Band protocols that control STB operation. There are two main OOB systems in use and they are defined in SCTE specifications.

- SCTE 55-1: This is the Motorola/Arris system that uses MPEG-TS packets in the downstream and an Aloha polling system in the upstream.
- SCTE 55-2: This is the SA/Cisco system that uses ATM over a modified T1 frame.

Analysis showed that the 55-1 system could be implemented using the pure Remote PHY strategy. However, the 55-2 system has a 3 millisecond turn around time from upstream to downstream that would of made it extremely sensitive to network latency. As a result, the decision was made to include the OOB framer along with the OOB PHY in the Remote PHY Entity. All the signaling for OOB and the carousel generation would remain centralized.

This also allows the OOB system to be driven directly by provisioning systems and OOB controllers independent of the CCAP-Core if so desired.

OOB would use a dedicated DEPI and UEPI pseudowire so that the links between the CCAP-Core and the R-PHY Entity can be reconfigured in conjunction with the other links for DOCSIS and video.

REMOTE PHY TIMING

Timing in a Remote PHY Network is managed with the Remote DTI (R-DTI) protocol.

The goal of R-DTI is also to get approximately the same timestamp value in the CCAP-Core and the Remote PHY. However, the technology for R-DTI is completely different than the technology used for DTI. Only the name is similar. Whereas DTI was a local protocol that ran over a maximum distance of 200 meters from DTI Server to DTI Client, R-DTI is required to work over long distances.

The R-DTI specification specifies multiple modes of operation that provide different levels of performance. There is a simple low cost mode at one option and a complete IEEE-1588 mode as another option.

R-DTI – One-Way Reverse

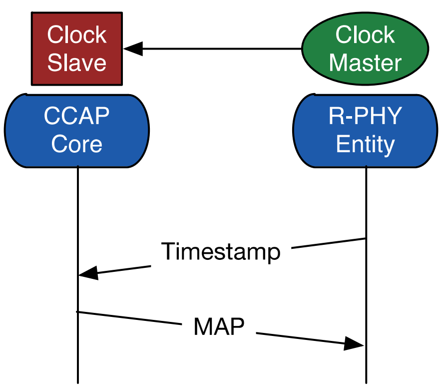


Figure 13 - R-DTI One-Way Reverse

The reverse direction refers to the R-PHY Entity being a clock master and the CCAP-Core being a clock slave.

The one-way refers to the Remote-PHY entity sending a timestamp to the CCAP-Core. The CCAP-Core filters the timestamp traffic, adds a MAP advance time, and uses the result to generate MAPs.

The advantage of the reverse method is that the physical clock in the R-PHY Entity does not need to be adjusted. The act of aligning the clock in the R-PHY entity to the CMTS-Core may cause enough disturbances in the DOCSIS baud rate to cause the R-PHY entity to fail the DRFI specifications. The disadvantage of the reverse method is the scaling required at the CCAP-Core. The CCAP-Core may now have to track hundreds of clocks. This, however, is not unlike what EQAMs have to do for video dejittering.

In this method it is not known what the delay is from the R-PHY entity to the CCAP-Core. And maybe it does not really matter. That delay, whatever it may be, becomes engineering margin. The longer the network distance, and hence the delay, the more margin is required at the CMTS-Core. The more jitter the network introduces, the more margin that is required at the CMTS-Core. So, it is somewhat of a self-compensating mechanism.

R-DTI – Two-Way Reverse

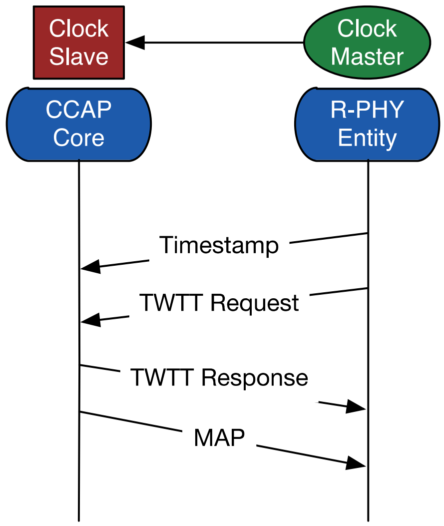


Figure 14 - R-DTI Two-Way Reverse

When the CMTS-Core receives a timing message from the R-PHY entity, it returns a timing message, creating what is known as a TWTT or Two-Way Time Transfer. TWTT collects outbound and inbound timestamps in each direction. Using these four timestamps, the one-way network delay can be calculated. That network delay can then managed more precisely with the MAP advance.

There are variations on the style of signaling as to whether or not the timestamp from the R-PHY Entity is in the same message as the request/response messages that actually get stamped on ingress and egress.

This method is superior to the one-way reverse method only if the time stamping of the timing packets happen in a timely and accurate manner. Such mechanisms usually are hardware based.

R-DTI – Two-Way Forward

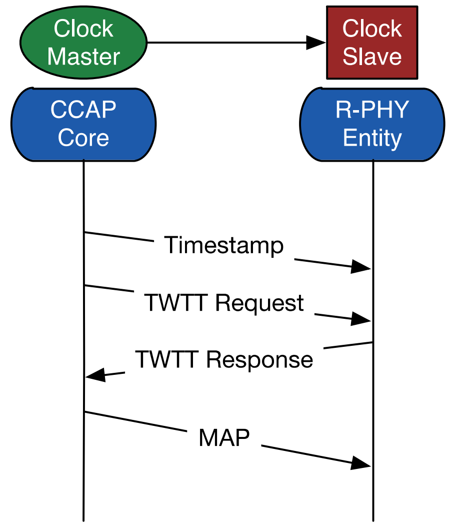


Figure 15 - R-DTI Two-Way Forward

In the two-way forward mode, the CCAP-Core is the clock master and the R-PHY entity is the clock slave. A TWTT protocol is run between the CCAP-Core and the R-PHY entity.

This is the classic clocking network, and is included to allow a full-blown level of accuracy. This is the classic IEEE-1588 implementation. This method would be applicable when the network is 1588 compatible.

Remote Scheduler

The Remote PHY specification permits the relocating of the DOCSIS scheduler from the CMTS-Core into the Remote PHY Entity. With the scheduler remotely located, there is no longer any timing requirement between the CMTS Core and the Remote PHY entity.

Although this sounds attractive at first, there are several drawbacks to remotely locating the scheduler. The first drawback is that the complexity of the Remote Node increases. The Remote Node entity now become subscriber aware and requires state information, QoS information, policy information and needs to track historical information for implementing of rate shaping. This is definitely an increased level of complexity.

The second reason that a remote scheduler is not attractive is interoperability. If the CCAP-Core is from one vendor, the scheduler and node are from another vendor, and something goes wrong, who is at fault? How is troubleshooting done without a centralized scheduler as a reference point?

Our current analysis shows that a centralized scheduler will work under currently known network conditions and that the timing design is quite manageable. (This will be the subject of a future white paper). The option for a remote scheduler is a future option should it ever be needed.

Details

Packet Formats

The two-way forward method is intended to be an IEEE-1588 implementation. It may also include a Synchronous Ethernet (SyncE) implementation for frequency alignment.

The one-way and two-way reverse methods could be implemented with a light version of IEEE-1588 or a Remote PHY specific control packet.

Support for DTP

DTP is the DOCSIS Timing Protocol that was developed by this author and is being introduced with DOCSIS 3.1. DTP allows a CM to provide timing services such as IEEE-1588 and Synchronous Ethernet derived from DOCSIS timing. This is explained in a white paper study [6] and in the DOCSIS 3.1 specification [14].

Distances

DOCSIS define a CMTS-to-CM, PHY-to-PHY distance of 100 miles (160 km) for DOCSIS 3.0 and 50 miles (80 km) for DOCSIS 3.1. Remote PHY maintains these distances.

Because Remote PHY separates the DOCSIS MAC and PHY, there is an additional distance specification. That is the MAC-to-MAC, CMTS-Core to CM distance. This distance is relevant when the CMTS-Core is removed from the hub and placed in the head end or regional data center.

In theory, there is no distance limitation to R-DTI. In practice, longer distances add jitter and latency that may impact services such as scheduling. While the maximum operating distance has not been chosen at the time this paper was written, research is being conducted to see if R-DTI and the scheduling applications it supports could run over a distance up to 2000 km. This number comes from the Indian market. The Norway market requires about 1500 km if everything was driven out of Oslo.

That is more than 10x the original DOCSIS distance of 160 km!

This additional distance is intended to allow the CCAP-Core to be located at the head end or regional data center instead of at the hub site.

NEXT STEPS

This white paper defined the operation of the Remote PHY transport. The next steps will include:

- agreeing on the bit definition of the various protocol headers,
- extending the DEPI control plane to cover UEPI, and
- defining a configuration and operational model for the Remote PHY entity.

SUMMARY

Remote PHY is an approach that literally takes the PHY chip out of a box and puts it at the end of an IP network. One of the philosophies of Remote PHY is to put the least amount of hardware and software at the end point and keep the complexity centralized.

Remote PHY infers centralized DOCSIS software. This allows the same software model to be used for I-CCAP and Remote PHY CCAP. Remote PHY, I-CMTS and M-CMTS can all co-exist in the same chassis and use the same software base and configuration systems. This is a very powerful concept for feature velocity and backwards compatibility.

Remote PHY works and works well. The design of remote PHY is built on top of open standards such as Ethernet, IP, L2TPv3, and CableLabs MHA.

Remote PHY will allow CCAP devices to be deployed in more creative manners such as using digital fiber in the HFC plant. For the Cable Operators, this will allow their network to have higher performance with lower OPEX, lower CAPEX, and an evolutionary path the FTTH.

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