Data-Over-Cable Service Interface Specifications
DCA - MHAv2

Remote Out-of-Band Specification

CM-SP-R-OOB-I01-150615

ISSUED

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Document Status Sheet

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Key to Document Status Codes

Work in Progress	An incomplete document designed to guide discussion and generate feedback, and may include several alternative solutions for consideration.
Draft	A document in Specification format considered largely complete, but lacking review by Members and Technology Suppliers. Drafts are susceptible to substantial change during the review process.
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Closed	A static document, reviewed, tested, validated, and closed to further ECs.

Trademarks

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1 SCOPE

1.1 Introduction and Purpose

Digital (MPEG transport) video delivery in traditional HFC distribution networks has utilized a unique two-way physical layer signaling as a core requirement. Two standards were widely deployed and are described in references [SCTE 55-1] and [SCTE 55-2]. These two signaling systems have been deployed en masse in parallel with digital MPEG Video transport.

Millions of deployed STBs remain dependent upon this legacy 2-way communication framework for localization, video control/enablement data delivery, code upgrades, and two-way interactive applications. Other devices, such as cable-ready TVs rely on this data to for program location and emergency alert notifications. DOCSIS Set-top Gateway [DSG] has been developed and fielded as an alternative delivery mechanism for the same data, however the physical OOB signaling remains a "MUST" to support for the aforementioned reasons.

1.2 MHAv2 Interface Documents

A list of the documents in the MHAv2 family of specifications is provided below. For updates, refer to http://www.cablelabs.com/specs/specification-search/.

Designation	Title
CM-SP-R-PHY	Remote PHY Specification
CM-SP-R-DEPI	Remote Downstream External PHY Interface Specification
CM-SP-R-UEPI	Remote Upstream External PHY Interface Specification
CM-SP-GCP	Generic Control Plane Specification
CM-SP-R-DTI	Remote DOCSIS Timing Interface Specification
CM-SP-R-OOB	Remote Out-of-Band Specification
CM-SP-R-OSSI	Remote PHY OSS Interface Specification

NOTE: MHAv2 does not explicitly use any of the original Modular Headend Architecture specifications.

1.3 Requirements and Conventions

Throughout this document, the words that are used to define the significance of particular requirements are capitalized. These words are:

"MUST" This word means that the item is an absolute requirement of this specification.

"MUST NOT" This phrase means that the item is an absolute prohibition of this specification

"SHOULD" This word means that there may exist valid reasons in particular circumstances to ignore this item, but the full implications should be understood and the case carefully weighed before choosing a different course.

"SHOULD NOT" This phrase means that there may exist valid reasons in particular circumstances when the listed behavior is acceptable or even useful, but the full implications should be understood and the case carefully weighed before implementing any behavior described with this label.

"MAY" This word means that this item is truly optional. One vendor may choose to include the item because a particular marketplace requires it or because it enhances the product, for example; another vendor may omit the same item.

2 REFERENCES

At the time of publication, the editions indicated were valid. All references are subject to revision, and users of this document are encouraged to investigate the possibility of applying the most recent editions of the documents listed below. References are either specific (identified by date of publication, edition number, version number, etc.) or non-specific. For a nonspecific reference, the latest version applies.

2.1 Normative References

In order to claim compliance with this specification, it is necessary to conform to the following standards and other works as indicated, in addition to the other requirements of this specification. Notwithstanding, intellectual property rights may be required to use or implement such normative references.

[DEPI]	Downstream External PHY Interface Specification, CM-SP-DEPI-I08-100611, June 11, 2010, Cable Television Laboratories, Inc.
[DSG]	DOCSIS Set-top Gateway, CM-SP-DSG-I24-130808, August 8, 2013, Cable Television Laboratories, Inc.
[R-DTI]	Remote DOCSIS Timing Interface, CM-SP-R-DTI-I01-150615, June 15, 2015, Cable Television Laboratories, Inc.
[RFC 2684]	IETF RFC 2684, Multiprotocol Encapsulation over ATM Adaptation Layer 5, September 1999.
[RFC 3931]	IETF RFC 3931, Layer Two Tunneling Protocol - Version 3 (Layer 2TPv3), March 2005.
[R-PHY]	Remote PHY System Specification, CM-SP-R-PHY-I01-150615, June 15, 2015, Cable Television Laboratories, Inc.
[R-UEPI]	Remote Upstream External PHY Interface Specification, CM-SP-R-UEPI-I01-150615, June 15, 2015, Cable Television Laboratories, Inc.
[SCTE 55-1]	ANSI SCTE 55-1 2009, Digital Broadband Delivery System: Out of Band Transport Part 1: Mode A.
[SCTE 55-2]	ANSI/SCTE 55-2 2008, Digital Broadband Delivery System: Out of Band Transport Part 2: Mode B.

2.2 Informative References

This document uses the following informative references:

[IEEE 802.3]	IEEE Std 802.3™-2002, Part 3: Carrier Sense Multiple Access With Collision Detection (CSMA/CD) Access Method and Physical Layer Specifications, March 2002.
[SCTE 18]	CEA/SCTE 18 2013, Emergency Alert Messaging for Cable.

2.3 Reference Acquisition

- European Telecommunications Standards Institute, ETSI, http://www.etsi.org
- The Institute of Electrical and Electronics Engineers, Inc., Internet: http://standards.ieee.org
- International Telecommunications Union, Telecommunications Sector, http://www.itu-t.org/
- Internet Engineering Task Force (IETF), Internet: http://www.ietf.org
- Internet Assigned Numbers Authority, IANA, Internet: http://www.iana.org
- Society of Cable Telecommunications Engineers (SCTE) Standards, http://www.scte.org

3 TERMS AND DEFINITIONS

This specification uses the following terms:

Cable Modem (CM)	A modulator-demodulator at subscriber locations intended for use in conveying data communications on a cable television system.
Converged Interconnect Network	The network (generally gigabit Ethernet) that connects a CCAP-Core to an EQAM.
Customer Premises Equipment (CPE)	Equipment at the end user's premises; may be provided by the service provider.
Data Rate	Throughput, data transmitted in units of time usually in bits per second (bps).
Decibels (dB)	Ratio of two power levels expressed mathematically as dB = $10\log_{10}(P_{OUT}/P_{IN})$.
Decibel-Millivolt (dBmV)	Unit of RF power expressed in decibels relative to 1 millivolt, where dBmV = $20\log_{10}$(value in mV/1 mV).
Downstream (DS)	1. Transmissions from CMTS to RPD. This includes transmission from the CCAP-Core to the EQAM, as well as the RF transmissions from the EQAM to the RPD. 2. RF spectrum used to transmit signals from a cable operator's headend or hub site to subscriber locations.
Edge QAM modulator (EQAM)	A headend or hub device that receives packets of digital video or data. It re-packetizes the video or data into an MPEG transport stream and digitally modulates the digital transport stream onto a downstream RF carrier using quadrature amplitude modulation (QAM).
Flow	A stream of packets in [DEPI] used to transport data of a certain priority from the CCAP-Core to a particular QAM channel of the EQAM. In PSP operation, there can exist several flows per QAM channel.
Gbps	Gigabits per second
Gigahertz (GHz)	A unit of frequency; 1,000,000,000 or 10^9 Hz.
GigE (GE)	Gigabit Ethernet (1 Gbps)
Hertz (Hz)	A unit of frequency; formerly cycles per second.
Hybrid Fiber/Coax (HFC) System	A broadband bidirectional shared-media transmission system using optical fiber trunks between the headend and the fiber nodes, and coaxial cable distribution from the fiber nodes to the customer locations.
Institute of Electrical and Electronic Engineers (IEEE)	A voluntary organization which, among other things, sponsors standards committees and is accredited by the American National Standards Institute (ANSI).
Internet Engineering Task Force (IETF)	A body responsible for, among other things, developing standards used in the Internet.
Internet Protocol (IP)	An Internet network-layer protocol
kilohertz (kHz)	Unit of frequency; 1,000 or 10^3 Hz; formerly kilocycles per second
Link Rate	Total effective throughput, i.e., data transmitted in units of time usually in symbols per second (Sps).
MAC Domain	A grouping of Layer 2 devices that can communicate with each other without using bridging or routing. In DOCSIS is the group of CMs that are using upstream and downstream channels linked together through a MAC forwarding entity.

Maximum Transmission Unit (MTU)	Maximum size of the Layer 3 payload of a Layer 2 frame.
Mbps	Megabits per second
Media Access Control (MAC)	Used to refer to the Layer 2 element of the system which would include DOCSIS framing and signaling.
Megahertz (MHz)	A unit of frequency; 1,000,000 or 106 Hz; formerly megacycles per second
Microsecond (µs)	10^{-6} second
Millisecond (ms)	10^{-3} second
Modulation Error Ratio (MER)	The ratio of the average symbol power to average error power
Multiple System Operator (MSO)	A corporate entity that owns and/or operates more than one cable system.
Nanosecond (ns)	10^{-9} second
Physical Media Dependent (PMD) Sublayer	A sublayer of the Physical layer which is concerned with transmitting bits or groups of bits over particular types of transmission link between open systems and which entails electrical, mechanical, and handshaking procedures.
QAM channel (QAM ch)	Analog RF channel that uses quadrature amplitude modulation (QAM) to convey information
Quadrature Amplitude Modulation (QAM)	A modulation technique in which an analog signal's amplitude and phase vary to convey information, such as digital data.
Radio Frequency (RF)	In cable television systems, this refers to electromagnetic signals in the range 5 to 1000 MHz.
Radio Frequency Interface	Term encompassing the downstream and the upstream radio frequency interfaces.
Upconverter	A device used to change the frequency range of an analog signal, usually converting from a local oscillator frequency to an RF transmission frequency.
Upstream (US)	1. Transmissions from CM to CMTS. This includes transmission from the RPD to the CCAP-Core as well as the RF transmissions from the CM to the CCAP-Core. 2. RF spectrum used to transmit signals from a subscriber location to a cable operator's headend or hub site.
Upstream Channel Descriptor (UCD)	The MAC Management Message used to communicate the characteristics of the upstream physical layer to the cable modems.

4 ABBREVIATIONS AND ACRONYMS

This specification uses the following abbreviations:

µsec, µsecond	Microsecond (10^{-6} second)
AAL 5 SAR	ATM Adaptation Layer 5 Segmentation and Reassembly
AM	Amplitude Modulation
CA	Conditional Access
CCAP	Converged Cable Access Platform
CDL	Common Download
CIN	Converged Interconnect Network
CMTS	Cable Modem Termination System
CPE	Customer Premise Equipment
DAC	Digital Addressable Controller
DCA	Distributed CCAP Architecture
DEPI	Downstream External PHY Interface
DHCT	Digital Home Communications Terminal
DOCSIS	Data-Over-Cable Service Interface Specifications
DS	Downstream
DSG	DOCSIS Set-top Gateway
DSP	Digital Signal Processing
DTI	DOCSIS Timing Interface
EAS	Emergency Alert System
EMM	Entitlement Management Message
EQAM	Edge QAM
FIFO	First In, First Out (buffer)
FM	Frequency Modulation
HE	Headend
HFC	Hybrid Fiber Coax
IEEE	Institute of Electrical and Electronic Engineers
IETF	Internet Engineering Task Force
IGMP	Internet Group Management Protocol
IP	Internet Protocol
I/Q	In-phase Quadrature (Used to denote the complex RF data format)
kHz	Kilohertz
LFG	Live Feed Generator
MAC	Media Access Control
MHz	Megahertz
MPEG	Moving Picture Experts Group
MTU	Maximum Transmission Unit
NC	Network Controller
NDF	Narrowband Digital Forward

NDR	Narrowband Digital Return
NIT	Network Information Table
OAM&P	Operations, Administration, Maintenance, & Provisioning
OM	Out-of-Band Modulator
OOB	Out-of-Band
PAT	Program Association Table
PHY	Physical Layer
PID	Packet Identifier
PMT	Program Map Table
PSP	Packet Streaming Protocol
PW	Pseudowire
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
RADD	Remotely Addressable DANIS and DLS
RCVR	Receive Module
RF	Radio Frequency
RPD	1) Remote PHY Device or 2) Return Path Demodulator
SC-QAM	Single Carrier Quadrature Amplitude Modulation
S, G	Source (unicast) Address and Group (Multicast) Address
STB	Set-top Box
TDMA	Time Division Multiple Access
UDP	User Datagram Protocol
UEPI	Upstream External PHY Interface
VCI	Virtual Channel Identifier
VLAN	Virtual Local Area Network
VPI	Virtual Path Identifier
WAN	Wide Area Network
XMIT	(Transmit) Forward Lasers

5 OVERVIEW

Multiple approaches to passing OOB signals through a Remote PHY Device (RPD) will be specified. Each approach differs in the functionality hosted on the CCAP-Core, constraints/capacities/demands placed on the CIN, and functionality placed in the RPD.

The [SCTE 55-1] and [SCTE 55-2] systems are fundamentally different in that the SCTE 55-2 system includes a scheduled TDMA upstream that is intolerant of packet network latency/jitter and does not include provisions of equivalent "map advance" DOCSIS features to compensate. The SCTE 55-1 system does not include such upstream scheduling capabilities (and timing/jitter constraints), however requires multiple upstream frequencies to operate. For reference, the legacy SCTE 55-1 and SCTE 55-2 system solutions are detailed in Appendix I and Appendix II respectively.

Three approaches for passing OOB signals are specified in this document as follows:

- SCTE 55-2 Remote PHY solution (detailed in Section 6.1) serves to replace the existing SCTE 55-2 modulator/demodulator hardware and RF combining circuitry deployed in legacy headends with small-scale SCTE 55-2 modulator/demodulator functions embedded in each RPD. The high-level MAC functionality resides in an external server.
- SCTE 55-1 Remote PHY solution (detailed in Section 6.2) serves to utilize existing SCTE 55-1 modulator functionality (packet based output instead of RF output) in the downstream, and place upstream demodulator and reassembly functions in the RPD.
- Narrowband Digital Forward (NDF) and Narrowband Digital Return (NDR) digitizes a small portion of the spectrum, and sends the digital samples as payload within packets which traverse between the CMTS and the RPD. This approach works with any type of OOB signal as long as the signal can be contained within the defined pass bands. This approach is detailed in Section 7.

The SCTE 55-2 Remote PHY and SCTE 55-1 Remote PHY solutions are targeted specifically at supporting legacy Set-top Box (STB) equipment that employs either [SCTE 55-1] or [SCTE 55-2] PHY layer signaling. This approach requires that the RPD has specific knowledge of the protocols such that it can de-modulate/modulate the OOB data, and perform some portion of the MAC layer processing of this data.

6 R-OOB REMOTE PHY ARCHITECTURE

6.1 [SCTE 55-2] Remote PHY Solution

The SCTE 55-2 R-OOB MHAv2/ Remote PHY architecture is best understood through examination and comparison to existing system deployments. For reference more information, Appendix II contains an overview of the existing 55-2 system deployment.

Figure 1 depicts the SCTE 55-2 system in a Remote PHY architecture. As shown, the SCTE 55-2 Mod/Demod functionality is relocated to the RPD and serves a much smaller number of active two-way STBs. The remaining (grayed out) STBs are served by a different RPD which may or may not be served from the same CCAP-Core. Characteristics of the Remote PHY deployment include:

- An SCTE 55-2 controller client/server IP connection (reference ‘A' in Figure 1) is used to manage the operations of the RPD-deployed SCTE 55-2 Modulator/Demodulator. This client/server connection is made via the "Modulator IP" – a single IP address that exists on the CIN and is reachable from the outside world without tunneling. Note: this Modulator IP is not unique to OOB; it is the same reachable IP used for the RPD OAM&P.
- The high-level MAC functionality is performed in an external server, low level time critical functions are performed in the R-PHY. Downstream MAC messages are encapsulated onto the Downstream OOB tunnel; upon reaching the R-PHY, IP is terminated and the payloads are mapped onto reserved VPI/VCI channels for delivery to the STBs. Upstream MAC message payloads have power and timing offset measurements appended, encapsulated in IP and then onto the Upstream OOB tunnel for delivery to the MAC server.
- All *Video Control Data* (unicast or multicast delivered to the CCAP-Core) are encapsulated onto the downstream OOB tunnel (reference ‘B’ in Figure 1). The DHCT subnet is not directly reachable by the outside world (in-line with the DOCSIS CPEs). Upon reaching the RPD, the packets from the tunnel are decapsulated and are IP terminated at the RPD. The payloads are mapped onto particular VPI/VCI channels for delivery to the STBs.
- All *DHCT Application Data* (either IP unicast or broadcast packets) are also encapsulated onto the downstream OOB tunnel (reference ‘C’ in Figure 1) by the CCAP-Core. Upon reaching the RPD, the packets from the tunnel are decapsulated and a standard Layer 3(IPv4) address to VPI/VCI mapping using AAL5 functionality (with segmentation) is performed for delivery to the STBs. Reassembly and IP stack operations are performed on the DHCT.
- In the upstream direction, all DHCT-originated IP unicast traffic is delivered to the RPD using AAL5 functionality. The reassembled IPv4 packets from the STBs are encapsulated on a single upstream IP encapsulation tunnel and delivered to the CCAP-Core (reference ‘C’ in Figure 1) where they are decapsulated. A forwarding decision is made in the CCAP-Core based on the destination IP address of the DHCT-originated packet.

6.1.1 CCAP-Core Support of Multiple RPD-enabled 55-2 Modulators/Demodulators

To support multiple RPDs, the CCAP-Core provides the following features:

- Provide the proper forwarding of the multiple SCTE 55-2 client/server IPv4 connections (one per RPD). This functionality should already be enabled in an RPD-enabled CCAP-Core because each SCTE 55-2 Modulator is using the RPD management IP (for which forwarding is already supported on the CIN).
- **MAC and Video Control Data**: The CCAP-Core MUST provide the proper forwarding of MAC and video control flows to the proper IP encapsulation tunnel. This is accomplished in two different possible manners dependent upon its delivery to the CCAP-Core as follows:
    - For each unicast-delivered MAC and video control flow, the destination address will fall within the subnet mask of one of the DHCT subnets (unique to an RPD). Traditional Layer 3 L3 forwarding is sufficient to forward the packet through the CCAP-Core to the appropriate tunnel.

      If the same content is to be delivered to more than one RPD, the Video Control System is required to generate a unicast IPv4 video control flow for each RPD (matching the DHCT subnet). Given the nature of the multiplicity of SCTE 55-2 Mod/Demods it is anticipated that today’s IP unicast Video

Control flows may be converted to multicast delivery to more readily scale. The CCAP-Core MUST be prepared to handle either delivery mechanism.

- For multicast delivered video control flow(s), the CCAP-Core MUST add the (S,G) of the flow(s) to the forwarding table for each tunnel. The CCAP-Core MUST support the forwarding of a single multicast flow to multiple tunnels (each serving a different RPD).

- **DHCT Application Data**: The CCAP-Core MUST provide the proper southbound forwarding of IP-destined unicast downstream packets from the WAN interface to the output interface. These packets are classified through a Layer 3 lookup (one single contiguous subnet range per RPD-enabled 55-2 Mod/Demod). Each DHCT subnet (one per RPD) is supported by a single IP encapsulated downstream tunnel.
    - The CCAP-Core MUST provide the proper northbound forwarding of external world-destined upstream packets (which originated at the DHCT). Northbound forwarding of these upstream packets is analogous to forwarding of DOCSIS upstream IPv4 packets.

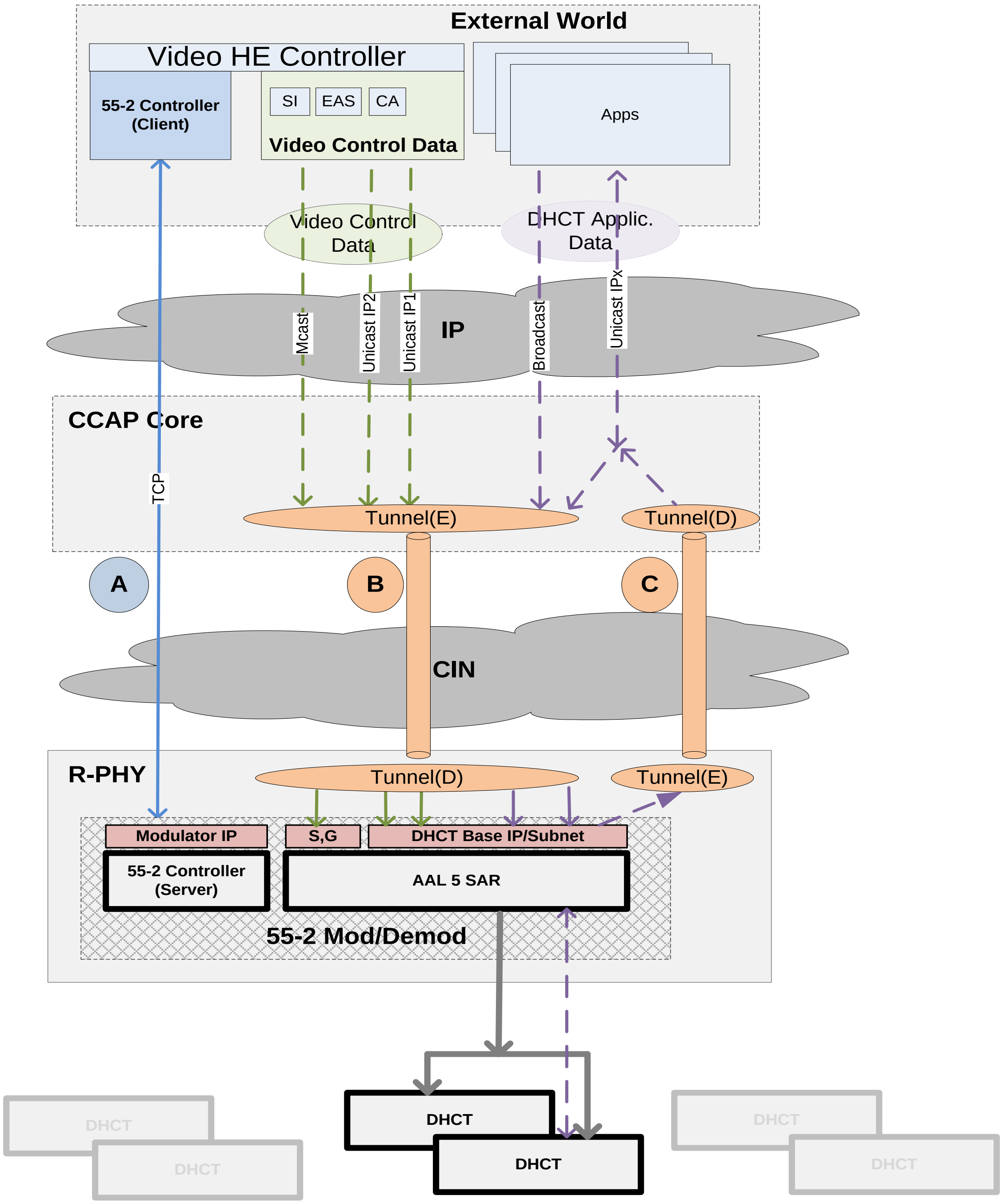

Figure 1 - SCTE 55-2 Remote PHY System Deployment Architecture

6.1.2 R-OOB Data Path

The downstream OOB data path relies on tunneling to isolate the OOB traffic from the DOCSIS and MPEG Video traffic. The tunneling greatly simplifies the networking requirements placed on the RPD by isolating the DHCT IP subnet range. STBs may only be addressed through the upstream/downstream tunnels which terminate/originate at the CCAP-Core respectively.

The expected capacity of each of the downstream/upstream tunnels (one upstream/downstream tunnel per RPD) needs to align with the throughput of the SCTE 55-2 link, i.e., 1.544 Mbps. Each RPD MUST have enough buffering capacity to support the bursty nature of downstream delivery (the implementation is vendor specific).

L2TPv3 (see [RFC 3931]) is the chosen tunneling mechanism. No Layer 2-Specific Sublayer header is specified (it is optional and provides no additional value) because all necessary metadata is contained in the header of the encapsulated payload.

The structure of the packet and headers is shown in Figure 2. An Ethernet [IEEE 802.3] header and optional VLAN headers are in common with the DOCSIS and MPEG Video packet descriptions contained in [DEPI] and [R-UEPI]. The L2TPv3 header contains the Session Id which will (after control plane configuration) identify the payload as SCTE 55-2 OOB control data.

The encapsulated payload is made up of the IP packet header and payload. This is the exact packet header plus payload that arrived on the CCAP-Core WAN interface (after its Layer 2 Ethernet header was stripped). The packet is left intact. The TTL field is not decremented by the CCAP-Core upon encapsulation. Descriptions of each field are contained in Table 1.

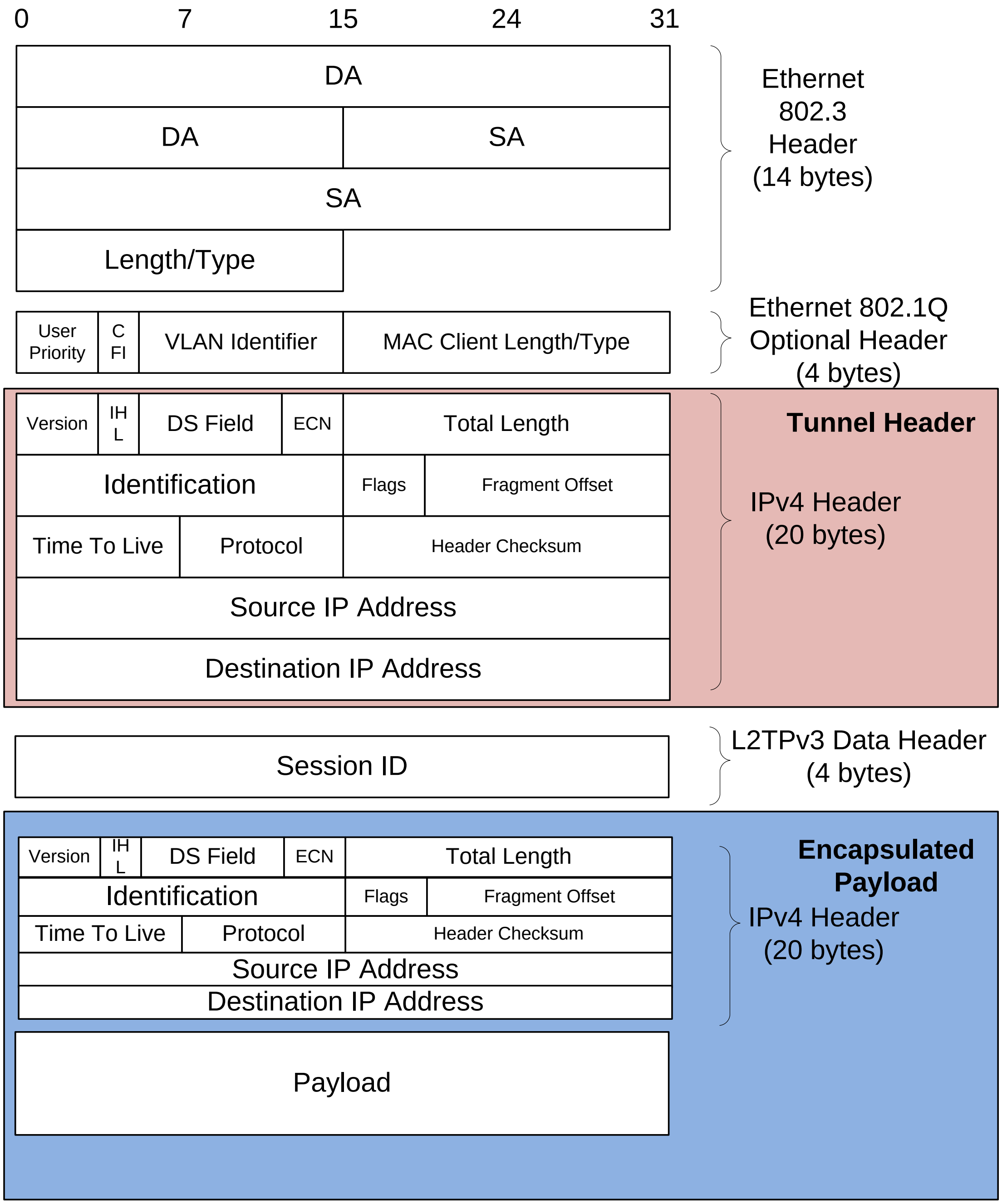

Figure 2 - Downstream/Upstream SCTE 55-2 OOB Packet Structure

Table 1 - Downstream Tunnel Header Field Descriptions

Field	Size (bits)	Description
Version	4	Always set to 4.
IHL	4	The length of the outer IP header measured in 32-bit words.
TOS	8	Copied from encapsulated payload header.
Total Length	16	This contains the length of the entire encapsulated IP datagram, including the outer IP header, the inner IP header, and its payload.

Field	Size (bits)	Description
Ident	16	Unique value for the tunnel header.
Flags	3	R – Unused DF – Copied from encapsulated payload header MF – Unused
Fragment Offset	13	Unused
TTL	8	Set to appropriate value to pass through to the CIN.
Protocol	8	Set to 115
Header Checksum	16	IP checksum of tunnel header.
Source IP Addr	32	IP address of the CCAP-Core tunnel ingress point.
Dest IP Addr	32	IP address of the RPD tunnel egress point.

The entire tunnel header is created in the CCAP-Core. The tunnel header is shown in Figure 2 and is identical to the tunnel header created for [DEPI].

The upstream packet structure is also depicted in Figure 2. Descriptions of each field in the tunnel header are contained in Table 2. The tunnel header is identical to the L2TPv3 tunnel header described in [R-UEPI].

The encapsulated payload comprises the IP packet header and payload. This is the exact packet header plus payload that originated at the DHCT. This packet is left unmodified upon encapsulation. Descriptions of each field are contained in Table 2.

Table 2 - Upstream Tunnel Header Field Descriptions

Field	Size (bits)	Description
Version	4	Always set to 4.
IHL	4	The length of the outer IP header measured in 32-bit words.
TOS	8	Copied from encapsulated payload header.
Total Length	16	This contains the length of the entire encapsulated IP datagram, including the outer IP header, the inner IP header, and its payload.
Ident	16	Unique value for the tunnel header.
Flags	3	R – Unused DF – Copied from encapsulated payload header MF – Unused
Fragment Offset	13	Unused
TTL	8	Set to appropriate value to pass through to the CIN.
Protocol	8	Set to 115
Header Checksum	16	IP checksum of tunnel header.
Source IP Addr	32	IP address of the RPD tunnel ingress point.
Dest IP Addr	32	IP address of the CCAP-Core tunnel egress point.

6.1.3 Networking Considerations

6.1.3.1 CCAP-Core Requirements

The CCAP-Core MUST be capable of processing downstream OOB packets in these ways:

- Receiving IP unicast packets, classifying based on destination IP, and forwarding to the proper internal tunnel resource for tunneling to the appropriate RPD.
- Receiving IP broadcast packets, classifying based on the subnet range, and forwarding to the proper internal tunnel resource for tunneling to the appropriate RPD.

- Receiving IP multicast packets, classifying based on (S,G), and forwarding to the proper internal tunnel resource(s) for tunneling to the proper RPD(s).
- Tunneling the aforementioned packets to the proper RPD (building the Encapsulation Header per Table 1, and placing on the appropriate interface for forwarding to the appropriate RPD).
- Receiving IP unicast packets (OOB server to client), classifying based on source IP address and destination IP address, and forwarding to the proper egress port for delivery through the CIN to the appropriate RPD.

The CCAP-Core MUST be capable of processing upstream OOB packets in these ways:

- Receiving L2TPv3 packets that originate from one or more RPDs, terminating the tunnel (stripping the tunnel header), classifying based on destination IP address of the Encapsulated Payload Header, and forwarding to the proper egress port for delivery through the IP network.
- Receiving IP unicast packets (OOB Client to Server), classifying based on destination IP, and forwarding to the proper egress port for delivery through the IP network.

6.1.3.2 CIN Requirements

The CIN MUST be capable of transporting a MTU size of not less than 1874 bytes (see [DEPI]) in both the upstream and downstream direction. Doing so permits L2TPv3 tunneling without any need for fragmentation.

6.1.3.3 RPD Requirements

The RPD MUST be capable of processing downstream OOB packets in these ways:

- Receiving L2TPv3 packets.
- Classifying the downstream OOB tunnel based on Source IP Address/Destination IP Address/IP Type and Session ID fields in the tunnel header and L2TPv3 header respectively.
- Termination of the tunnel (decapsulation of packets).
- Classification of the encapsulated payload based on the Encapsulated IP Header's Source IP/Destination IP (informative- part of internal "white box" functionality).

The RPD MUST be capable of processing upstream OOB packets in these ways:

- IP encapsulation of IPv4 packets that originated at the STBs, and forward them to the AAL5 reassembler as IPv4 packets.
- The RPD MUST place all packets in an L2TPv3 tunnel.
- Forwarding of IP unicast packets (OOB client to server) for delivery through the CIN to the appropriate CCAP-Core port.

6.1.4 R-PHY System Implementation

The RPD MUST implement sections 2.1 and 2.2 of the [SCTE 55-2] specification. Only Grade A (1.544 Mbps) in the downstream and Grade B (1.544 Mbps) in the upstream MUST be supported. Section 2.3 (MAC Functionality) of [SCTE 55-2] will be implemented in an external MAC server.

6.1.4.1 Interaction Between the R-PHY and MAC Server

These interactions and communication between the R-PHY and MAC Server are required:

- The RPD MUST forward both upstream and downstream MAC messages to the MAC Server via the upstream and downstream tunnels using a reserved subnet IP address. In the downstream, the IP is terminated and the payload is encapsulated in ATM using the reserved MAC VPI/VCI. In the upstream, ATM is terminated, timing offset (2 bytes) and power offset (1 byte) for that received MAC message is appended to the MAC PDU; and the resultant payload is IP encapsulated and forwarded to the MAC Server. Timing and Power offset measurements are formatted according to section 2.3.4.4.1.5 of [SCTE 55-2].
- The Slot Configuration fields in the downstream frame MUST be configurable by the MAC Server over a reserved subnet IP address. The Ranging Control Slot Indicator (b0) MUST be asserted active by the R-PHY

once every “x” frames where “x” is a parameter configurable by the MAC server. The Slot Boundary Definition field (b1-b6) will be configured by the MAC Server and remain constant until changed.

- The MAC Server will configure the RPD with the value of the Service_Channel_Last_Slot, which is the maximum value of the Upstream_Slot_Position_Register before it rolls over. The RPD MUST forward an indication to the MAC Server when the Upstream_Slot_Position_Register rolls over.

6.1.4.2 Mapping of DHCT Base IP Address to ATM

The RPDMUST map IP connectivity of the external world to ATM connectivity of the STB. In some cases this means terminating IP before ATM encapsulation, for others it means encapsulation of the entire IP datagram. Each RPD is assigned a dedicated IP subnet, with each connected STB having IP addresses within that subnet. There is a range of reserved subnet addresses that are used for processing video control data and MAC messages. These addresses may require special processing. The following table lists these addresses and how they map into ATM.

Table 3 - Current Mapping from the DHCT Base IP Address to ATM

Type	IP address	VPI	VCI	Comments
CA	10.1.x.**001**	0	0xFA0	Strip the IP header*
SAR	10.1.x.**002**	0		Not used
PassThru	10.1.x.**003**	0	0xFA1	Strip the IP header*
SI: base	10.1.x.**004**	0	0xFA2	Strip the IP header*
Broadcast	10.1.x.**255**	0xFF	0xFFFF	Does not strip the IP header
EMMG	223.0.0.0 through 239.255.255.255	0	0xFA0	The QPSK will strip the IP header from the packet, and will prepend an 8-byte CA header. Broadcast: FF | FF | FF | FF | FF | FF | 80 | 80 |
EMMU	223.0.0.0 through 239.255.255.255	0	0xFA0	The QPSK will strip the IP header from the packet, and prepend an 8-byte CA header. Unicast: 00 | 00 | 00 | 00 | 00 | 00 | 80 | 80 |
MAC	10.1.x.05	0	0x021	Strip the IP header*
MAC Config	10.1.x.06	N/A	N/A	MAC configuration messages
Unused	10.1.x.07 through 10.1.x.19	MOD ID	Last 14 bits of IP address	Send the whole packet using AAL5 with LLC/SNAP [RFC 2684].
DHCT Unicast	10.1.x.20 through end	MOD ID	Last 14 bits of IP address	Send the whole packet using AAL5 with LLC/SNAP [RFC 2684].

* The UDP/IP header and TCP/IP header are stripped but only the IP header in the case of ICMP and IGMP.

6.1.5 Timing Considerations

The approach specified for SCTE 55-2 places all SCTE 55-2 Link and PHY layer functionality in the R-PHY itself. MAC level functionality is performed in a remote server. The R-PHY functions themselves have stringent latency, jitter, and synchronization requirements. This approach places no additional latency and/or jitter constraints on the CIN network, and places no synchronization/timing requirement between the CCAP-Core and the RPD(s) it serves. The CIN network is effectively an additional IP "hop" (via L2TPv3 tunnel) between the Video Control System/DHCT Applications and the Modulator/Demodulator functions.

6.2 [SCTE 55-1] Remote PHY Solution

To facilitate the delivery of OOB streams from the headend to the customer-facing CPE via the Remote PHY architecture, a solution is needed that delivers the OOB streams to the RPD via the same Ethernet carriers that the rest of the services traverse. The following sections describe two approaches to this transport:

- **Ethernet from the OM**: The OM processes OOB source streams per SCTE-55-1 and outputs UDP datagrams via IP multicast
- **CCAP-Core as OM**: The CCAP joins and processes streams per SCTE-55-1 and forwards them downstream to the RPD

6.2.1 Ethernet from the OM

This approach is similar to the process used today to deliver OOB control data. The OM is responsible for receiving the OOB source data streams and creating a multiplexed signal in accordance with [SCTE 55-1]. However, the OM does not RF modulate the processed MPEG transport stream; instead the MPEG transport stream containing the OOB is IP multicast via UDP to the CCAP-Core over an Ethernet link.

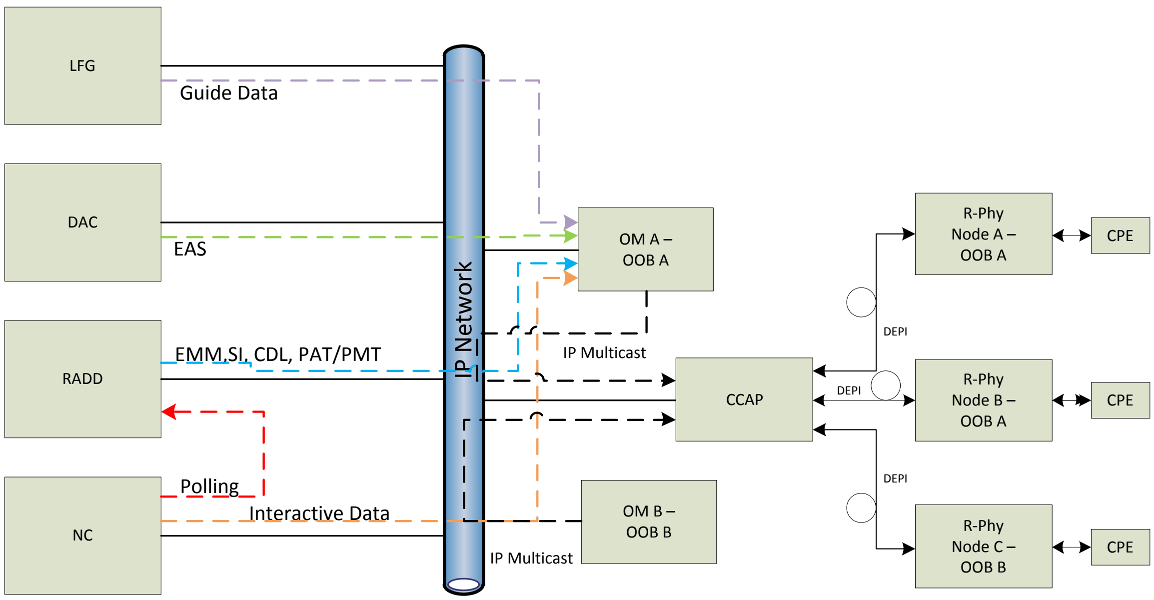

Figure 3 - OM as a Multiplexer

The CCAP-Core joins each IP multicast stream that is destined to the RPDs it serves and transparently forwards the received multicast payload contents. The CCAP-Core encapsulates the OOB payload received via [DEPI] and forwards the DEPI-encapsulated payload to the appropriate RPD. There may be more than one OM providing OOB streams that the CCAP-Core joins and forwards to the configured RPD.

The RPD receives the DEPI-encapsulated packets and QPSK modulates per SCTE-55-1. The modulated signal is output in the downstream RF spectrum, as instructed by the CCAP-Core via DEPI.

DEPI encapsulation for OOB data is detailed in Section 6.2.4.

6.2.1.1 Out-of-Band Stream Type and Scope

The CCAP-Core is expected to deliver OOB MPEG transport streams to each RPD it serves. While some of the OOB data will be the same for all RPDs, some data types will be unique per RPD. Therefore, the CCAP-Core will likely need to deliver more than one OOB MPEG transport stream and ensure that each is delivered to the appropriate RPD. Each OM can only output a single OOB multiplex; therefore, a CCAP-Core may receive OOB streams from multiple OMs. Each of these streams is destined for a different set of RPDs. See the example in the scenario depicted in Figure 4.

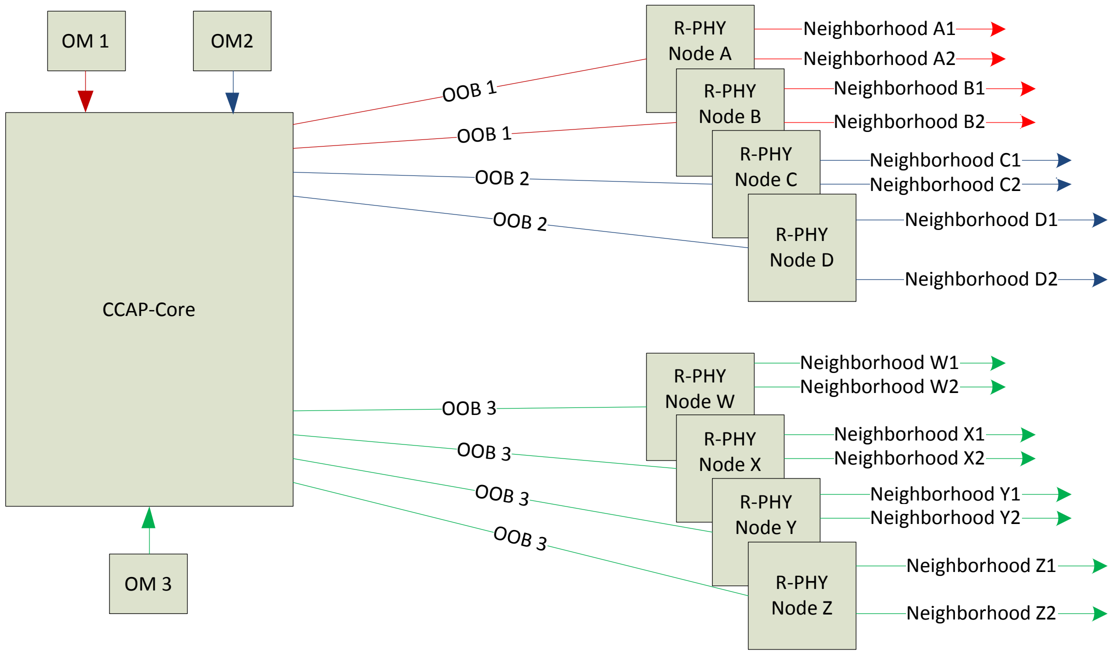

Figure 4 - Unique OOB Delivery to Multiple Sets of RPDs

In this case, the CCAP-Core delivers three different OOB MPEG transport streams, one from each unique OM. Note that while different RPDs may receive a different OOB MPEG transport stream, it is not anticipated that a given RPD would receive more than one; in other words, an RPD will deliver the same OOB multiplex to all its downstream ports. An RPD will always have only one OOB MPEG transport stream to deliver on its RF downstreams.

6.2.2 CCAP-Core as Out-of-Band Multiplexer

In this approach, the CCAP-Core performs the multiplexing functions of the OM. The CCAP-Core MUST multiplex MPEG transport streams containing OOB signals for the RPDs it serves. The process of creating this multiplexed stream is detailed in [SCTE 55-1]. While some of the OOB streams are common to all of the RPDs the CCAP-Core serves (guide data, for example), some OOB streams are different (EMMs, for example). For this reason, the CCAP-Core needs to be able to independently create multiplexes of common and unique OOB data streams available in the network.

In this scenario, the CCAP-Core will be configured to assemble MPEG transport streams containing the OOB source data streams required for each RPD group served. OOB data streams are multicast from their source and the CCAP-Core joins each needed stream via IGMP. The CCAP-Core then processes these incoming streams per [SCTE 55-1], creating one MPEG transport stream for each unique OOB stream required.

Table 4 provides an overview of which streams are common and which streams are unique.

Table 4 - OOB Stream Source and Scope

Stream	Source	Unique per RPD Group
EMM	RADD	No
SI	RADD	No
Network	RADD	Yes
CDL	RADD	No
PAT/PMT	RADD	No
EAS	EAS Server	Yes
Guide Data	Live Feed Generator	No
Interactive Data	NC	Yes

Since some of these source streams are unique for a given RPD, the CCAP-Core needs to be able to create multiple unique OOB multiplexed streams. Each unique OOB multiplexed stream created by the CCAP-Core is forwarded via [DEPI] to the appropriate RPDs.

Each RPD receives the OOB stream via DEPI. The RPD QPSK modulates the OOB stream and transmits it via RF at the appropriate frequency on its downstream RF ports.

These streams, their sources, and their transmission paths are illustrated in Figure 5.

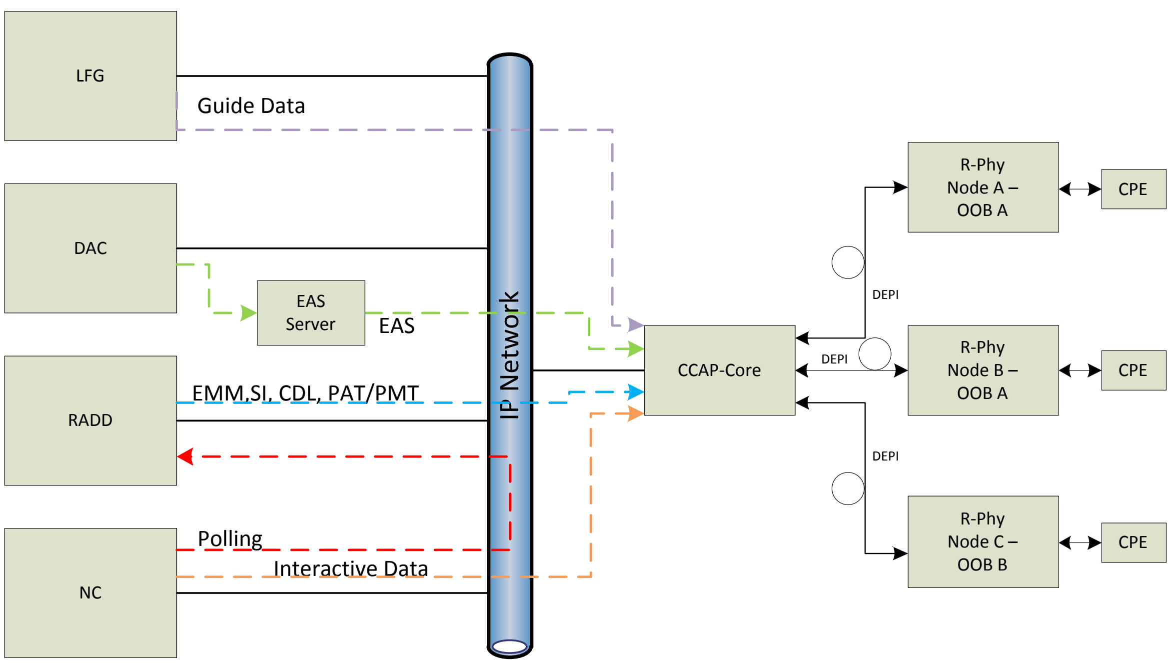

Figure 5 - CCAP-Core as OM - OOB Transmission

6.2.2.1 Delivery of EAS Messages

In this scenario, a new network element is introduced to supply EAS messages. The EAS Server, depicted in Figure 5, stores EAS messages that were generated by the DAC and listens for EAS triggers from the EAS ENDEC (encoder/decoder), a role previously performed by the OM. When the EAS Server receives a trigger message for an emergency alert message destined for a particular RPD group, the EAS Server begins to output the packets that contain the message on the multicast stream that the CCAP-Core has joined. The message data in the joined multicast stream is then transmitted to the appropriate service group on the appropriate PID.

6.2.3 Remote PHY Delivery of Upstream OOB Streams

In the upstream direction, the RPD demodulates the RF OOB signals as specified in [SCTE 55-1]. The demodulated payload is encapsulated via [R-UEPI] and forwarded to the CCAP-Core. The frequency on which a packet was received by the RPD is communicated to the CCAP-Core via R-UEPI. The CCAP-Core transparently forwards these packets via UDP unicast to the IP address of the network controller (NC) using the UDP port number configured in the CCAP-Core.

The CCAP-Core needs to be configured to forward upstream packets, based on the frequency on which they were received, to the appropriate NC or other network entity. This demodulation and IP forwarding were previously the role of a Return Path Demodulator, but the CCAP-Core now performs this function (see Figure 6).

UEPI encapsulation for OOB data is detailed in Section 6.2.4.

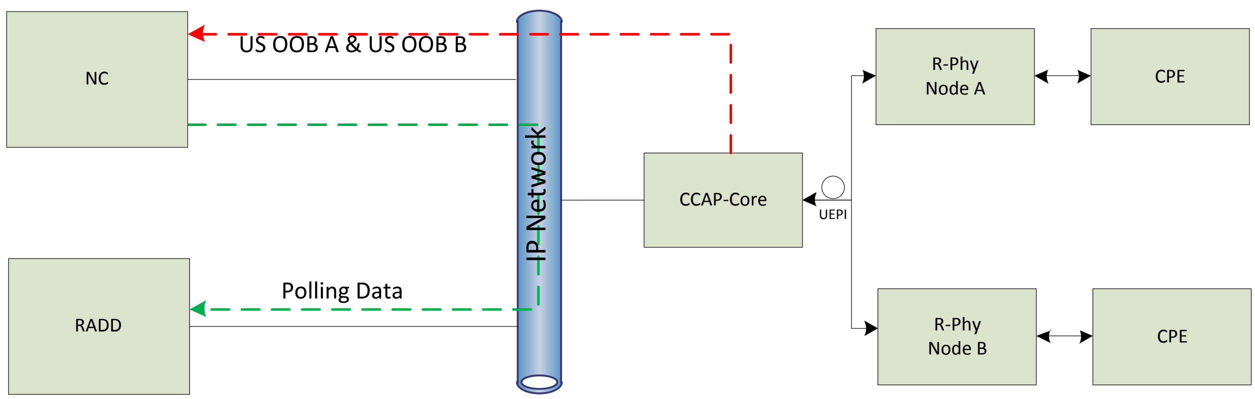

Figure 6 - Upstream OOB Transmission in the SCTE 55-1 Remote PHY Solution

6.2.4 R-OOB Data Path Downstream

The downstream OOB data path relies on tunneling to isolate the OOB traffic from the DOCSIS and MPEG Video traffic. The tunneling greatly simplifies the networking requirements placed on the RPD.

The capacity of each of the downstream/upstream tunnels (one upstream/downstream tunnel per RPD) needs to align with the throughput of the SCTE 55-1 link, i.e., 2.048 Mbps. Each RPD MUST have enough buffering capacity to support the bursty nature of downstream delivery (the implementation is vendor specific).

L2TPv3 (see [RFC 3931]) was chosen for the tunneling mechanism used by Remote PHY.

This section will be updated in a future revision of the specification.

6.2.5 Networking Considerations

- CCAP-Core Requirements
- CIN Requirements
- RPD Requirements

This section will be updated in a future revision of the specification.

6.2.6 System Timing Considerations

This section will be updated in a future revision of the specification.

7 R-OOB NARROWBAND ARCHITECTURE

This section defines the functionality required to support Out-Of-Band (OOB) signaling through an RPD by digitizing narrow portions of the spectrum. OOB signaling consists of any signals operating within the defined DOCSIS upstream and downstream spectrum that are not part of the DOCSIS specification.

Figure 7 shows the basic structure of an OOB system. In the forward direction, an OOB modulator device sends an analog signal into the CMTS. The CMTS samples the signal, packetizes the samples, and sends the samples through the CIN to the RPD. The RPD then converts the digitized spectrum back into the analog domain and sends them to the OOB CPE equipment. This process is called Narrowband Digital Forward (NDF). Likewise, in the reverse direction the OOB CPE equipment generates an analog signal which is then sampled by the RPD. The RPD packs the samples into packets and sends the packets through the CIN to the CMTS. The CMTS then converts the digitized spectrum back into an analog signal which is sent out to an OOB demodulator. This process is called Narrowband Digital Return (NDR).

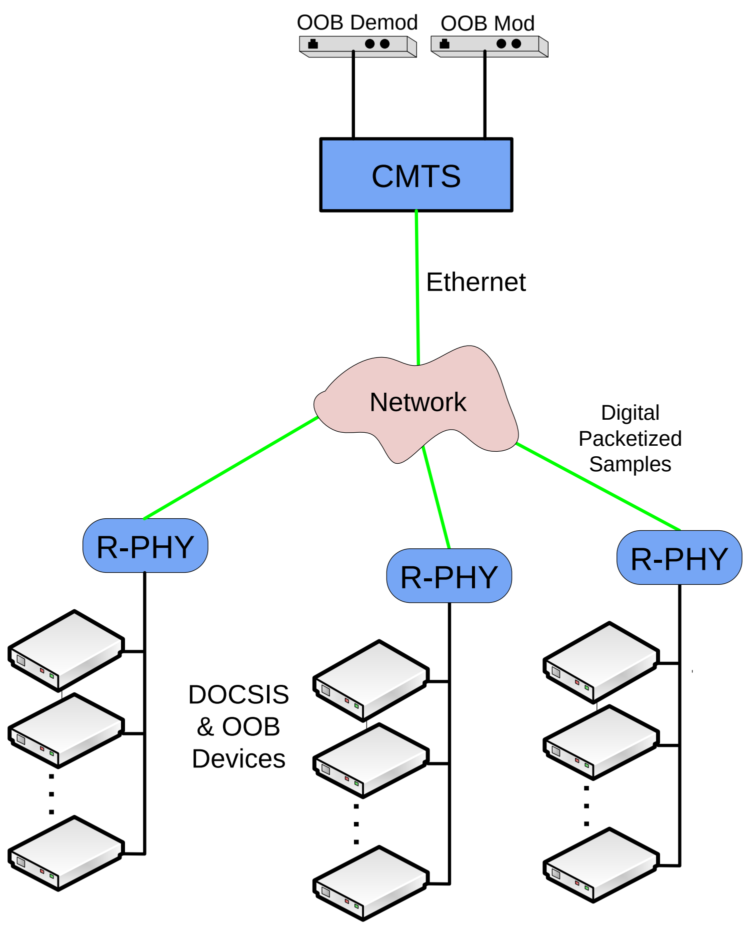

Figure 7 - NDF/NDR OOB Network Topology

7.1 Remote PHY Narrowband Digital Forward (NDF)

7.1.1 Overview

Remote PHY Narrowband Digital Forward (NDF) refers to the digitizing of an analog portion of the downstream spectrum at the headend, sending the digital samples as payload in [DEPI] packets to the RPD, and then re-creating the original analog stream at the RPD. A defined contiguous portion of spectrum, within which the OOB signals reside, is referred to here as an NDF channel.

The RPD MUST support a single NDF channel, but MAY support more than one NDF channels. The CMTS MAY support one or more NDF channels. The number of supported NDF channels will be identified via the RPD capabilities field.

Since the RPD plays out the samples into a D to A convertor as a continuous stream of samples, the samples provided by the CMTS cannot overflow or underrun the FIFOs in the RPD. As such, the CMTS and the RPD must remain frequency locked.

Table 5 provides a reference of common OOB signals which could be supported by NDF. The NDF specification uses these references to help identify the requirements.

Table 5 - Common Forward OOB Signals

DS OOB	DS Frequency Range	DS Channels
[SCTE 55-1]	70–130 MHz	1 x 1.8 MHz
[SCTE 55-2]	70–130 MHz	1 x 2.0 MHz
FM	87.5–108.0 MHz	-

7.1.2 NDF Channel Definition

The NDF channel is defined by a channel width and center frequency. In this context, the channel width refers to the total width of the spectrum including any required guardband. Table 6 shows the supported values for the NDF Channel. The RPD MUST support the NDF parameter requirements shown in Table 6. The CCAP-Core SHOULD support the NDF parameter requirements shown in Table 6.

Table 6 - NDF Channel Parameters

Parameter	Value	RPD Support	CCAP-Core Support
Channel Width	Symbol_Rate / 2 Annex A = ~2.5 MHz Annex B = 3.476 MHz	MUST	SHOULD
	Up to 25.6 MHz[1]	MAY	SHOULD
Center Frequency	70 – 130 MHz[2]	MUST	SHOULD
Allocated Guardband	0.25 MHz	MUST	SHOULD
Sample Resolution	10-bits	MUST	SHOULD

1. To support the 20.5 MHz FM band, 87.5 to 108.0, 25.6 MHz of spectrum is required assuming 1.25x oversampling for guardband. This has been rounded down from 25.625 because the 25.6M Hz frequency is a convenient multiple of 5.12 MHz, and the extra 0.25 MHz of bandwidth should be easily recoverable from the guardband.
2. Center frequency is taken directly from the [SCTE 55-1] and [SCTE 55-2] requirements. FM requirements of 87.5 to 108.0 fall within this specification.

The CCAP-Core sends 10-bit I/Q symbols packed into [DEPI] frames. A separate NDF pseudowire is established in order to identify the characteristics of the NDF channel. Symbols are sent in I/Q pairs with the 10-bit I sample followed by the 10-bit Q sample. As shown in Figure 8, the symbols are carried in a DEPI PSP frame with no segmentation. The CCAP-Core MUST send an integral number of number of I/Q symbols in each L2TPv3 DEPI packet.

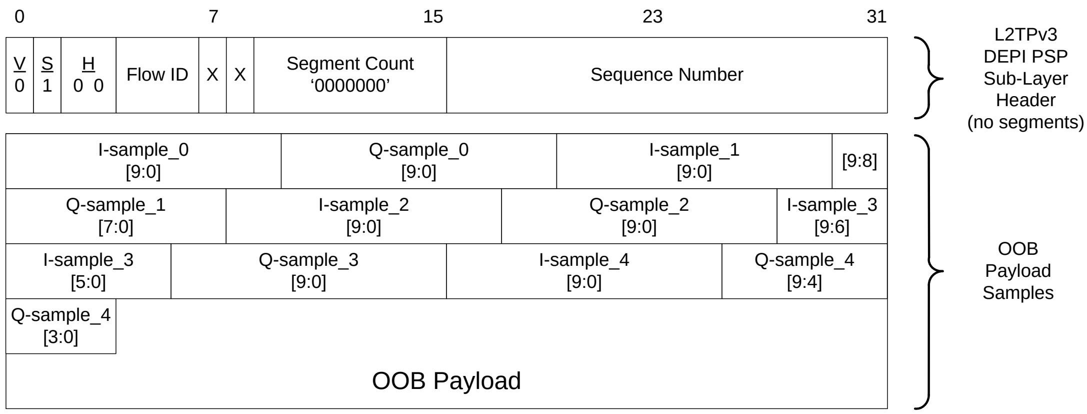

Figure 8 - PSP OOB Header Format

7.1.3 NDF Channel Rate

The I/Q symbols from the headend to the RPD are sent at baseband (i.e., the center frequency is '0' MHz). The symbol rate is equal to the width of the defined channel. For example, for a 2.5 MHz channel, symbols are sent at a rate of 2.5 Msymbols/s. Since a single symbol is represented by 20 bits, this translates into a link data rate of (2.5 MS/s × 20 bits/S) = 50 Mbps.

Because samples from the OOB modulator are condensed into a packet and then sent across a high speed link, there is some amount of latency associated with the process of packing symbols into the packet. Both the channel width and the packet size determine what this latency value is. For example, a 2.5 MHz channel will play out its samples at a rate of 2.5 Msymbols/s. If the CMTS were to send an MTU worth of data in the DEPI packet (i.e., ~1500 bytes), then the number of symbols that can be sent is (1500 bytes × 8 bits/byte)/20 bits per symbol = 600 symbols. The amount of time to send 600 symbols at a rate of 2.5 Msymbols/s is (600 symbols / 2.5 MS/s) = 240 µseconds.

In addition to the packetization latency, the RPD's jitter buffer threshold value introduces latency. Using the previous example, if the jitter buffer's threshold is set to 150 µseconds, then an additional 150 µseconds is added to the 240 µsecond packetization latency for a total of 390 µseconds. Ultimately, the value of the RPD's jitter buffer threshold will be determined by the jitter contribution of both the CMTS and the network. For latency-sensitive applications, such as SCTE 55-2, latency can be reduced by using smaller packet sizes and/or by keeping the network between the CMTS and the RPD as simple as possible.

7.1.4 NDF Signal Processing Requirements

A CCAP-Core that supports NDF MUST send 10-bit quadrature sampled I/Q symbols at baseband, and at a symbol rate equal to the specified channel width. Definition of the original carrier frequency of the signal or the signal processing chain in the CMTS is beyond the scope of this specification.

After reception, the samples received at the RPD need to be up-converted and then converted back to the analog domain. A guardband of 0.25 is provided for the DSP chain. This guardband allows for the DSP implementation of upsampling, or decimation filters. For example, if a passband of 2.0 MHz is required, then the required spectrum is 2.0 MHz × 1.25 = 2.5 MHz. The guardband is defined as the 250 kHz portion of the spectrum on either side of the usable 2.0 MHz. The OOB signal source SHOULD NOT have additional signals present within the guardband of the defined NDF channel.

The center frequency of the channel and the channel width are provided to the RPD when the NDF channel session is established. This specification does not dictate the specific DSP implementation for the up-conversion process, but it is required that the digital sample rate converters of the CMTS and RPD be phase locked. The required sampling rate is one half the DOCSIS downstream sampling rate. Higher sampling rates, and thus wider channels, MAY be supported by the RPD up to 25.6 MHz. For higher sampling rates, the chosen rate MUST be selected such that a rational fractional number of symbols fits into an integer number of 10.24 MHz clocks. The fraction will be defined as M/N, and the CMTS is responsible to provide the M and N values to the RPD, when the NDF channel is established. The resulting symbol rate is referred to hereafter as the "passband symbol rate".

The act of down-conversion at the CMTS and up-conversion at the RPD can incorporate in-band energy from out-of-band frequencies, and can generate out-of-band spectral replications. As such, the spurious emissions and out-of-band noise requirements apply to the NDF channel.

7.2 Remote PHY Narrowband Digital Return (NDR)

7.2.1 Overview

Remote PHY Narrowband Digital Return (NDR) refers to the digitizing of an analog portion of the upstream spectrum at the RPD, sending the digital samples as payload in [R-UEPI] packets to the CMTS, and then re-creating the original analog stream at the headend. A defined contiguous portion of spectrum, within which the OOB signals reside, is called an NDR channel.

The RPD MUST support a single NDR channel. The RPD MAY support more than one NDR channel. The CMTS MAY support one or more NDR channels. The number of supported NDR channels is identified via the RPD capabilities field.

Since the headend must play out the digital samples at fixed rate, the rate of samples received from the RPD needs to match the CMTS rate such that the FIFO buffers in the CMTS do not overflow or underrun. Alternatively stated, the CMTS and the RPD must remain frequency locked.

Table 7 provides a list of common return OOB signals that could be supported by NDR. The Remote PHY NDR uses these references to help identify the requirements.

Table 7 - Common Return OOB Signals

US OOB	US Frequency Range	US Channels
[SCTE 55-1]	5–42 MHz	1 x 3.2 MHz 3 x 192 kHz
[SCTE 55-2]	8–26.5 MHz	1 x 2.0 MHz

7.2.2 NDR Channel Definition

The NDR channel is defined by a channel width and center frequency. Table 8 shows the supported values for the NDR channel. The RPD MUST support the NDR parameter requirements shown in Table 8. The CCAP-Core SHOULD support the NDR parameter requirements shown in Table 8.

Table 8 - NDR Channel Parameters

Parameter	Value	RPD Support	CCAP-Core Support
Channel Width	1.28, 2.56, or 5.12 MHz[1]	MUST	SHOULD
Center Frequency	5–26.5 MHz[2]	MUST	SHOULD
Allocated Guardband	25%	MUST	SHOULD
Sample Resolution	10 bits	MUST	SHOULD

1. Defined channel widths based on the sampling rates in the DOCSIS upstream burst receivers.
2. Specified center frequencies are a subset of the center frequencies supported by [SCTE 55-1] and [SCTE 55-2].

The RPD sends 10-bit I/Q symbols packed into [R-UEPI] frames. A separate NDR pseudowire is established in order to identify the characteristics of the NDR channel. Symbols are sent in I/Q pairs with the 10-bit I sample followed by the 10-bit Q sample. As shown in Figure 9, the symbols are carried in a UEPI PSP frame with no segmentation. The RPD MUST send an integral number of I/Q symbols in each L2TPv3 UEPI packet.

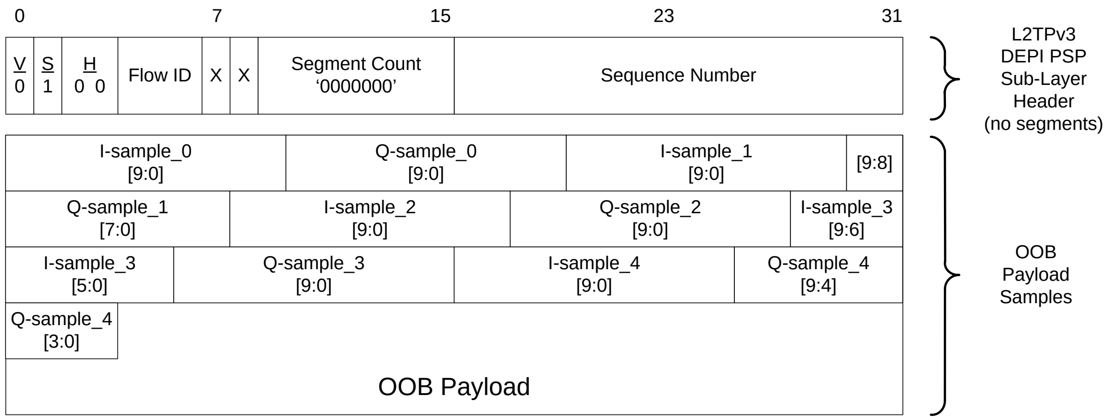

Figure 9 - PSP OOB Header Format

7.2.3 NDR Channel Rate

The I/Q symbols from the RPD to the headend are sent at baseband (i.e., the center frequency is '0' MHz). The symbol rate is equal to the width of the defined channel. For example, for a 5.12 MHz channel, symbols are sent at a rate of 5.12 Msymbols/s. Because a single symbol is represented by 20 bits, this translates into a link data rate of (5.12MSps × 20 bps) = 102.4 Mbps.

Because symbols are condensed into a packet and then sent across a high speed link, there is some amount of latency associated with the process of packing symbols into the packet. Both the channel width and the packet size determine what this latency value is. For example, a 5.12 MHz channel will play out its samples at a rate of 5.12 Msymbols/s. If the CMTS were to send an MTU worth of data in the UEPI packet (i.e., ~1500 bytes), then the number of symbols that can be sent is (1500 bytes × 8 bits/byte)/20 bits per symbol = 600 symbols. The amount of time to send 600 symbols at a rate of 5.12 Msymbols/s is (600 symbols / 5.12Msps) = 117 µseconds.

In addition to the packetization latency, the CMTS jitter buffer threshold value introduces latency. Using the previous example, if the jitter buffer's threshold is set to 1.5 x 117 µseconds = 176 µseconds, then an additional 176 µseconds is added to the 117 µsecond packetization latency for a total of 293 µseconds. Ultimately, the value of the jitter buffer threshold in the CMTS will be determined by the jitter contribution of both the RPD and the network. For latency-sensitive applications, such as SCTE 55-2, latency can be reduced by using smaller packet sizes and/or by keeping the network between the CMTS and the RPD as simple as possible.

7.2.4 NDR Signal Processing Requirements

The RPD MUST down-convert the specified NDR channel from the specified center frequency to baseband, and provide 10-bit quadrature sampled I/Q symbols for the specified NDR channel. The I/Q symbol rate MUST be equal to the specified channel width. This specification does not define the detailed DSP methods used to down-convert the channel.

The I/Q symbol stream received by the CMTS is up-converted, converted back to the analog domain, and then sent to an OOB device at the headend. The DSP processing requirements of the symbols received by the headend is beyond the scope of this specification.

As shown in Table 7, the allowable channel widths have been restricted to fractions of the DOCSIS 10.24MHz clock in order to obviate the need for symbol rate conversion. A guardband of 0.25 is included in the channel width specification. Therefore, for example, a channel width of 5.12 MHz has a usable passband of 4.096 MHz

(4.096 MHz * 1.25 = 5.12 MHz). The guardband of 0.25 provides a reasonable compromise between filter complexity and bandwidth efficiency.

The act of down-conversion at the RPD can incorporate in-band energy from out-of-band frequencies. As such, spurious emissions and out-of-band noise requirements apply to the NDR channel. Specification of additional emissions caused by the act of up-conversion at the headend is beyond the scope of this document.

7.3 NDR/NDF Power Level and Digital Sample Representation

For each NDF channel, the RPD is configured with a target RMS output power level, P_{NDF}. For each NDR channel, the RPD is configured with a target RMS input power level, P_{NDR}. These values are expressed in dBmV.

The I and Q samples carried in NDF or NDR frames are represented as 10-bit values. The format of these values is s3.6 (i.e. one sign bit, three bits to the left of the binary point, and six bits to the right of the binary point). A complex RMS signal magnitude of 1.414 (i.e., *sqrt(2)*) as expressed in s3.6 format corresponds to the commanded RMS output or input power level of the NDF or NDR signal.

For an NDF channel, an RPD MUST translate a stream of 10-bit digital samples with a complex RMS signal magnitude of *sqrt(2)* when the samples are interpreted in s3.6 format into an analog output signal with an RMS power of P_{NDF} (as configured for that channel). See also the accuracy requirements in Section 7.4.

For an NDR channel, an RPD MUST translate an input signal with an RMS power of P_{NDR} (as configured for that channel) into a stream of 10-bit digital samples with a complex RMS signal magnitude of *sqrt(2)* when the samples are interpreted in s3.6 format. See also the accuracy requirements in Section 7.4.

7.4 NDF/NDR Power Level Range and Performance Requirements

The RPD MUST support configured NDF power levels, P_{NDF}, which are within +3 to -12 dB of the highest power level configured on the same port for a single downstream SC-QAM channel.

The RPD MUST support configured NDR power levels, P_{NDR}, which are within +3 to -12 dB of the highest power level configured on the same port for a single upstream SC-QAM channel of the same width as the NDR channel.

The CCAP-Core MUST NOT attempt to configure NDR/NDF power levels outside of the RPD’s supported ranges.

The RPD MUST support a step size of 0.2 dB for configuration of NDR and NDF power levels.

The RPD MUST translate NDF digital samples into an analog output signal as described above with a power level accuracy of (TBD).

The RPD MUST translate analog input signals into NDR digital samples as described above with a power level accuracy of (TBD).

7.5 Networking Considerations

As shown in Figure 7, an OOB network consists of several elements. At the ends of the network are OOB modulators and demodulators in the headend, and CPE devices such as STBs on the other end. In between there is the CMTS, an Ethernet network, and the RPDs. Each of these devices can introduce latency and jitter in the OOB network.

The RPD MUST have sufficient NDF buffering to support the maximum network jitter as specified in [R-PHY]. The RPD MUST have a programmable jitter buffer threshold that can be adjusted to take advantage of lower network jitter.

The latency of the NDF and NDR paths through the RPD MUST NOT exceed 200 microseconds. This latency does not include latency induced by the jitter buffers or by the act of packetization.

The CMTS MUST have sufficient NDR buffering to support the maximum network jitter as specified in [R-PHY]. The CMTS MUST have a programmable jitter buffer threshold that can be adjusted to take advantage of lower network jitter.

The latency of the NDF and NDR paths through the CMTS device MUST NOT exceed 200 microseconds. This latency does not include latency induced by the jitter buffers or by the act of packetization.

Note that some OOB protocols, such as [SCTE 55-2], require low latency. For these types of applications, it is the responsibility of the operator to ensure that the latency and/or jitter of the network is small enough to support the desired OOB application.

7.6 System Timing Considerations

The RPD MUST have sufficient NDF buffering to support the timing requirements specified in [R-DTI]. The CMTS MUST have sufficient NDR buffering to support the timing requirements specified in [R-DTI].

Appendix I SCTE 55-1 OOB System Notes (Informative)

I.1 OOB Delivery Overview

OOB data is used by set-top boxes on the cable plant for the delivery of data streams that support set-top box operation in the downstream and to convey responses and commands from the STB in the upstream. For SCTE 55-1 systems, an Out-of-Band Multiplexer/Modulator (OM) is used to create the OOB signal that is delivered to STBs via the HFC network. Upstream OOB data is destined for the Network Controller (NC), which processes the data and responds as appropriate.

OOB data comprises the following streams:

- EMM – Entitlement Management Message: Carries conditional access (CA) system data for use by the STB.
- Network: The Network PID carries the virtual channel map and the network information table (NIT).
- Code Download Images: Carries STB software updates and delivered as MPEG Programs within the OOB transport stream.
- PAT/PMT – Program Association Table/Program Map Table: Carries MPEG tables that identify programs available in the transport stream.
- Non-[SCTE 18] EAS – Emergency Alert System: Carries EAS messages to STBs that display on the user screen.
- Guide Data: Carries program details that are displayed in the schedule grid.
- Interactive Data: Carries data that is used in interactive applications on the STB.

I.1.1 OOB Delivery in Headends Today

Today, these streams are multiplexed by an Out-of-band Multiplexer/Modulator (OM) as specified in [SCTE 55-1], creating MPEG transport streams that are carried via a QPSK channel and transmitted at a specific RF frequency into the headend combining network, typically 75.25 MHz or 104.25 MHz (frequency depends on system and CPE). This RF signal is combined with EQAM /CCAP downstream signals for transmission on the cable plant. Each OM outputs a single OOB signal to the CIN; in some larger implementations, more than one OM may be required to create unique OOB signals for different populations. The RF OOB signals are converted to optical signals and sent via AM laser to the appropriate node, which coverts it back into RF-modulated electrical signals and transmits them on the downstream HFC plant.

Upstream OOB signals—primarily polling and interactive application signals—are sent upstream by the STB. These signals are handled in one of two ways:

- The upstream RF signals are received at the fiber node and are converted to analog optical signals. The optical signals are transmitted to the headend via analog laser. At the headend, an analog receiver converts the upstream optical signal to RF and splits out the upstream OOB signals (based on frequency), delivering to a return path demodulator. The return path demodulator converts the RF to IP packets and forwards the resulting packets to an NC.
- The upstream RF signals are received at the fiber node and are converted to digital signals. The digital signal is transmitted upstream to the headend, where it is received by an upstream receiver that converts the signal to RF. The OOB RF signal is delivered to a return path demodulator. The return path demodulator converts the RF to IP packets and forwards the resulting packets to an NC.

There may be more than one return path demodulator and NC in a given headend, but there is always a many-to-one relationship between return path demodulators and their NC. Routing the correct feeds from the appropriate fiber nodes is performed in the combining/splitting network in the headend.

I.2 SCTE 55-1 OOB System Components

The various streams, their sources, and their transmission paths are illustrated in Figure 10. Although not depicted, OM A and OM B both receive source OOB streams.

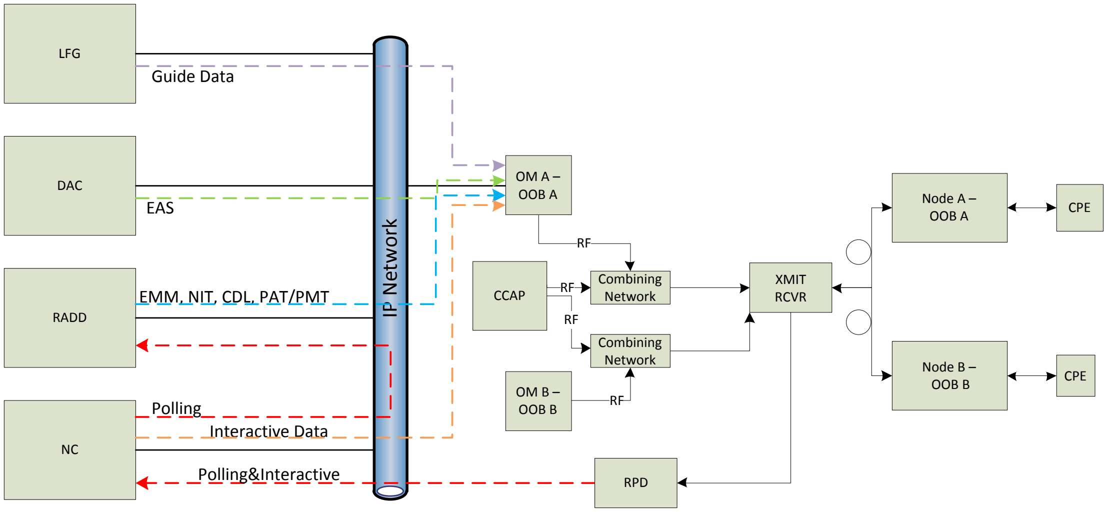

Figure 10 - Traditional OOB Transmission

The network components depicted here have the following functions:

- LFG – Live Feed Generator: Provides guide data for STB consumption.
- DAC – Digital Addressable Controller: Builds EAS messages for consumption by the OM.
- RADD – Remotely Addressable DANIS and DLS: Provides MPEG data necessary for video operation.
- NC – Network Controller: Provides data for interactive applications and responds to messages from STBs in the plant.
- OM – Out-of-Band Modulator: Per [SCTE 55-1], receives data streams for the OOB channel, processes them into MPEG transport streams and QPSK modulates an RF signal that is transmitted into the headend combining network.
- Combining Network – Takes RF signals from various network components and combines them into a single downstream RF signal.
- XMIT/RCVR – Forward Lasers and Receive Modules: The forward lasers convert RF electrical signals to optical signals and transmit to the fiber node. The receive modules receive convert optical signals to RF signals and transmit into the plant combining and splitting network. Upstream OOB signals are split out by frequency and sent to the return path demodulator.
- RPD – Return Path Demodulator: Receives RF modulated MPEG transport streams, demodulates the signal, and sends the MPEG packets to the NC via IP.

Appendix II SCTE 55-2 System Notes (Informative)

The [SCTE 55-2] R-OOB Remote PHY architecture is best understood through examination and comparison to existing system deployments.

Figure 11 depicts a legacy (pre Remote PHY) end-to-end SCTE 55-2 system level deployment.

A SCTE 55-2 Controller Client/Server IP connection is used to manage operations of the SCTE 55-2 Modulator/Demodulator as a single entity which is serving 5K to 10K two-way DHCTs. Most relevant is that today's Modulator/Demodulator is addressed on a distinct "management IP" subnet (independent of the subnet used to communicate with the various DHCTs).

The external world communicates with DHCTs through a distinct "DHCT IP" subnet. The subnet may be fairly large (capable of supporting up to 16K DHCTs). Each SCTE 55-2 Modulator/Demodulator manages routing within its own distinct subnet – each DHCT is assigned an IP address from this subnet.

The SCTE 55-2 Mod/Demod delivers two different "types" of information from the outside world to the DHCTs. *Video Control Data* is information delivered to the DHCT to enable the video/service offerings. As shown in Figure 11, this information may be delivered in IP unicast or multicast form to the SCTE 55-2 Modulator/Demodulator. Regardless of the unicast/multicast IP delivery method used, the SCTE 55-2 Mod/Demod maps this data onto VPI/VCI channels that deliver the content to a broad range of DHCTs (even though it was delivered in IP unicast format to the SCTE 55-2 Mod/Demod). DHCTs have ability to filter content appropriately.

The second type of information is *DHCT Application Data* (see Figure 11). This data is delivered via "unicast" VPI/VCI channels to unique DHCT destinations and is processed by the IP stack on the DHCT. With this method a full unicast IP stack capability is enabled on the DHCT. Additionally, IP broadcast packets addressed to the subnet may be forwarded via an IP Broadcast VPI/VCI tunnel so that all DHCTs can receive IP broadcast packets.

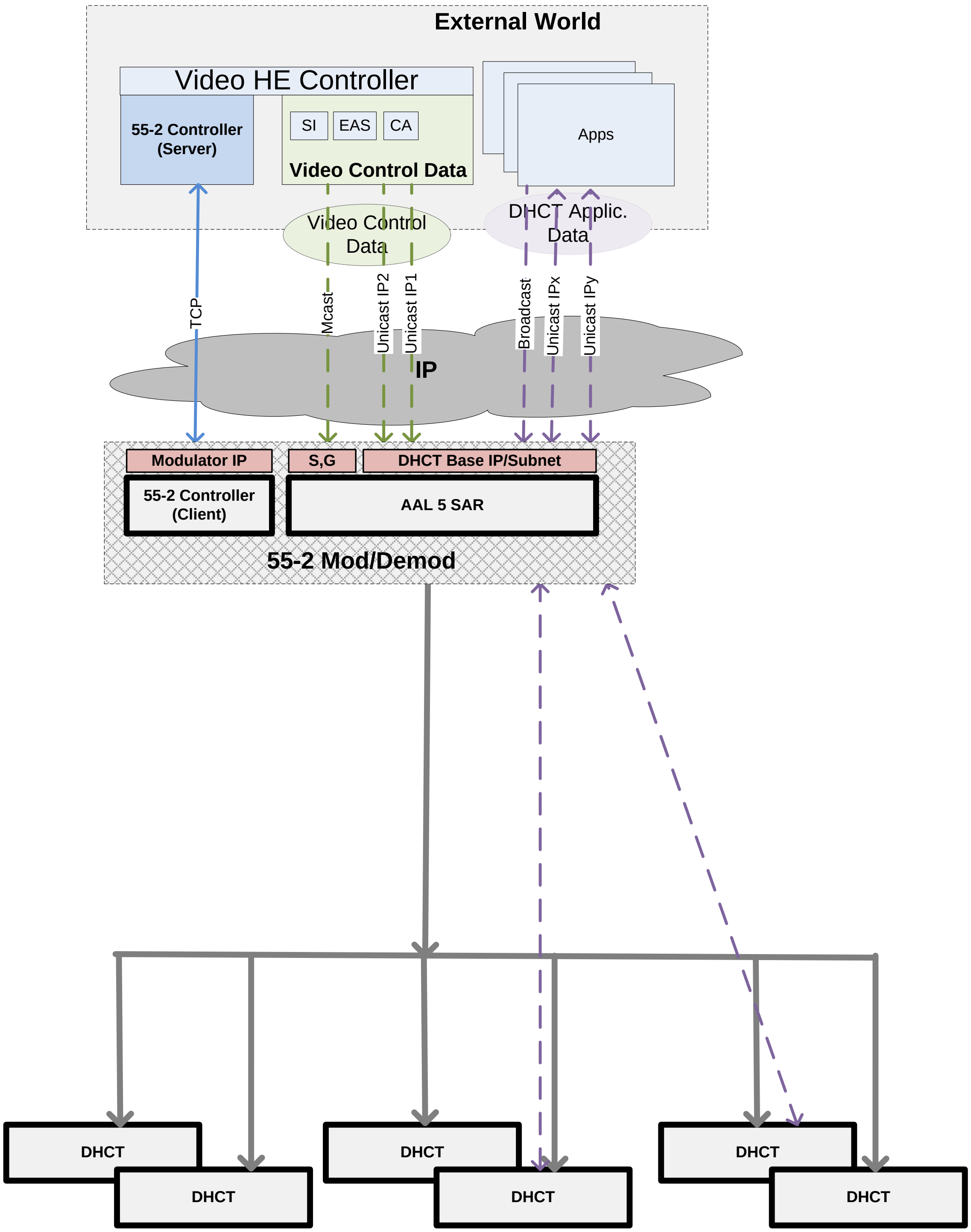

Figure 11 - Legacy SCTE 55-2 System Deployment Architecture

Appendix III Acknowledgements

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Contributor	Company Affiliation
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Dave Fox	Casa Systems
John T. Chapman	Cisco
Don Strausberger	Cisco
Bill Wall	Cisco
Douglas Will	Comcast

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