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**ANSI/SCTE 22-1 2002R2007**

**Data-Over-Cable Service Interface Specification DOCSIS  
1.0 Radio Frequency Interface (RFI)**

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# 1 SCOPE AND PURPOSE

## 1.1 Scope

This document defines the radio-frequency interface specifications for high-speed data-over-cable systems. They were developed by Cable Television Laboratories (CableLabs) for the benefit of the cable industry, including contributions by operators and vendors from North America, Europe, and other regions.

There are differences in the cable spectrum planning practices adopted for different networks in the world. Therefore two options for physical-layer technology are included, which have equal priority and are not required to be interoperable. One technology option is based on the downstream multi-program television distribution that is deployed in North America using 6 MHz channeling, and supports upstream transmission in the region 5-42 MHz. The other technology option is based on the corresponding European multi-program television distribution and supports upstream in the region 5-65 MHz. Although both options have the same status, the first option was documented earlier and the second option introduced at a later time as an amendment, resulting in the document structure not reflecting this equal priority. The first of these options is defined in Sections 2, 4, 5, Appendix G, and Appendix C.1.1.1, whereas the second is defined by replacing the content of those sections with the content of Appendix N. Correspondingly, [ITU-T.J. 83-B], [NCTA] and [SMS] apply only to the first option, and [EN 300 429] only to the second. Compliance with this document requires compliance with one or other of these implementations, not with both. It is not required that equipment built to one option shall inter-operate with equipment built to the other.

These optional physical-layer technologies allow operators some flexibility within any frequency planning, EMC and safety requirements that are mandated for their area of operation. For example, the 6 MHz downstream based option defined by Sections 2, 4, and 5 might be deployable within an 8 MHz channel plan. Compliance with frequency planning and EMC requirements is not covered by this specification and remains the operators responsibility. In this respect, [FCC15], [FCC76] and [EIA-S542] are relevant to North America and [EN 50081-1], [EN 50082-1], [EN 50083-2], [EN 50083-7], and [EN 50083-10] are relevant to the European Community.

Any reference in this document to the transmission of television in the forward channel that is not consistent with [EN 300 429] is outside the normative scope as only [EN 300 429] is used for digital multi-program TV distribution by cable in European applications.

Requirements for safety are outside the scope of the present document. Safety standards for European applications are published by the CENELEC.

Note 1: Examples of such CENELEC product safety standards are [EN 60950] and [EN 50083-1].

Note 2: For CENELEC safety categories of interfaces, see [EG 201 212].

## 1.2 Requirements

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

|            |                                                                                                                                                                                                                                                      |
|------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| “MUST”     | This word or the adjective “REQUIRED” 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 or the adjective “RECOMMENDED” 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 or the adjective “OPTIONAL” 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.

Other text is descriptive or explanatory.

## 1.3 Background

### 1.3.1 Service Goals

Cable operators are interested in deploying high-speed data communications systems on cable television systems. Cable Television Laboratories, Inc., and its member companies, have prepared a series of interface specifications that permit the early definition, design, development and deployment of data-over-cable systems on a uniform, consistent, open, non-proprietary, multi-vendor interoperable basis.

The intended service will allow transparent bi-directional transfer of Internet Protocol (IP) traffic, between the cable system headend and customer locations, over an all-coaxial or hybrid fiber/coax (HFC) cable network. This is shown in simplified form in Figure 1-1.

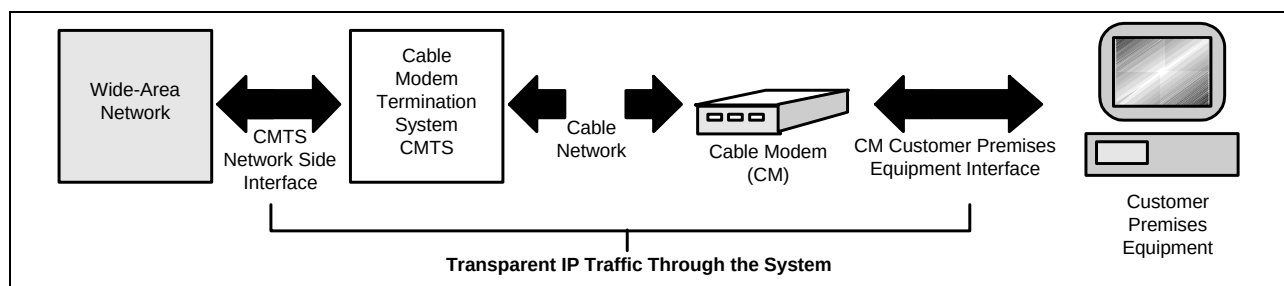


**Figure 1-1. Transparent IP Traffic Through the Data-Over-Cable System**

The transmission path over the cable system is realized at the headend by a Cable Modem Termination System (CMTS), and at each customer location by a Cable Modem (CM). At the headend (or hub), the interface to the data-over-cable system is called the Cable Modem Termination System - Network-Side Interface (CMTS-NSI) and is specified in [DOCSIS3]. At the customer locations, the interface is called the cable-modem-to-customer-premises-equipment interface (CMCI) and is specified in [DOCSIS4]. The intent is for the operators to transparently transfer IP traffic between these interfaces, including but not limited to datagrams, DHCP, ICMP, and IP Group addressing (broadcast and multicast).

### 1.3.2 Reference Architecture

**Note:** This architecture illustrates the North American frequency plans only and is not normative for European applications. Refer to section 1 for applicability.

The reference architecture for the data-over-cable services and interfaces is shown in Figure 1-2.

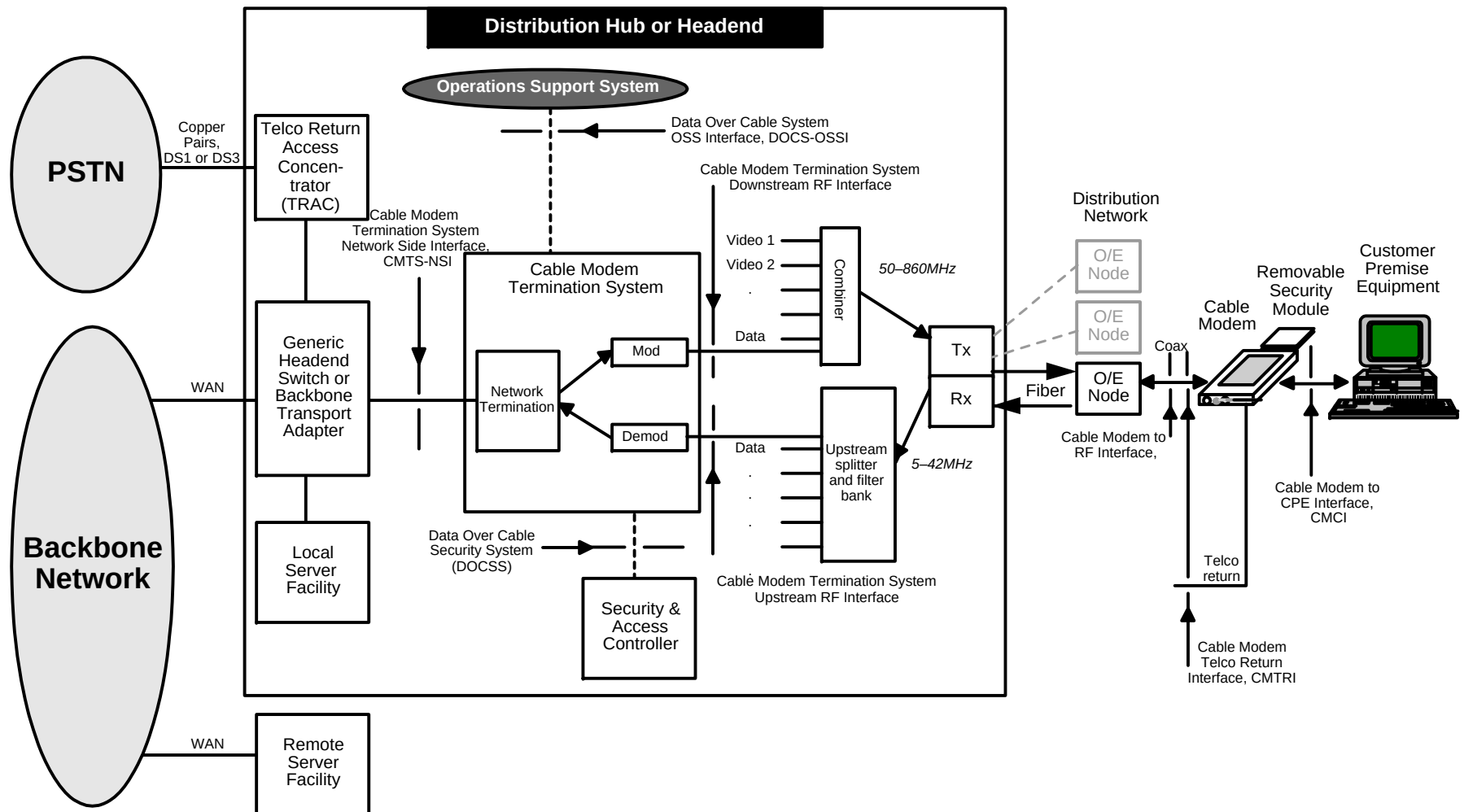


Figure 1-2. Data-Over-Cable Reference Architecture

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### 1.3.2.1 Categories of Interface Specification

The basic reference architecture of Figure 1-2 involves three interface categories. These are being developed in phases.

#### Phase 1

**Data Interfaces** - These are the CMCI [DOCSIS4] and CMTS-NSI [DOCSIS3], corresponding respectively to the cable-modem-to-customer-premises-equipment (CPE) interface (for example, between the customer's computer and the cable modem), and the cable modem termination system network-side interface (between the cable modem termination system and the data network).

#### Phase 2

**Operations Support Systems Interfaces** - These are network element management layer interfaces between the network elements and the high-level OSSs (operations support systems) which support the basic business processes, and are documented in [DOCSIS5].

**Telephone Return Interface** - CMTRI - This is the interface between the cable modem and a telephone return path, for use in cases where the return path is not provided or not available via the cable network, and is documented in [DOCSIS6].

#### Phase 3

**RF Interfaces** - The RF interfaces defined in this document are the following:

- Between the cable modem and the cable network
- Between the CMTS and the cable network, in the downstream direction (traffic toward the customer)
- Between the CMTS and the cable network, in the upstream direction (traffic from the customer)

**Security requirements** -

- The Baseline Privacy Interface is defined in [DOCSIS8].

### 1.3.2.2 Data-Over-Cable Interface Documents

A list of the documents in the Data-Over-Cable Interface Specifications family is provided below. Please refer to <http://www.cablemodem.com> for updates.

| Designation | Title                                                                        |
|-------------|------------------------------------------------------------------------------|
| SP-BPI      | Baseline Privacy Interface Specification                                     |
| SP-CMCI     | Cable Modem to Customer Premises Equipment Interface Specification           |
| SP-CMTRI    | Cable Modem Telco Return Interface Specification                             |
| SP-CMTS-NSI | Cable Modem Termination System Network Side Interface Specification          |
| SP-OSSI     | Operations Support System Interface Specification                            |
| SP-OSSI-BPI | Operations Support System Interface Specification Baseline Privacy Interface |
| SP-OSSI-RFI | Operations Support System Interface Specification Radio Frequency Interface  |
| SP-RFI      | Radio Frequency Interface Specification                                      |

Key to Designation:

SP                      Specification

### 1.3.3 Server Location

This document refers to several servers which are central to the system operation (e.g., provision and security servers).

The message sequence charts used as examples within this document show sample message exchanges in which access to the servers is via the CMTS. It is important to note that access to these servers need not necessarily be via the CMTS, but MAY be via any CM suitably configured. In this case, the scenarios become slightly more complex, as the message flows are as shown in Figure 1-3. Allowing placement of these components to be at locations other than the CMTS allows the system operator the maximum flexibility in server placement and network configuration. Note that the CMTS MUST be able to initialize without access to the servers in this configuration.

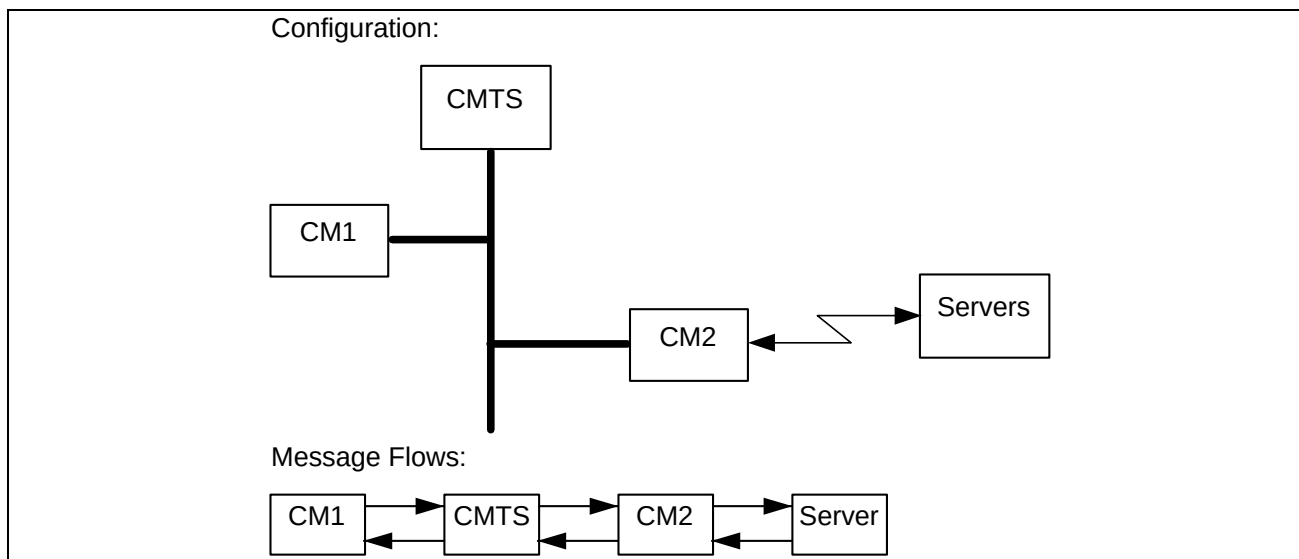


Figure 1-3. Server Location Not At CMTS

## 2. FUNCTIONAL ASSUMPTIONS

This section describes the characteristics of cable television plant to be assumed for the purposes of operation of the data-over-cable system. It is not a description of CMTS or CM parameters. The data-over-cable system is expected to operate satisfactorily in the environment described in this section.

This section applies to the first technology option referred to in Section 1 (“Scope”). For the second option, refer to Appendix N.

Whenever any reference in this section to frequency plans or compatibility with other services conflicts with any legal requirement for the area of operation, the latter shall take precedence. Any reference to NTSC analog signals in 6 MHz channels does not imply that such signals are physically present.

### 2.1 Broadband Access Network

A coaxial-based broadband access network is assumed. This may take the form of either an all-coax or hybrid fiber/coax (HFC) network. The generic term “cable network” is used here to cover all cases.

A cable network uses a shared-medium, tree-and-branch architecture with analog transmission. The key functional characteristics assumed in this document are the following:

- Two-way transmission
- A maximum optical/electrical spacing between the CMTS and the most distant customer terminal of 100 miles, although typical maximum separation may be 10-15 miles
- A maximum differential optical/electrical spacing between the CMTS and the closest and most distant modems of 100 miles, although this would typically be limited to 15 miles

### 2.2 Equipment Assumptions

#### 2.2.1 Frequency Plan

In the downstream direction, the cable system is assumed to have a passband with a lower edge at 50 or 54 MHz and an upper edge which is implementation-dependent but is typically in the range of 300 to 860 MHz. Within that passband, NTSC analog television signals in 6-MHz channels are assumed to be present on the standard, HRC or IRC frequency plans of EIA Interim Standard IS-6 (later became EIA standard EIA-542), as well as other narrowband and wideband digital signals.

In the upstream direction, the cable system may have a subsplit (5-30 MHz) or extended subsplit (5-42 MHz) passband. NTSC analog television signals in 6-MHz channels may be present, as well as other signals.

#### 2.2.2 Compatibility with Other Services

The CM and CMTS MUST coexist with the other services on the cable network. In particular, they MUST operate satisfactorily in the cable spectrum assigned for CMTS-CM interoperation while the balance of the cable spectrum is occupied by any combination of television and other signals; and they MUST NOT cause harmful interference to any other services that are assigned to the cable network in spectrum outside of that allocated to the CMTS.

#### 2.2.3 Fault Isolation Impact on Other Users

As the data-over-cable system is a shared-media, point-to-multipoint system, fault-isolation procedures MUST take into account the potential harmful impact of faults and fault-isolation procedures on numerous users of the data-over-cable and other services.

## 2.3 RF Channel Assumptions

The data-over-cable system, configured with at least one set of defined physical-layer parameters (e.g., modulation, forward error correction, symbol rate, etc.) from the range of configuration settings described in this specification, is expected to be capable of operating with a 1500-byte packet loss rate of less than one percent while forwarding at least 100 packets per second on cable networks having characteristics defined in Section 2.3.

### 2.3.1 Transmission Downstream

The RF channel transmission characteristics of the cable network in the downstream direction assumed for the purposes of minimal operating capability are described in Table 2-1. This assumes nominal analog video carrier level (peak envelope power) in a 6-MHz channel bandwidth. All conditions are present concurrently.

**Table 2-1. Assumed Downstream RF Channel Transmission Characteristics**

| Parameter                                                                                      | Value                                                                                                                                                           |
|------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Frequency range                                                                                | Cable system normal downstream operating range is from 50 MHz to as high as 860 MHz. However, the values in this table apply only at frequencies $\leq$ 88 MHz. |
| RF channel spacing (design bandwidth)                                                          | 6 MHz                                                                                                                                                           |
| Transit delay from headend to most distant $\square\square\square\square\square\square\square$ | $\square$ 0.800 msec (typically much less)                                                                                                                      |
| Carrier-to-noise ratio in a 6-MHz band (analog video level)                                    | Not less than 35 dB (Note 4)                                                                                                                                    |
| Carrier-to-interference ratio for total power (discrete and broadband ingress signals)         | Not less than 35 dB within the design bandwidth                                                                                                                 |
| Composite triple beat distortion for analog modulated carriers                                 | Not greater than -50 dBc within the design bandwidth                                                                                                            |
| Composite second order distortion for analog modulated carriers                                | Not greater than -50 dBc within the design bandwidth                                                                                                            |
| Cross-modulation level                                                                         | Not greater than -40 dBc within the design bandwidth                                                                                                            |
| Amplitude ripple                                                                               | 0.5 dB within the design bandwidth                                                                                                                              |
| Group delay ripple in the spectrum occupied by the CMTS                                        | 75 ns within the design bandwidth                                                                                                                               |
| Micro-reflections bound for dominant echo                                                      | -10 dBc @ $\square$ 0.5 $\mu$ sec, -15 dBc @ $\square$ 1.0 $\mu$ sec<br>-20 dBc @ $\square$ 1.5 $\mu$ sec, -30 dBc @ $\square$ > 1.5 $\mu$ sec                  |
| Carrier hum modulation                                                                         | Not greater than -26 dBc (5%)                                                                                                                                   |
| Burst noise                                                                                    | Not longer than 25 $\mu$ sec at a 10 Hz average rate                                                                                                            |
| Seasonal and diurnal signal level variation                                                    | 8 dB                                                                                                                                                            |
| Signal level slope, 50-750 MHz                                                                 | 16 dB                                                                                                                                                           |
| Maximum analog video carrier level at the CM input, inclusive of above signal level variation  | 17 dBmV                                                                                                                                                         |
| Lowest analog video carrier level at the CM input, inclusive of above signal level variation   | -5 dBmV                                                                                                                                                         |

**Notes to Table 2-1**

1. Transmission is from the headend combiner to the CM input at the customer location.
2. For measurements above the normal downstream operating frequency band (except hum), impairments are referenced to the highest-frequency NTSC carrier level.
3. For hum measurements above the normal downstream operating frequency band, a continuous-wave carrier is sent at the test frequency at the same level as the highest-frequency NTSC carrier.
4. This presumes that the digital carrier is operated at analog peak carrier level. When the digital carrier is operated below the analog peak carrier level, this C/N may be less.
5. Measurement methods defined in [NCTA] or [CableLabs2].

### 2.3.2 Transmission Upstream

The RF channel transmission characteristics of the cable network in the upstream direction assumed for the purposes of minimal operating capability are described in Table 2-2. All conditions are present concurrently.

**Table 2-2. Assumed Upstream RF Channel Transmission Characteristics**

| Parameter                                                                                                 | Value                                                                             |
|-----------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|
| Frequency range                                                                                           | 5 to 42 MHz edge to edge                                                          |
| Transit delay from the most distant CM to the nearest CM or CMTS                                          | □ 0.800 msec (typically much less)                                                |
| Carrier-to-noise ratio                                                                                    | Not less than 25 dB                                                               |
| Carrier-to-ingress power (the sum of discrete and broadband ingress signals) ratio                        | Not less than 25 dB (Note 2)                                                      |
| Carrier-to-interference (the sum of noise, distortion, common-path distortion and cross-modulation) ratio | Not less than 25 dB                                                               |
| Carrier hum modulation                                                                                    | Not greater than -23 dBc (7.0%)                                                   |
| Burst noise                                                                                               | Not longer than 10 µsec at a 1 kHz average rate for most cases (Notes 3, 4 and 5) |
| Amplitude ripple                                                                                          | 5-42 MHz: 0.5 dB/MHz                                                              |
| Group delay ripple                                                                                        | 5-42 MHz: 200 ns/MHz                                                              |
| Micro-reflections -- single echo                                                                          | -10 dBc @ □ 0.5 µsec<br>-20 dBc @ □ 1.0 µsec<br>-30 dBc @ > 1.0 µsec              |
| Seasonal and diurnal signal level variation                                                               | Not greater than 8 dB min to max                                                  |

**Notes to Table 2-2**

1. Transmission is from the CM output at the customer location to the headend.
2. Ingress avoidance or tolerance techniques MAY be used to ensure operation in the presence of time-varying discrete ingress signals that could be as high as 0 dBc [CableLabs1].
3. Amplitude and frequency characteristics sufficiently strong to partially or wholly mask the data carrier.
4. CableLabs report containing distribution of return-path burst noise measurements and measurement method is forthcoming.
5. Impulse noise levels more prevalent at lower frequencies (< 15 MHz).

**2.3.2.1 Availability**

Typical cable network availability is considerably greater than 99%.

**2.4 Transmission Levels**

The nominal power level of the downstream CMTS 64QAM signal(s) within a 6-MHz channel is targeted to be in the range -10 dBc to -6 dBc relative to analog video carrier level and will normally not exceed analog video carrier level. The nominal power level of the upstream CM signal(s) will be as low as possible to achieve the required margin above noise and interference. Uniform power loading per unit bandwidth is commonly followed in setting upstream signal levels, with specific levels established by the cable network operator to achieve the required carrier-to-noise and carrier-to-interference ratios.

**2.5 Frequency Inversion**

There will be no frequency inversion in the transmission path in either the downstream or upstream directions, i.e., a positive change in frequency at the input to the cable network will result in a positive change in frequency at the output.

### 3 COMMUNICATION PROTOCOLS

This section provides a high-level overview of the communication protocols that **MUST** be used in the data-over-cable system. Detailed specifications for the physical media dependent, downstream transmission, and media access control sublayers are provided in Section 4, Section 5, and Section 6, respectively.

#### 3.1 Protocol Stack

The CM and CMTS operate as forwarding agents and also as end-systems (hosts). The protocol stacks used in these modes differ as shown below.

The principal function of the cable modem system is to transmit Internet Protocol (IP) packets transparently between the headend and the subscriber location. Certain management functions also ride on IP, so that the protocol stack on the cable network is as shown in Figure 3-1 (this does not restrict the generality of IP transparency between the headend and the customer). These management functions include, for example, supporting spectrum management functions and the downloading of software.

##### 3.1.1 CM and CMTS as Hosts

CMs and CMTSes will operate as IP and LLC hosts in terms of IEEE Standard 802 [IEEE802] for communication over the cable network. The protocol stack at the CM and CMTS RF interfaces is shown in Figure 3-1.

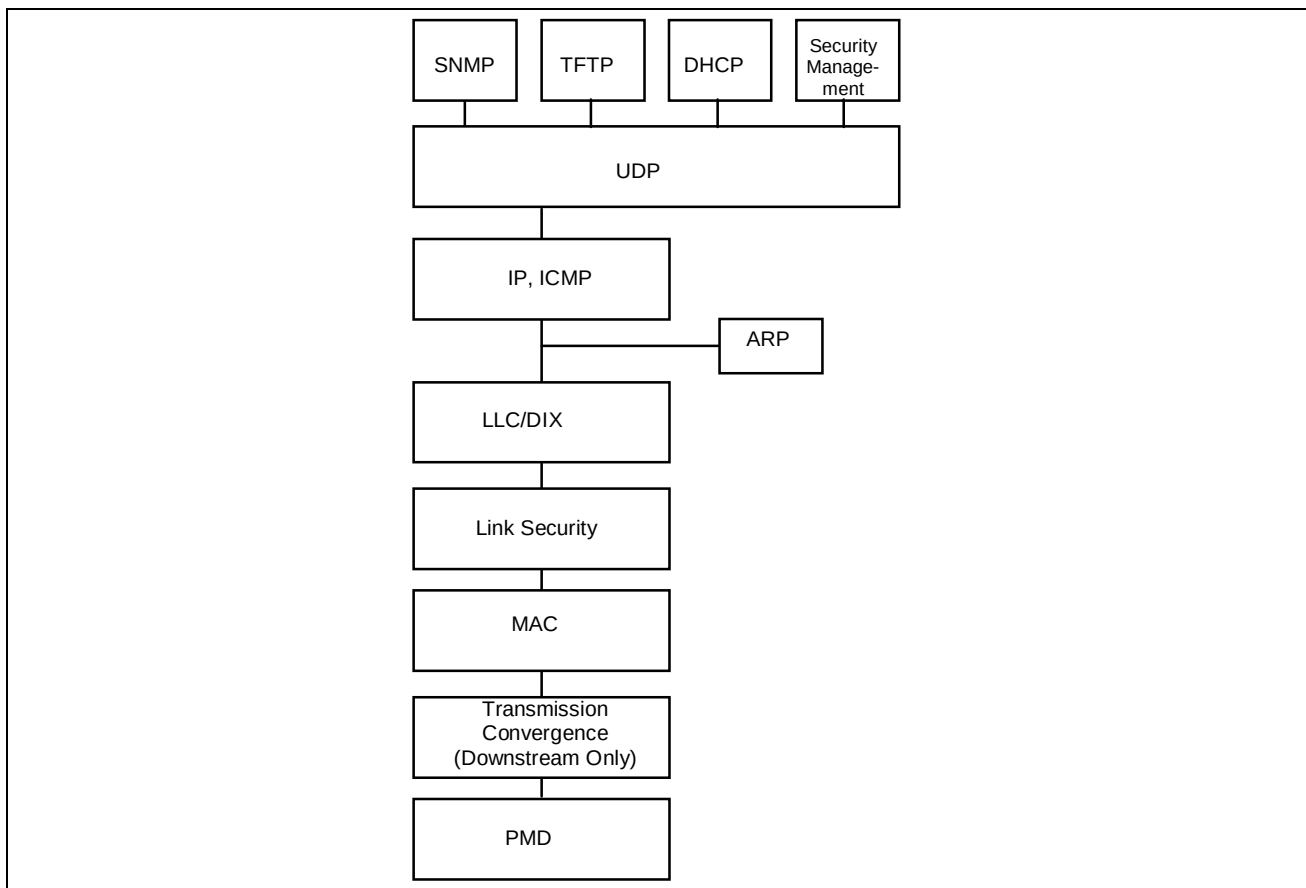


**Figure 3-1. Protocol Stack on the RF Interface**

The CM and CMTS MUST function as IP hosts. As such, the CM and CMTS MUST support IP and ARP over DIX link-layer framing (see [DIX]). The CMTS MUST NOT transmit frames that are smaller than the DIX 64-byte minimum on a downstream channel. However, the CM MAY transmit frames that are smaller than the DIX 64-byte minimum on an upstream channel.

The CM and CMTS MAY also support IP and ARP over SNAP framing [RFC-1042].

The CM and CMTS also MUST function as LLC hosts. As such, the CM and CMTS MUST respond appropriately to TEST and XID requests per [ISO8802-2].

### 3.1.2 Data Forwarding Through the CM and CMTS

#### 3.1.2.1 General

Data forwarding through the CMTS MAY be transparent bridging<sup>1</sup>, or MAY employ network-layer forwarding (routing, IP switching) as shown in Figure 3-2.

Data forwarding through the CM is link-layer transparent bridging, as shown in Figure 3-2. Forwarding rules are similar to [ISO/IEC10038] with the modifications described in Section 3.1.2.2 and Section 3.1.2.3. This allows the support of multiple network layers.

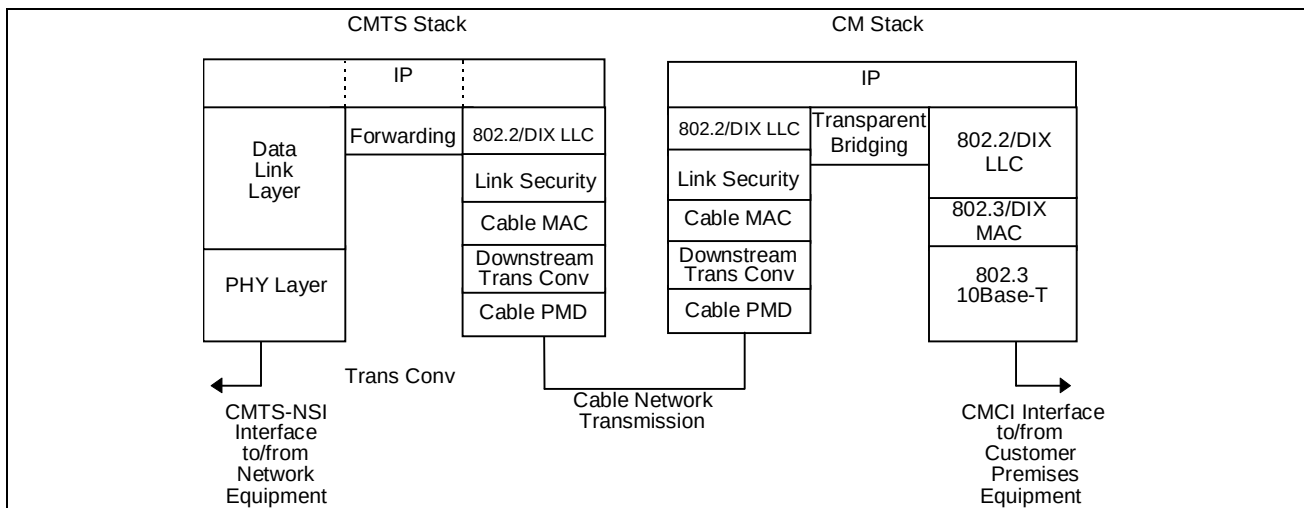


**Figure 3-2. Data Forwarding Through the CM and CMTS**

Forwarding of IP traffic MUST be supported. Support of other network layer protocols is OPTIONAL. The ability to restrict the network layer to a single protocol such as IP is required.

Support for the 802.1d spanning tree protocol of [ISO/IEC10038] with the modifications described in Section 3.1.2.3 is OPTIONAL for CMs intended for residential use. CMs intended for commercial use and bridging CMTSes MUST support this version of spanning tree (see Appendix H). CMs and CMTSes MUST include the ability to filter (and disregard) 802.1d BPDUs.

This specification assumes that CMs intended for residential use will not be connected in a configuration which would create network loops such as that shown in Figure 3-3.

<sup>1</sup> With the exception that for packet PDUs less than 64 bytes to be forwarded from the upstream RFI, a CMTS MUST pad out the packet PDU and recompute the CRC.

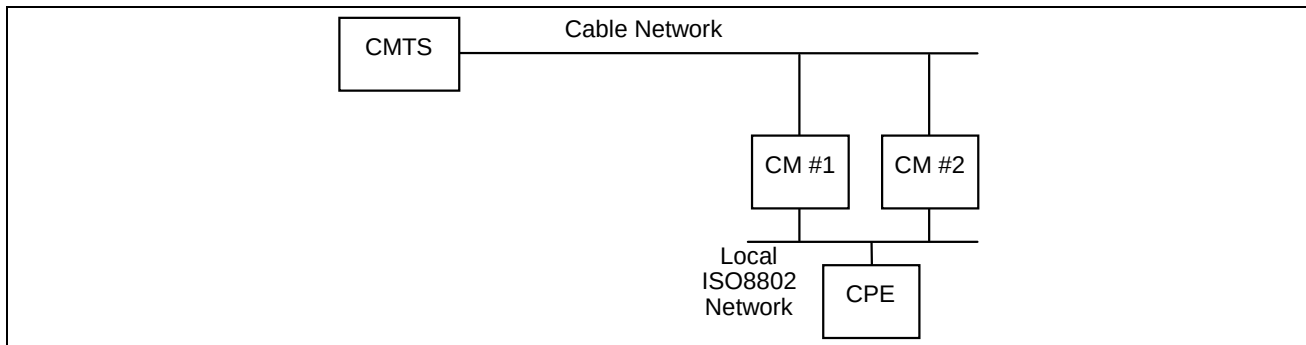


**Figure 3-3. Example Condition for Network Loops**

### 3.1.2.2 CMTS Forwarding Rules

At the CMTS, if link-layer forwarding is used, it MUST conform to the following general 802.1d guidelines:

- Link-layer frames between a given pair of end-stations MUST be delivered in order.
- Link-layer frames MUST NOT be duplicated.
- Stale frames (those that cannot be delivered in a timely fashion) MUST be discarded.

The address-learning and -aging mechanisms used are vendor-dependent.

If network-layer forwarding is used, the CMTS should conform to IETF Router Requirements [RFC-1812] with respect to its CMTS-RFI and CMTS-NSI interfaces.

Conceptually, the CMTS forwards data packets at two abstract interfaces: between the CMTS-RFI and the CMTS-NSI, and between the upstream and downstream channels. The CMTS MAY use any combination of link-layer (bridging) and network-layer (routing) semantics at each of these interfaces. The methods used at the two interfaces need not be the same.

Forwarding between the upstream and downstream channels within a MAC layer differs from traditional LAN forwarding in that:

- A single channel is simplex, and cannot be considered a complete interface for most protocol (e.g., 802.1d spanning tree, Routing Information Protocol per [RFC-1058]) purposes.
- Upstream channels are essentially point-to-point, whereas downstream channels are shared-media.
- As a public network, policy decisions may override full connectivity.

For these reasons, an abstract entity called the MAC Forwarder exists within the CMTS to provide connectivity between stations within a MAC domain (see Section 3.2).

### 3.1.2.3 CM Forwarding Rules

Data forwarding through the CM is link-layer bridging with the following specific rules.

### 3.1.2.3.1 CPE MAC Address Acquisition

- The CM MUST acquire Ethernet MAC addresses of connected CPE devices, either from the provisioning process or from learning, until the CM acquires its maximum number of CPE addresses (a device-dependent value). Once the CM acquires its maximum number of CPE addresses, newly-discovered CPE addresses MUST NOT replace previously acquired addresses. The CM MUST support acquisition of at least one CPE address.
- The CM MUST allow configuration of CPE addresses during the provisioning process (up to its maximum number of CPE addresses) to support configurations in which learning is not practical nor desired.
- Addresses provided during the CM provisioning MUST take preference over learned addresses.
- CPE addresses MUST NOT be aged out.
- On a CM reset (e.g., a power cycle), all learned addresses MUST be discarded (they are not retained in non-volatile storage, to allow modification of user MAC addresses or movement of the CM).

### 3.1.2.3.2 Forwarding

CM forwarding in both directions MUST conform to the following general 802.1d guidelines:

- Link-layer frames between a given pair of end-stations MUST be delivered in order.
- Link-layer frames MUST NOT be duplicated.
- Stale frames (those that cannot be delivered in a timely fashion) MUST be discarded.

Cable-network-to-Ethernet forwarding MUST conform to the following specific rules:

- Frames addressed to unknown destinations MUST NOT be forwarded from the cable port to the Ethernet port.
- Broadcast frames MUST be forwarded to the Ethernet port, unless they are from source addresses which are provisioned or learned as supported CPE devices, in which case they MUST NOT be forwarded.
- The CM MAY use IGMP messages from the CPE to determine which multicast frames to accept from the HFC interface for forwarding. If IGMP is not supported, the CM MUST accept all multicast frames from the HFC for forwarding. All accepted multicast frames MUST be forwarded to the CMCI ports in accordance with filtering configuration settings specified by the cable operator's operation and business support systems, unless they are from source addresses which are provisioned or learned as supported CPE devices, in which case they MUST NOT be forwarded.

Ethernet-to-cable-network forwarding MUST conform to the following specific rules:

- Frames addressed to unknown destinations MUST be forwarded from the Ethernet port to the cable port.
- Broadcast frames MUST be forwarded to the cable port.
- Multicast frames MUST be forwarded to the cable port in accordance with filtering configuration settings specified by the cable operator's operations and business support systems.
- Frames from source addresses other than those provisioned or learned as supported CPE devices MUST NOT be forwarded.
- If a single-user CM has acquired a MAC address (see Section 3.1.2.3.1), it MUST NOT forward data from a second source. Other (non-supported) CPE source addresses MUST be learned from the Ethernet port and this information used to filter local traffic as in a traditional learning bridge.
- If a single-user CM has acquired MAC address A as its supported CPE device and learned B as a second device connected to the Ethernet port, it MUST filter any traffic from A to B.

## 3.2 The MAC Forwarder

The MAC Forwarder is a MAC sublayer that resides on the CMTS just below the MAC service access point (MSAP) interface, as shown in Figure 3-4. It is responsible for delivering upstream frames to:

- One or more downstream channels
- The MSAP interface

In Figure 3-4, the LLC sublayer and link security sublayers of the upstream and downstream channels on the cable network terminate at the MAC Forwarder.

The MSAP interface user MAY be the NSI-RFI Forwarding process or the CMTS's host protocol stack.

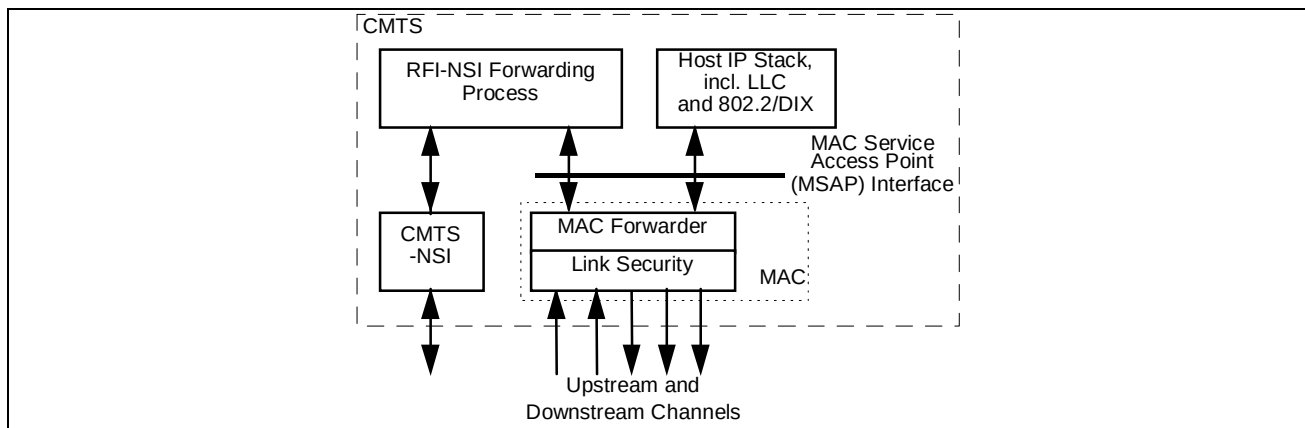


**Figure 3-4. MAC Forwarder**

Delivery of frames may be based on data-link-layer (bridging) semantics, network-layer (routing) semantics, or some combination. Higher-layer semantics may also be employed (e.g., filters on UDP port numbers). The CMTS **MUST** provide IP connectivity between hosts attached to cable modems, and must do so in a way that meets the expectations of Ethernet-attached customer equipment. For example, the CMTS must either forward ARP packets or it must facilitate a proxy ARP service. The CMTS MAC Forwarder **MAY** provide service for non-IP protocols.

Note that there is no requirement that all upstream and downstream channels be aggregated under one MSAP as shown above. The vendor could just as well choose to implement multiple MSAPs, each with a single upstream and downstream channel.

### 3.2.1 Example Rules for Data-Link-Layer Forwarding

If the MAC Forwarder is implemented using only data-link-layer semantics, the requirements in this section apply.

Delivery of frames is dependent on the Destination Address within the frame. The means of learning the location of each address is vendor-dependent, and **MAY** include:

- Transparent-bridging-like source-address learning and aging
- Gleaning from MAC Registration Request messages
- Administrative means

If the destination address of a frame is unicast, and that address is associated with a particular downstream channel, the frame **MUST** be forwarded to that channel.<sup>2</sup>

If the destination address of a frame is unicast, and that address is known to reside on the other (upper) side of the MSAP interface, the frame **MUST** be delivered to the MSAP interface.

If the destination address is broadcast, multicast<sup>3</sup>, or unknown, the frame **MUST** BE delivered to both the MSAP and to all downstream channels.

Delivery rules are similar to those for transparent bridging:

- Frames from a specific source to a particular destination **MUST** be delivered in order.
- Frames **MUST NOT** be duplicated.
- Frames that cannot be delivered in a timely fashion **MUST** be discarded.
- The Frame Check Sequence **SHOULD** be preserved rather than regenerated.

<sup>2</sup> Vendors may implement extensions, similar to static addresses in 802.1d/ISO 10038 bridging, that cause such frames to be filtered or handled in some other manner.

<sup>3</sup> Note: all multicasts, including 802.1d/ISO 10038 Spanning Tree Bridge BPDUs, **MUST** be forwarded, except for those addressed to the all-CMTSes multicast address which **MUST NOT** be forwarded.

### 3.3 Network Layer

As stated above, the purpose of the data-over-cable system is to transport IP traffic transparently through the system.

The Network Layer protocol is the Internet Protocol (IP) version 4, as defined in [RFC-791], and migrating to IP version 6.

This document imposes no requirements for reassembly of IP packets.

### 3.4 Above the Network Layer

Subscribers will be able to use the transparent IP capability as a bearer for higher-layer services. Use of these services will be transparent to the CM.

In addition to the transport of user data, there are several network management and operation capabilities which depend upon the Network Layer. These include:

- SNMP (Simple Network Management Protocol, [RFC-1157]), for network management
- TFTP (Trivial File Transfer Protocol, [RFC-1350]), a file transfer protocol, for downloading software and configuration information
- DHCP (Dynamic Host Configuration Protocol, DHCP [RFC-2131]), a framework for passing configuration information to hosts on a TCP/IP network

DHCP, TFTP, and ToD client messages generated by the CM MUST only be sent via the RF Interface. DHCP, TFTP and ToD client messages include DHCPDISCOVER, DHCPREQUEST, DHCPDECLINE, DHCPRELEASE, DHCPINFORM, TFTP-RRQ, TFTP-ACK, and ToD request.

The CM's DHCP, TFTP, and ToD client MUST ignore DHCP, TFTP and ToD server message received on the CMCI port. DHCP, TFTP, and ToD server messages included: DHCP OFFER, DHCPACK, DHCPNAK, TFTP-DATA, and ToD time message.

### 3.5 Data Link Layer

The Data Link Layer is divided into sublayers in accordance with [IEEE802], with the addition of Link-Layer security in accordance with [DOCSIS8]. The sublayers, from the top, are:

- Logical Link Control (LLC) sublayer (Class 1 only)
- Link-Layer Security sublayer
- Media Access Control (MAC) sublayer

#### 3.5.1 LLC Sublayer

The LLC sublayer MUST be provided in accordance with [ISO/IEC10039]. Address resolution MUST be used as defined in [RFC-826]. The MAC-to-LLC service definition is specified in [ISO/IEC10039].

#### 3.5.2 Link-Layer Security Sublayer

Link-layer security MUST be provided in accordance with [DOCSIS8].

#### 3.5.3 MAC Sublayer

The definition, in detail, of the MAC sublayer and associated interfaces is provided in Section 6 of this document.

The MAC sublayer defines a single transmitter for each downstream channel — the CMTS. All CMs listen to all frames transmitted on the downstream channel upon which they are registered and accept those where the destination matches the CM itself or CPEs reached via the CMCI port. CMs can communicate with other CMs only through the CMTS.

The upstream channel is characterized by many transmitters (CMs) and one receiver (the CMTS). Time in the upstream channel is slotted, providing for Time Division Multiple Access at regulated time ticks. The CMTS provides the time reference and controls the allowed usage for each interval. Intervals may be granted for transmissions by particular CMs, or for contention by all CMs. CMs may contend to request transmission time. To a limited extent, CMs may also contend to transmit actual data. In both cases, collisions can occur and retries are used.

Section 6 describes the MAC-sublayer messages from the CMTS which direct the behavior of the CMs on the upstream channel, as well as messaging from the CMs to the CMTS.

### 3.5.3.1 Overview

Some of the MAC protocol highlights include:

- Bandwidth allocation controlled by CMTS
- A stream of mini-slots in the upstream
- Dynamic mix of contention- and reservation-based upstream transmit opportunities
- Bandwidth efficiency through support of variable-length packets
- Extensions provided for future support of ATM or other Data PDU
- Class-of-service support
- Extensions provided for security at the Data Link layer
- Support for a wide range of data rates

### 3.5.3.2 MAC Service Definition

The MAC sublayer service definition is in Appendix D.

## 3.6 Physical Layer

The Physical (PHY) layer is comprised of two sublayers:

- Transmission Convergence sublayer (present in the downstream direction only)
- Physical Media Dependent (PMD) sublayer

### 3.6.1 Downstream Transmission Convergence Sublayer

The Downstream Transmission Convergence sublayer exists in the downstream direction only. It provides an opportunity for additional services over the physical-layer bitstream. These additional services might include, for example, digital video. Definition of any such additional services is beyond the scope of this document.

This sublayer is defined as a continuous series of 188-byte MPEG [ITU-T H.222.0] packets, each consisting of a 4-byte header followed by 184 bytes of payload. The header identifies the payload as belonging to the data-over-cable MAC. Other values of the header may indicate other payloads. The mixture of payloads is arbitrary and controlled by the CMTS.

The Downstream Transmission Convergence sublayer is defined in Section 5 of this document.

### 3.6.2 PMD Sublayer

#### 3.6.2.1 Overview

The PMD sublayer involves digitally modulated RF carriers on the analog cable network.

In the downstream direction, the PMD sublayer is based on [ITU J.83-B], with the exceptions called out in Section 4.3.2, and includes these features:

- 64 and 256 QAM modulation formats
- 6-MHz occupied spectrum coexists with all other signals on the cable plant
- Concatenation of Reed-Solomon block code and Trellis code supports operation in a higher percentage of North American cable networks
- Variable-depth interleaver supports both latency-sensitive and -insensitive data

The features in the upstream direction are as follows:

- Flexible and programmable CM under control of the CMTS
- Frequency agility
- Time division multiple access
- QPSK and 16 QAM modulation formats
- Support of both fixed-frame and variable-length PDU formats
- Multiple symbol rates
- Programmable Reed-Solomon block coding
- Programmable preambles

### 3.6.2.2 Interface Points

Three RF interface points are defined at the PMD sublayer:

- a) Downstream output on the CMTS
- b) Upstream input on the CMTS
- c) Cable in/out at the cable modem

Separate downstream output and upstream input interfaces on the CMTS are required for compatibility with typical downstream and upstream signal-combining and -splitting arrangements in headends.

## 4. PHYSICAL MEDIA DEPENDENT SUBLAYER SPECIFICATION

This section applies to the first technology option referred to in section 1 (“scope”). For the second option, refer to Appendix N.

Whenever any reference in this section to spurious emissions conflicts with any legal requirement for the area of operation, the latter shall take precedence.

### 4.1 Scope

This specification defines the electrical characteristics and protocol for a cable modem (CM) and cable modem termination system (CMTS). It is the intent of this specification to define an interoperable CM and CMTS such that any implementation of a CM can work with any CMTS. It is not the intent of this specification to imply any specific implementation.

### 4.2 Upstream

#### 4.2.1 Overview

The upstream Physical Media Dependent (PMD) sublayer uses a FDMA/TDMA burst modulation format, which provides five symbol rates and two modulation formats (QPSK and 16QAM). The modulation format includes pulse shaping for spectral efficiency, is carrier-frequency agile, and has selectable output power level. The PMD sublayer format includes a variable-length modulated burst with precise timing beginning at boundaries spaced at integer multiples of 6.25  $\mu$ sec apart (which is 16 symbols at the highest data rate).

Each burst supports a flexible modulation, symbol rate, preamble, randomization of the payload, and programmable FEC encoding.

All of the upstream transmission parameters associated with burst transmission outputs from the CM are configurable by the CMTS via MAC messaging. Many of the parameters are programmable on a burst-by-burst basis.

The PMD sublayer can support a near-continuous mode of transmission, wherein ramp-down of one burst MAY overlap the ramp-up of the following burst, so that the transmitted envelope is never zero. The system timing of the TDMA transmissions from the various CMs MUST provide that the center of the last symbol of one burst and the center of the first symbol of the preamble of an immediately following burst are separated by at least the duration of five symbols. The guard time MUST be greater than or equal to the duration of five symbols plus the maximum timing error. Timing error is contributed by both the CM and CMTS. CM timing performance is specified in Section 4. Maximum timing error and guard time may vary with CMTSes from different vendors.

The upstream modulator is part of the cable modem which interfaces with the cable network. The modulator contains the actual electrical-level modulation function and the digital signal-processing function; the latter provides the FEC, preamble prepend, symbol mapping, and other processing steps. This specification is written with the idea of buffering the bursts in the signal processing portion, and with the signal processing portion (1) accepting the information stream a burst at a time, (2) processing this stream into a complete burst of symbols for the modulator, and (3) feeding the properly-timed burst symbol stream to a memoryless modulator at the exact burst transmit time. The memoryless portion of the modulator only performs pulse shaping and quadrature upconversion.

At the Demodulator, similar to the Modulator, there are two basic functional components: the demodulation function and the signal processing function. Unlike the Modulator, the Demodulator resides in the CMTS and the specification is written with the concept that there will be one demodulation function (not necessarily an actual physical demodulator) for each carrier frequency in use. The demodulation function would receive all bursts on a given frequency.

**Note:** Unit design approach should be cognizant of the multiple-channel nature of the demodulation and signal processing to be carried out at the headend, and partition or share functionality appropriately to optimally leverage the multi-channel application. A Demodulator design supporting multiple channels in a Demodulator unit may be appropriate.

The demodulation function of the Demodulator accepts a varying-level signal centered around a commanded power level and performs symbol timing and carrier recovery and tracking, burst acquisition, and demodulation. Additionally, the demodulation function provides an estimate of burst timing relative to a reference edge, an estimate of received signal power, an estimate of signal-to-noise ratio, and may engage adaptive equalization to mitigate the effects of a) echoes in the cable plant, b) narrowband ingress and c) group delay. The signal-processing function of the Demodulator performs the inverse processing of the signal-processing function of the Modulator. This includes accepting the demodulated burst data stream and decoding, etc., and possibly multiplexing the data from multiple channels into a single output stream. The signal-processing function also provides the edge-timing reference and gating-enable signal to the demodulators to activate the burst acquisition for each assigned burst slot. The signal-processing function may also provide an indication of successful decoding, decoding error, or fail-to-decode for each codeword and the number of corrected Reed-Solomon symbols in each codeword. For every upstream burst, the CMTS has a prior knowledge of the exact burst length in symbols (see Sections 4.2.6, 4.2.10.1, and A.2).

## 4.2.2 Modulation Formats

The upstream modulator **MUST** provide both QPSK and 16QAM modulation formats.

The upstream demodulator **MUST** support QPSK, 16QAM, or both modulation formats.

### 4.2.2.1 Modulation Rates

The upstream modulator **MUST** provide QPSK at 160, 320, 640, 1,280, and 2,560 ksym/sec, and 16QAM at 160, 320, 640, 1,280, and 2,560 ksym/sec.

This variety of modulation rates, and flexibility in setting upstream carrier frequencies, permits operators to position carriers in gaps in the pattern of narrowband ingress, as discussed in Appendix F.

The upstream symbol rate **MUST** be fixed for each upstream frequency.

### 4.2.2.2 Symbol Mapping

The modulation mode (QPSK or 16QAM) is programmable. The symbols transmitted in each mode and the mapping of the input bits to the I and Q constellation **MUST** be as defined in Table 4-1. In the table,  $I_1$  is the MSB of the symbol map,  $Q_1$  is the LSB for QPSK, and  $Q_0$  is the LSB for 16QAM.  $Q_1$  and  $I_0$  have intermediate bit positions in 16QAM. The MSB **MUST** be the first bit in the serial data into the symbol mapper.

**Table 4-1. I/Q Mapping**

| QAM Mode | Input bit Definitions |
|----------|-----------------------|
| QPSK     | $I_1 Q_1$             |
| 16QAM    | $I_1 Q_1 I_0 Q_0$     |

The upstream QPSK symbol mapping **MUST** be as shown in Figure 4-1.

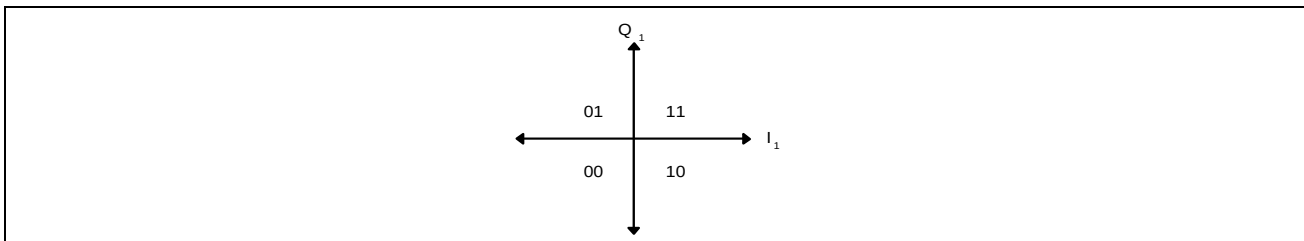


**Figure 4-1. QPSK Symbol Mapping**

The 16QAM non-inverted (Gray-coded) symbol mapping MUST be as shown in Figure 4-2.

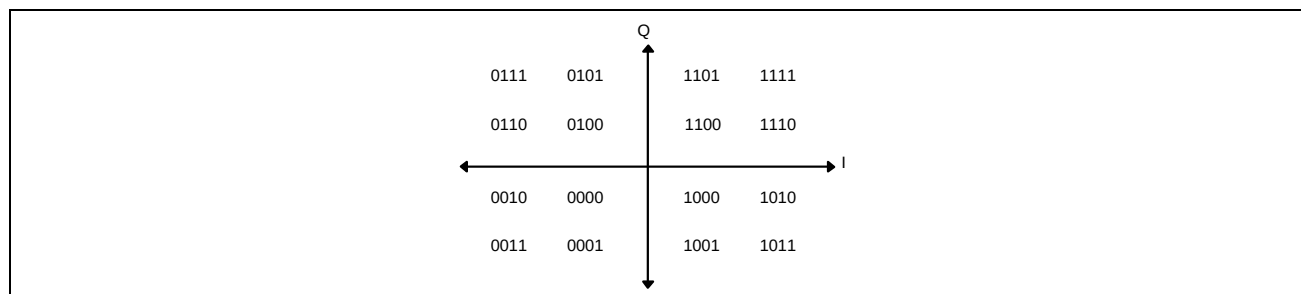


**Figure 4-2. 16QAM Gray-Coded Symbol Mapping**

The 16QAM differential symbol mapping MUST be as shown in Figure 4-3

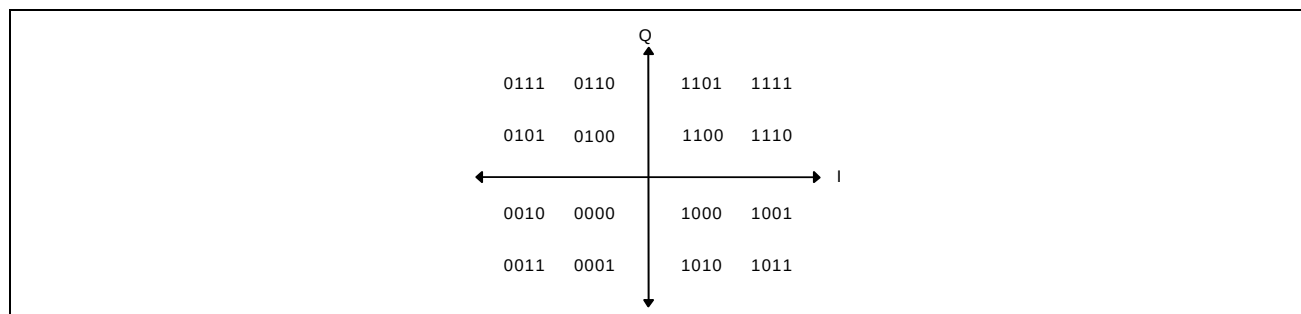


**Figure 4-3. 16QAM Differential-Coded Symbol Mapping**

If differential quadrant encoding is enabled, the currently-transmitted symbol quadrant is derived from the previously transmitted symbol quadrant and the current input bits via Table 4-2.

**Table 4-2. Derivation of Currently Transmitted Symbol Quadrant**

| Current Input Bits<br>I(1) Q(1) | Quadrant Phase<br>Change | MSBs of Previously<br>Transmitted Symbol | MSBs for Currently<br>Transmitted Symbol |
|---------------------------------|--------------------------|------------------------------------------|------------------------------------------|
| 00                              | 0□                       | 11                                       | 11                                       |
| 00                              | 0□                       | 01                                       | 01                                       |
| 00                              | 0□                       | 00                                       | 00                                       |
| 00                              | 0□                       | 10                                       | 10                                       |
| 01                              | 90□                      | 11                                       | 01                                       |
| 01                              | 90□                      | 01                                       | 00                                       |
| 01                              | 90□                      | 00                                       | 10                                       |
| 01                              | 90□                      | 10                                       | 11                                       |
| 11                              | 180□                     | 11                                       | 00                                       |
| 11                              | 180□                     | 01                                       | 10                                       |
| 11                              | 180□                     | 00                                       | 11                                       |
| 11                              | 180□                     | 10                                       | 01                                       |
| 10                              | 270□                     | 11                                       | 10                                       |
| 10                              | 270□                     | 01                                       | 11                                       |
| 10                              | 270□                     | 00                                       | 01                                       |
| 10                              | 270□                     | 10                                       | 00                                       |

### 4.2.2.3 Spectral Shaping

The upstream PMD sublayer MUST support a 25% Nyquist square root raised cosine shaping.

The occupied spectrum MUST NOT exceed the channel widths shown in Table 4-3.

**Table 4-3. Maximum Channel Width**

| Symbol Rate (ksym/sec) | Channel Width (kHz) <sup>a</sup> |
|------------------------|----------------------------------|
| 160                    | 200                              |
| 320                    | 400                              |
| 640                    | 800                              |
| 1,280                  | 1,600                            |
| 2,560                  | 3,200                            |

<sup>a</sup> Channel width is the -30 dB bandwidth.

### 4.2.2.4 Upstream Frequency Agility and Range

The upstream PMD sublayer MUST support operation over the frequency range of 5-42 MHz edge to edge.

Offset frequency resolution MUST be supported having a range of  $\pm 32$  kHz (increment = 1 Hz; implement within  $\pm 10$  Hz).

### 4.2.2.5 Spectrum Format

The upstream modulator MUST provide operation with the format  $s(t) = I(t) \cdot \cos(\omega t) - Q(t) \cdot \sin(\omega t)$ , where  $t$  denotes time and  $\omega$  denotes angular frequency.

## 4.2.3 FEC Encode

### 4.2.3.1 FEC Encode Modes

The upstream modulator MUST be able to provide the following selections: Reed-Solomon codes over GF(256) with  $T = 1$  to 10 or no FEC coding.

The following Reed-Solomon generator polynomial MUST be supported:

$$g(x) = (x + \alpha^0)(x + \alpha^1) \dots (x + \alpha^{2T-1}) \text{ where the primitive element } \alpha \text{ is } 0x02 \text{ hex}$$

The following Reed-Solomon primitive polynomial MUST be supported:

$$p(x) = x^8 + x^4 + x^3 + x^2 + 1$$

The upstream modulator MUST provide codewords from a minimum size of 18 bytes (16 information bytes  $[k]$  plus two parity bytes for  $T = 1$  error correction) to a maximum size of 255 bytes ( $k$ -bytes plus parity-bytes). The uncoded word can have a minimum size of one byte.

In Shortened Last Codeword mode, the CM MUST provide the last codeword of a burst shortened from the assigned length of  $k$  data bytes per codeword as described in Section 4.2.10.1.2 of this document.

The value of  $T$  MUST be configured in response to the Upstream Channel Descriptor from the CMTS.

#### 4.2.3.2 FEC Bit-to-Symbol Ordering

The input to the Reed-Solomon Encoder is logically a serial bit stream from the MAC layer of the CM, and the first bit of the stream **MUST** be mapped into the MSB of the first Reed-Solomon symbol into the encoder. The MSB of the first symbol out of the encoder **MUST** be mapped into the first bit of the serial bit stream fed to the Scrambler.

[Note that the MAC byte-to-serial upstream convention calls for the byte LSB to be mapped into the first bit of the serial bit stream per Section 6.2.1.3.]

#### 4.2.4 Scrambler (Randomizer)

The upstream modulator **MUST** implement a scrambler (shown in Figure 4-4) where the 15-bit seed value **MUST** be arbitrarily programmable.

At the beginning of each burst, the register is cleared and the seed value is loaded. The seed value **MUST** be used to calculate the scrambler bit which is combined in an XOR with the first bit of data of each burst (which is the MSB of the first symbol following the last symbol of the preamble).

The scrambler seed value **MUST** be configured in response to the Upstream Channel Descriptor from the CMTS.

The polynomial **MUST** be  $x^{15} + x^{14} + 1$ .

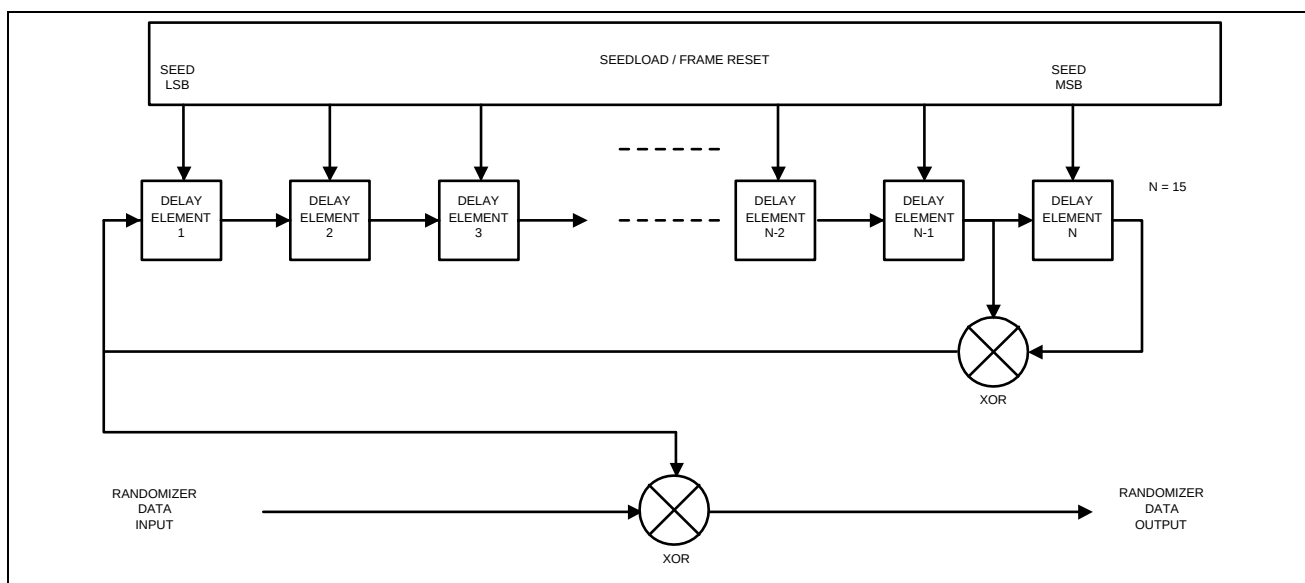


Figure 4-4. Scrambler Structure

#### 4.2.5 Preamble Prepend

The upstream PMD sublayer **MUST** support a variable-length preamble field that is prepended to the data after they have been randomized and Reed-Solomon encoded.

The first bit of the Preamble Pattern is the first bit into the symbol mapper (Figure 4-8), and is I1 in the first symbol of the burst (see Section 4.2.2.2). The first bit of the Preamble Pattern is designated by the Preamble Value Offset as described in Section 6.3.2.2, Table 6-15.

The value of the preamble that is prepended **MUST** be programmable and the length **MUST** be 0, 2, 4,..., or 1024 bits for QPSK and 0, 4, 8,..., or 1024 bits for 16QAM. Thus, the maximum length of the preamble is 512 QPSK symbols or 256 QAM symbols.

The preamble length and value MUST be configured in response to the Upstream Channel Descriptor message transmitted by the CMTS.

#### 4.2.6 Transmit Pre-Equalizer

The requirements in this section of the pre-equalization are optional for the CM. However, if a CM implements transmit equalization, the CM is required to be in conformance to the requirements in this section.

A transmit pre-equalizer of a linear equalizer structure, as shown in Figure 4-5, MUST be configured by the CM in response to the Ranging Response (RNG-RSP) message transmitted by the CMTS. The pre-equalizer MUST support a symbol (T)-spaced equalizer structure with 8 taps. The pre-equalizer MAY have 1, 2, or 4 samples per symbol, with a tap length longer than 8 symbols.

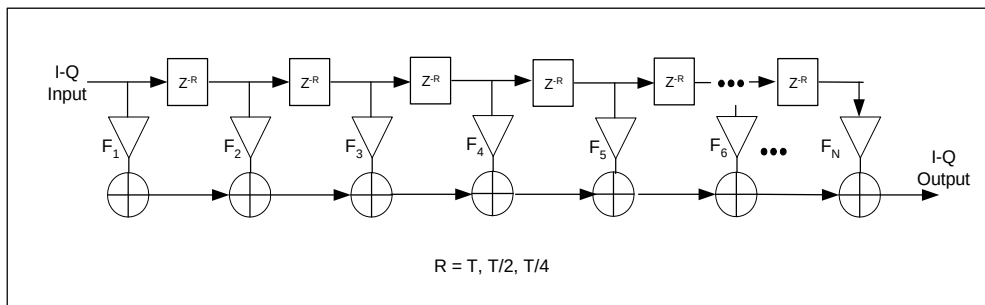


**Figure 4-5** Transmit Pre-Equalizer Structure

The RNG-RSP MAC message, (see Section 6.3.2.5) uses 16 bits per coefficient in fractional two's complement notation- "s1.14" (sign bit, integer bit, binary point, and 14 fractional bits) to define the CM transmit equalization information. The CM MUST convolve the coefficients sent by the CMTS with the existing coefficients to get the new coefficients.

In response to an initial ranging request and periodic ranging requests prior to CM registration, when the CMTS sends the pre-equalizer coefficients, the CMTS MUST compute and send them with an equalizer length of 8 and in symbol-spaced format. After registration, the CMTS MAY use a fractionally spaced equalizer format (T/2- or T/4-spaced) with a longer tap length to match the CM pre-equalizer capabilities that the CMTS learned from the REG-REQ message modem capabilities field. See section C.7.7 for proper use of the modem capabilities field.

Prior to making an initial ranging request and whenever the upstream channel frequency or upstream channel symbol rate changes, the CM MUST initialize the coefficients of the pre-equalizer to a default setting in which all coefficients are zero except the real coefficient of the first tap (i.e., F1). During initial ranging, the CM, not the CMTS, MUST compensate for the delay (ranging offset) due to a shift from the first tap to a new main tap location of the equalizer coefficients sent by the CMTS. The pre-equalizer coefficients are then updated through the subsequent ranging process (periodic station maintenance). The CMTS MUST not move the main tap location during periodic station maintenance. Equalizer coefficients may be included in every RNG-RSP message, but typically they only occur when the CMTS determines the channel response has significantly changed. The frequency of equalizer coefficient updates in the RNG-RSP message is determined by the CMTS.

The CM MUST normalize the pre-equalizer coefficients in order to guarantee proper operation (such as not to overflow or clip). The CM MUST also compensate for the change in transmit power due to the gain (or loss) of the new coefficients. If the CM equalizer structure implements the same number of coefficients as assigned in the RNG-RSP message, then the CM MUST not change the location of the main tap in the RNG-RSP message. If the CM equalizer structure implements a different number of coefficients than defined in the RNG-RSP message, the CM

MAY shift the location of the main tap value. Again, in doing so, the CM MUST adjust its ranging offset, in addition to any adjustment in the RNG-RSP message, by an amount that compensates for the movement of the main tap location.

## 4.2.7 Burst Profiles

The transmission characteristics are separated into three portions: a) Channel Parameters, b) Burst Profile Attributes, and c) User Unique Parameters. The Channel Parameters include i) the symbol rate (five rates from 160 ksym/sec to 2.56 Msym/sec in octave steps), ii) the center frequency (Hz), and iii) the 1024-bit Preamble Superstring. The Channel Parameters are further described in Section 6.3.2.2, Table 6-14; these characteristics are shared by all users on a given channel. The Burst Profile Attributes are listed in Table 4-4, and are further described in Section 6.3.2.2, Table 6-15; these parameters are the shared attributes corresponding to a burst type. The User Unique Parameters may vary for each user even when using the same burst type on the same channel as another user (for example, Power Level), and are listed in Table 4-5.

The CM MUST generate each burst at the appropriate time as conveyed in the mini-slot grants provided by the CMTS MAPs (Section 6.3.2.2).

The CM MUST support all burst profiles commanded by the CMTS via the Burst Descriptors in the UCD (Section 6.3.2.2), and subsequently assigned for transmission in a MAP (Section 6.3.2.3).

**Table 4-4. Burst Profile Attributes**

| Burst Profile Attributes                      | Configuration Settings                                                    |
|-----------------------------------------------|---------------------------------------------------------------------------|
| Modulation                                    | QPSK, 16 QAM                                                              |
| Diff Enc                                      | On/Off                                                                    |
| Preamble Length                               | 0-1024 bits (Note Section 4.2.5)                                          |
| Preamble Value offset                         | 0 to 1022                                                                 |
| FEC Error Correction (T bytes)                | 0 to 10 (0 implies FEC = off)                                             |
| FEC Codeword Information Bytes (k)            | Fixed: 16 to 253 (assuming FEC on) Shortened: 16 to 253 (assuming FEC on) |
| Scrambler Seed                                | 15 bits                                                                   |
| Maximum Burst Length (minislots) <sup>a</sup> | 0 to 255                                                                  |
| Guard Time                                    | 5 to 255 symbols                                                          |
| Last Codeword Length                          | Fixed, shortened                                                          |
| Scrambler On/Off                              | On/Off                                                                    |

- a. A burst length of 0 mini-slots in the Channel Profile indicates that the burst length is variable on that channel for that burst type. The burst length, while not fixed, is granted explicitly by the CMTS to the CM in the MAP.

**Table 4-5. User Unique Burst Parameters**

| User Unique Parameter                                                          | Configuration Settings                                        |
|--------------------------------------------------------------------------------|---------------------------------------------------------------|
| Power Level <sup>a</sup>                                                       | +8 to +55 dBmV (16QAM)<br>+8 to +58 dBmV (QPSK)<br>1-dB steps |
| Offset Frequency <sup>a</sup>                                                  | Range = □32 kHz; increment = 1 Hz; implement within □10 Hz    |
| Ranging Offset                                                                 | 0 to (216 - 1), increments of 6.25 μsec/64                    |
| Burst Length (mini-slots) if variable on this channel (changes burst-to-burst) | 1 to 255 mini-slots                                           |

|                                                       |                                                                      |
|-------------------------------------------------------|----------------------------------------------------------------------|
| Transmit Equalizer Coefficients(advanced modems only) | Up to 64 coefficients; 4 bytes per coefficient: 2 real and 2 complex |
|-------------------------------------------------------|----------------------------------------------------------------------|

- a. Values in table apply for this given channel and symbol rate

The CM MUST implement the Offset Frequency to within  $\pm 10$  Hz.

Ranging Offset is the delay correction applied by the CM to the CMTS Upstream Frame Time derived at the CM, in order to synchronize the upstream transmissions in the TDMA scheme. The Ranging Offset is an advancement equal to roughly the round-trip delay of the CM from the CMTS. The CMTS MUST provide feedback correction for this offset to the CM, based on reception of one or more successfully received bursts (i.e., satisfactory result from each technique employed: error correction and/or CRC), with accuracy within 1/2 symbol and resolution of 1/64 of the frame tick increment ( $6.25 \mu\text{sec}/64 = 0.09765625 \mu\text{sec} = 1/4$  the symbol duration of the highest symbol rate =  $10.24 \text{ MHz}^{-1}$ ). The CMTS sends adjustments to the CM, where a negative value implies the Ranging Offset is to be decreased, resulting in later times of transmission at the CM. The CM MUST implement the correction with resolution of at most 1 symbol duration (of the symbol rate in use for a given burst), and (other than a fixed bias) with accuracy within  $\pm 0.25 \mu\text{sec}$  plus  $\pm 1/2$  symbol owing to resolution. The accuracy of CM burst timing of  $\pm 0.25 \mu\text{sec}$  plus  $\pm 1/2$  symbol is relative to the mini-slot boundaries derivable at the CM based on an ideal processing of the timestamp signals received from the CMTS.

The CM MUST be capable of switching burst profiles with no reconfiguration time required between bursts except for changes in the following parameters: 1) Output Power, 2) Modulation, 3) Symbol Rate, 4) Offset frequency, 5) Channel Frequency, and 6) Ranging Offset.

For Symbol Rate, Offset frequency and Ranging Offset, the CM MUST be able to transmit consecutive bursts as long as the CMTS allocates at least 96 symbols in between the last symbol center of one burst and the first symbol center of the following burst. The maximum reconfiguration time of 96 symbols should compensate for the ramp-down time of one burst and the ramp-up time of the next burst as well as the overall transmitter delay time including the pipeline delay and optional pre-equalizer delay. For modulation type changes, the CM MUST be able to transmit consecutive bursts as long as the CMTS allocates at least 96 symbols in between the last symbol center of one burst and the first symbol center of the following burst.

Output Power, Symbol Rate, Offset frequency, Channel Frequency, and Ranging Offset MUST NOT be changed until the CM is provided sufficient time between bursts by the CMTS. Transmitted Output Power, Symbol Rate, Offset frequency, Channel Frequency and Ranging Offset MUST NOT change while more than -30 dB of any symbol's energy of the previous burst remains to be transmitted, or more than -30 dB of any symbol's energy of the next burst has been transmitted. The modulation MUST NOT change while more than -30 dB of any symbol's energy of the previous burst remains to be transmitted, or more than -30 dB of any symbol's energy of the next burst has been transmitted, EXCLUDING the effect of the transmit equalizer (if present in the CM). [This is to be verified with the transmit equalizer providing no filtering; delay only, if that. Note that if the CMTS has decision feedback in its equalizer, it may need to provide more than the 96 symbol gap between bursts of different modulation type which the same CM may use; this is a CMTS decision.] Negative ranging offset adjustments will cause the 96 symbol guard to be violated. The CMTS must assure that this does not happen by allowing extra guard time between bursts that is at least equal to the amount of negative ranging offset.

If Channel Frequency is to be changed, the CM MUST be able to implement the change between bursts as long as the CMTS allocates at least 96 symbols plus 100 msec between the last symbol center of one burst and the first symbol of the following burst.

The Channel Frequency of the CM MUST be settled within the phase noise and accuracy requirements of Sections 4.2.9.5 and 4.2.9.6 within 100 msec from the beginning of the change.

If Output Power is to be changed by 1 dB or less, the CM MUST be able to implement the change between bursts as long as the CMTS allocates at least 96 symbols plus 5  $\mu\text{sec}$  between the last symbol center of one burst and the first symbol center of the following burst.

If Output Power is to be changed by more than 1 dB, the CM MUST be able to implement the change between bursts as long as the CMTS allocates at least 96 symbols plus 10  $\mu\text{sec}$  between the last symbol center of one burst and the first symbol center of the following burst.

The Output Power of the CM MUST be settled to within  $\pm 0.1$  dB of its final output power level a) within 5  $\mu\text{sec}$  from the beginning of a change of 1 dB or less, and b) within 10  $\mu\text{sec}$  from the beginning of a change greater than 1 dB.

The output transmit power MUST be maintained constant within a TDMA burst to within less than 0.1 dB (excluding the amount theoretically present due to pulse shaping, and amplitude modulation in the case of 16 QAM).

#### 4.2.8 Burst Timing Convention

Figure 4-6 illustrates the nominal burst timing.

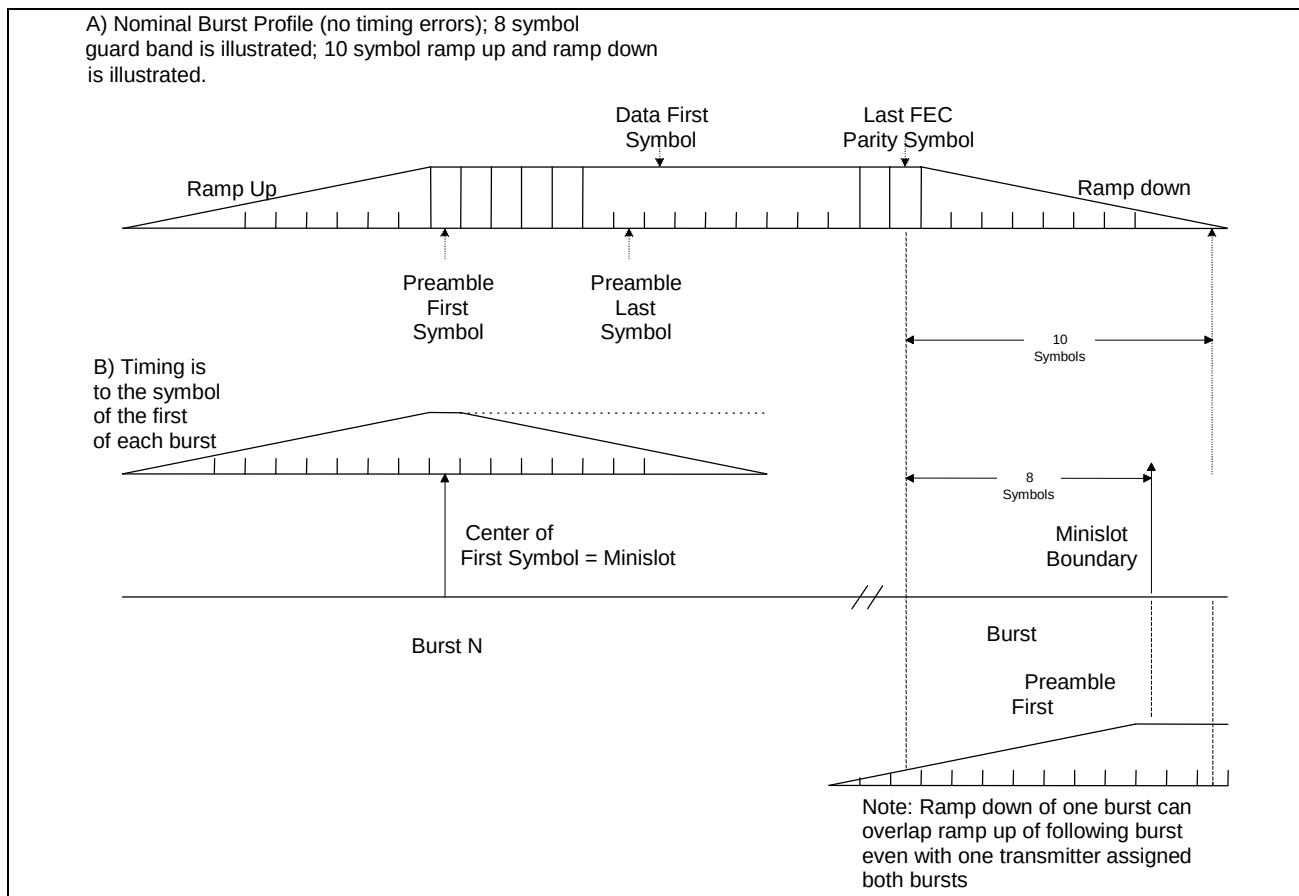


Figure 4-6 Nominal Burst Timing

Figure 4-7 indicates worst-case burst timing. In this example, burst N arrives 1.5 symbols late, and burst N+1 arrives 1.5 symbols early, but separation of 5 symbols is maintained; 8-symbol guardband shown.

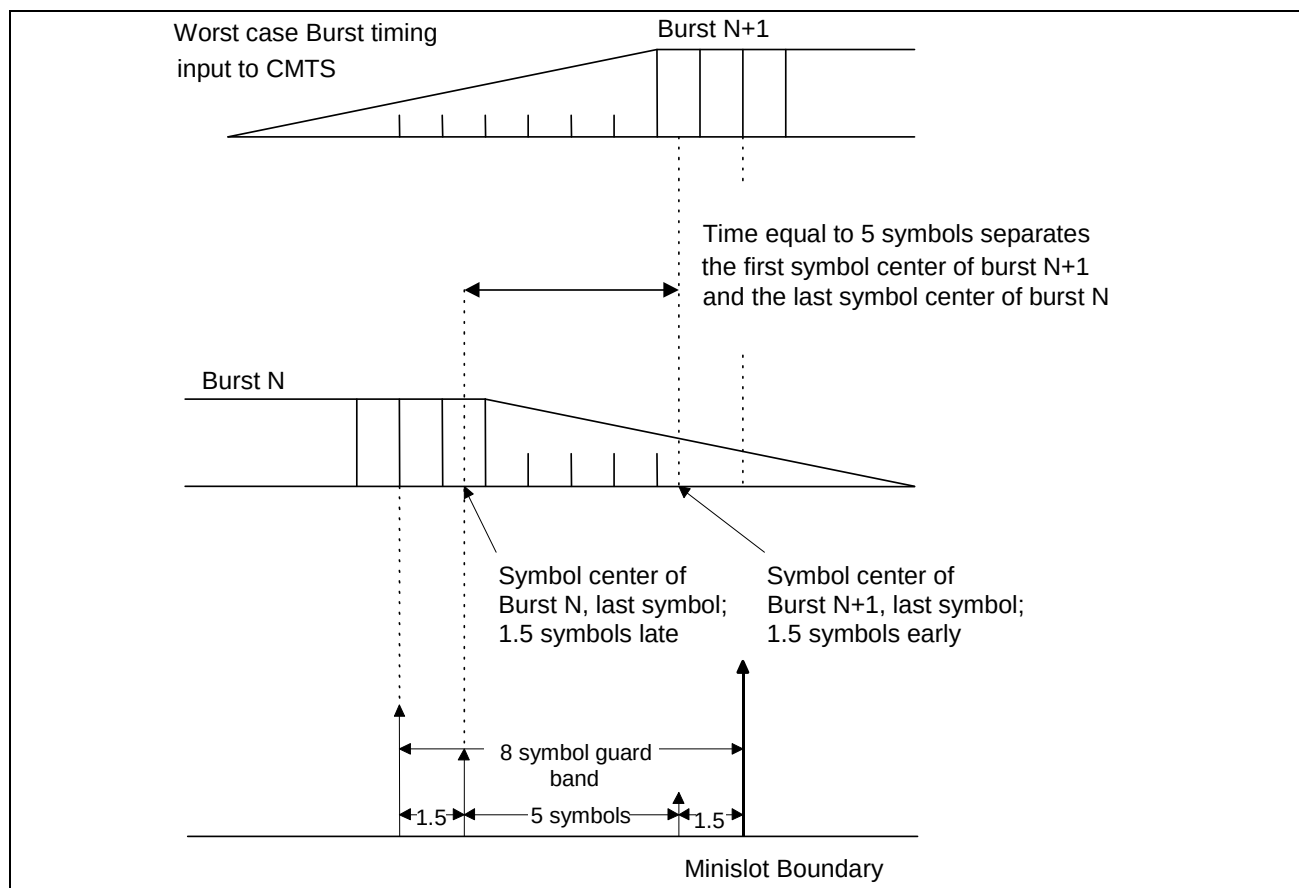


**Figure 4-7. Worst-Case Burst Timing**

At a symbol rate of  $R_s$ , symbols occur at a rate of one each  $T_s = 1/R_s$  seconds. Ramp Up and Ramp Down are the spread of a symbol in the time domain beyond  $T_s$  duration owing to the symbol-shaping filter. If only one symbol were transmitted, its duration would be longer than  $T_s$  due to the shaping filter impulse response being longer than  $T_s$ . The spread of the first and last symbols of a burst transmission effectively extends the duration of the burst to longer than  $N * T_s$ , where  $N$  is the number of symbols in the burst.

## 4.2.9 Transmit Power Requirements

The upstream PMD sublayer **MUST** support varying the amount of transmit power. Requirements are presented for 1) the range of commanded transmit power, 2) the step size of the power commands, and 3) the accuracy (actual output power compared to the commanded amount) of the response to the command.

The mechanism by which power adjustments are performed is defined in Section 7.2.4 of this document. Such adjustments **MUST** be within the ranges of tolerances described below.

### 4.2.9.1 Output Power Agility and Range

The output transmit power in the design bandwidth **MUST** be variable over the range of +8 dBmV to 55 dBmV (16 QAM) or 58 dBmV (QPSK), in 1-dB steps. The absolute accuracy of the transmitted power **MUST** be  $\pm 2$ dB, and the step size accuracy  $\pm 0.4$ dB, with an allowance for hysteresis while switching in/out a step attenuator (e.g., 20 dB) in which case the accuracy requirement is relaxed to  $\pm 1.4$ dB. For example, the actual power increase resulting from a command to increase the power level by 1dB in a CM's next transmitted burst **MUST** be between 0.6 and 1.4dB.

The step resolution **MUST** be 1dB or less. When a CM is commanded with finer resolution than it can implement, it **MUST** round to the nearest supported step size. If the commanded step is half way between two supported step sizes,

the CM MUST choose the smaller step. For example, with a supported step resolution of 1 dB, a command to step  $\pm 0.5$  dB would result in no step, while a command to step  $\pm 0.75$  dB would result in a  $\pm 1$  dB step.

## 4.2.10 Fidelity Requirements

### 4.2.10.1 Spurious Emissions

The noise and spurious power MUST NOT exceed the levels given in Table 4-6, Table 4-7, and Table 4-8.

In Table 4-6, Inband spurious includes noise, carrier leakage, clock lines, synthesizer spurious products, and other undesired transmitter products. It does not include ISI. The measurement bandwidth for Inband spurious is equal to the symbol rate (e.g., 160 kHz for 160 ksymbols/sec).

The measurement bandwidth for the 3 (or fewer) Carrier-Related Frequency Bands (below 42 MHz) is 160 kHz, with up to 3 160 kHz bands, each with no more than -47 dBc, allowed to be excluded from the “Bands within 5 to 42 MHz Transmitting Burst” specs of Table 4-8.

The measurement bandwidth is also 160 kHz for the Between Bursts specs of Table 4-6 below 42 MHz; the Transmitting Burst specs apply during the mini-slots granted to the CM (when the CM uses all or a portion of the grant), and for a minislot before and after the granted mini-slots. [Note that a minislot may be as short as 32 symbols, or 12.5 microseconds at the 2.56 Msym/sec rate, or as short as 200 microseconds at the 160 ksym/sec rate.] The Between Bursts specs apply except during a used grant of mini-slots, and the minislot before and after the used grant.

**Table 4-6. Spurious Emissions**

| Parameter                                                                                                                                                                                            | Transmitting Burst                                           | Between Bursts                                                          |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------|-------------------------------------------------------------------------|
| Inband (Inband spurious includes noise, carrier leakage, clock lines, synthesizer spurious products, and other undesired transmitter products. It does not include Inter Symbol Interference (ISI)). | -40 dBc                                                      | The greater of -72 dBc or -59 dBmV                                      |
| Adjacent Band                                                                                                                                                                                        | See Table 4-7                                                | The greater of -72 dBc or -59 dBmV                                      |
| 3 or Fewer Carrier-Related Frequency Bands (such as second harmonic, if < 42 MHz)                                                                                                                    | -47 dBc                                                      | The greater of -72 dBc or -59 dBmV                                      |
| Bands within 5 to 42 MHz (excluding assigned channel, adjacent channels, and carrier-related channels)                                                                                               | See Table 4-8                                                | The greater of -72 dBc or -59 dBmV                                      |
| CM Integrated Spurious Emissions Limits (all in 4 MHz, includes discretes) <sup>a</sup><br>42 to 54 MHz<br>54 to 60 MHz<br>60 to 88 MHz<br>88-860 MHz                                                | -max(-40 dBc, -26 dBmV) -<br>35 dBmV<br>-40 dBmV<br>-45 dBmV | -26 dBmV<br>-40 dBmV<br>-40 dBmV<br>max(-45 dBmV, -40 dBc) <sup>b</sup> |
| CM Discrete Spurious Emissions Limits <sup>a</sup><br>42 to 54 MHz<br>54 to 88 MHz<br>88 to 860 MHz                                                                                                  | -max(-50 dBc, -36 dBmV)<br>-50 dBmV<br>-50 dBmV              | -36 dBmV<br>-50 dBmV<br>-50 dBmV                                        |

- These spec limits exclude a single discrete spur related to the tuned received channel; this single discrete spur MUST be no greater than -40 dBmV.
- “dBc” is relative to the received downstream signal level. Some spurious outputs are proportional to the receive signal level.

#### 4.2.10.1.1 Adjacent Channel Spurious Emissions

Spurious emissions from a transmitted carrier may occur in an adjacent channel which could be occupied by a carrier of the same or different symbol rates. The following table lists the required adjacent channel spurious emission levels for all combinations of transmitted carrier symbol rates and adjacent channel symbol rates. The measurement is

performed in an adjacent channel interval that is of appropriate bandwidth and distance from the transmitted carrier based on the symbol rates of the transmitted carrier and the carrier in the adjacent channel.

**Table 4-7. Adjacent Channel Spurious Emissions**

| Transmitted carrier symbol rate | Specification in the interval | Measurement interval and distance from carrier edge | Adjacent channel carrier symbol rate |
|---------------------------------|-------------------------------|-----------------------------------------------------|--------------------------------------|
| 160 Ksym/sec                    | -45 dBc                       | 20 KHz to 180 KHz                                   | 160 Ksym/sec                         |
|                                 | -45 dBc                       | 40 KHz to 360 KHz                                   | 320 Ksym/sec                         |
|                                 | -45 dBc                       | 80 KHz to 720 KHz                                   | 640 Ksym/sec                         |
|                                 | -42 dBc                       | 160 KHz to 1440 KHz                                 | 1280 Ksym/sec                        |
|                                 | -39 dBc                       | 320 KHz to 2880 KHz                                 | 2560 Ksym/sec                        |
| All other symbol rates          | -45 dBc                       | 20 KHz to 180 KHz                                   | 160 Ksym/sec                         |
|                                 | -45 dBc                       | 40 KHz to 360 KHz                                   | 320 Ksym/sec                         |
|                                 | -45 dBc                       | 80 KHz to 720 KHz                                   | 640 Ksym/sec                         |
|                                 | -44 dBc                       | 160 KHz to 1440 KHz                                 | 1280 Ksym/sec                        |
|                                 | -41 dBc                       | 320 KHz to 2880 KHz                                 | sym/sec                              |

#### 4.2.10.1.2 Spurious Emissions in 5 to 42 MHz

Spurious emissions, other than those in an adjacent channel or carrier related emissions listed above, may occur in intervals that could be occupied by other carriers of the same or different symbol rates. To accommodate these different symbol rates and associated bandwidths, the spurious emissions are measured in an interval equal to the bandwidth corresponding to the symbol rate of the carrier that could be transmitted in that interval. This interval is independent of the current transmitted symbol rate.

The following table lists the possible symbol rates that could be transmitted in an interval, the required spurious level in that interval, and the initial measurement interval at which to start measuring the spurious emissions. Measurements should start at the initial distance and be repeated at increasing distance from the carrier until the upstream band edge, 5 MHz or 42 MHz, is reached. Measurement intervals should not include carrier related emissions.

**Table 4-8. Spurious Emissions in 5 to 42 MHz**

| Possible symbol rate in this interval | Specification in the interval | Initial measurement interval and distance from carrier edge |
|---------------------------------------|-------------------------------|-------------------------------------------------------------|
| 160 Ksym/sec                          | -53 dBc                       | 220 KHz to 380 KHz                                          |
| 320 Ksym/sec                          | -50 dBc                       | 240 KHz to 560 KHz                                          |
| 640 Ksym/sec                          | -47 dBc                       | 280 KHz to 920 KHz                                          |
| 1280 Ksym/sec                         | -44 dBc                       | 360 KHz to 1640 KHz                                         |
| 2560 Ksym/sec                         | -41 dBc                       | 520 KHz to 3080 KHz                                         |

#### 4.2.10.2 Spurious Emissions During Burst On/Off Transients

Each transmitter MUST control spurious emissions, prior to and during ramp up and during and following ramp down, before and after a burst in the TDMA scheme.

On/off spurious emissions, such as the change in voltage at the upstream transmitter output due to enabling or disabling transmission, MUST be no more than 100 mV, and such a step MUST be dissipated no faster than 2  $\mu$ s of constant slewing. This requirement applies when the CM is transmitting at +55 dBmV or more; at backed-off transmit

levels, the maximum change in voltage MUST decrease by a factor of 2 for each 6-dB decrease of power level from +55 dBmV, down to a maximum change of 7 mV at 31 dBmV and below. This requirement does not apply to CM power-on and power-off transients.

#### 4.2.10.3 Symbol Error Rate (SER)

Modulator performance MUST be within 0.5 dB of theoretical SER vs C/N (i.e.,  $E_s/N_0$ ), for SER as low as  $10^{-6}$  uncoded, for QPSK and 16 QAM.

The SER degradation is determined by the cluster variance caused by the transmit waveform at the output of an ideal square-root raised-cosine receive filter. It includes the effects of ISI, spurious, phase noise, and all other transmitter degradations.

Cluster SNR should be measured on a modulation analyzer using a square-root raised cosine receive filter with  $\alpha = 0.25$ . The measured SNR MUST be better than 30 dB.

#### 4.2.10.4 Filter Distortion

The following requirements assume that any pre-equalization is disabled.

##### 4.2.10.4.1 Amplitude

The spectral mask MUST be the ideal square root raised cosine spectrum with  $\alpha = 0.25$ , within the ranges given below:

- $f_c - R_s/4$  Hz to  $f_c + R_s/4$  Hz: -0.3 dB to +0.3 dB
- $f_c - 3R_s/8$  Hz to  $f_c - R_s/4$  Hz, and  $f_c + R_s/4$  Hz to  $f_c + 3R_s/8$  Hz: -0.5 dB to 0.3 dB
- $f_c - R_s/2$  Hz and  $f_c + R_s/2$  Hz: -3.5 dB to -2.5 dB
- $f_c - 5R_s/8$  Hz and  $f_c + 5R_s/8$  Hz: no greater than -30 dB

where  $f_c$  is the center frequency,  $R_s$  is the symbol rate, and the spectral density is measured with a resolution bandwidth of 10 KHz or less.

##### 4.2.10.4.2 Phase

$f_c - 5R_s/8$  Hz to  $f_c + 5R_s/8$  Hz: Group Delay Variation MUST NOT be greater than 100 nsec.

#### 4.2.10.5 Carrier Phase Noise

The upstream transmitter total integrated phase noise (including discrete spurious noise) MUST be less than or equal to -43 dBc summed over the spectral regions spanning 1 kHz to 1.6 MHz above and below the carrier.

#### 4.2.10.6 Channel Frequency Accuracy

The CM MUST implement the assigned channel frequency within  $\pm 50$  parts per million over a temperature range of 0 to 40 degrees C up to five years from date of manufacture.

#### 4.2.10.7 Symbol Rate Accuracy

The upstream modulator MUST provide an absolute accuracy of symbol rates  $\pm 50$  parts per million over a temperature range of 0 to 40 degrees C up to five years from date of manufacture.

#### 4.2.10.8 Symbol Timing Jitter

Peak-to-peak symbol jitter, referenced to the previous symbol zero-crossing, of the transmitted waveform, **MUST** be less than 0.02 of the nominal symbol duration over a 2-sec period. In other words, the difference between the maximum and the minimum symbol duration during the 2-sec period shall be less than 0.02 of the nominal symbol duration for each of the five upstream symbol rates.

The peak-to-peak cumulative phase error, referenced to the first symbol time and with any fixed symbol frequency offset factored out, **MUST** be less than 0.04 of the nominal symbol duration over a 0.1-sec period. In other words, the difference between the maximum and the minimum cumulative phase error during the 0.1-sec period shall be less than 0.04 of the nominal symbol duration for each of the five upstream symbol rates. Factoring out a fixed symbol frequency offset is to be done by using the computed mean symbol duration during the 0.1 sec.

#### 4.2.11 Frame Structure

Figure 4-8 shows two examples of the frame structure: one where the packet length equals the number of information bytes in a codeword, and another where the packet length is longer than the number of information bytes in one codeword, but less than in two codewords. Example 1 illustrates the fixed codeword-length mode, and Example 2 illustrates the shortened last codeword mode. These modes are defined in Section 4.2.10.1.

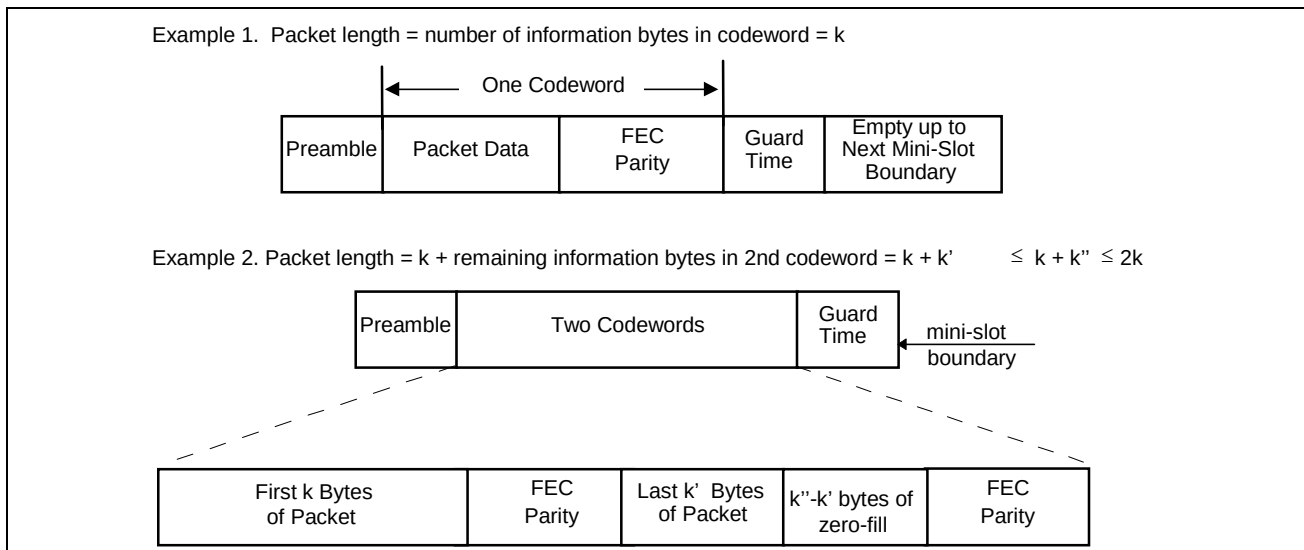


**Figure 4-8. Example Frame Structures with Flexible Burst Length Mode**

##### 4.2.11.1 Codeword Length

When FEC is enabled, the CM operates in either fixed-length codeword mode or in shortened-last codeword mode. The minimum number of information bytes in a codeword in either mode is 16. Shortened-last codeword mode only provides a benefit when the number of bytes in a codeword is greater than the minimum of 16 bytes.

The following descriptions apply to an allocated grant of mini-slots in both contention and non-contention regions. (Allocation of mini-slots is discussed in Section 6 of this document.) The intent of the description is to define rules and conventions such that CMs request the proper number of mini-slots and the CMTS PHY knows what to expect regarding the FEC framing in both fixed codeword length and shortened last codeword modes.

###### 4.2.11.1.1 Fixed Codeword Length

With the fixed-length codewords, after all the data are encoded, zero-fill will occur in this codeword if necessary to reach the assigned  $k$  data bytes per codeword, and zero-fill **MUST** continue up to the point when no additional fixed-

length codewords can be inserted before the end of the last allocated mini-slot in the grant, accounting for FEC parity and guard-time symbols.

#### 4.2.11.1.2 Shortened Last Codeword

As shown in Figure 4-7, let  $k'$  = the number of information bytes that remain after partitioning the information bytes of the burst into full-length ( $k$  burst data bytes) codewords. The value of  $k'$  is less than  $k$ . Given operation in a shortened last codeword mode, let  $k''$  = the number of burst data bytes plus zero-fill bytes in the shortened last codeword. In shortened codeword mode, the CM will encode the data bytes of the burst (including MAC Header) using the assigned codeword size ( $k$  information bytes per codeword) until 1) all the data are encoded, or 2) a remainder of data bytes is left over which is less than  $k$ . Shortened last codewords shall not have less than 16 information bytes, and this is to be considered when CMs make requests of mini-slots. In shortened last codeword mode, the CM will zero-fill data if necessary until the end of the mini-slot allocation, which in most cases will be the next mini-slot boundary, accounting for FEC parity and guard-time symbols. In many cases, only  $k'' - k'$  zero-fill bytes are necessary to fill out a mini-slot allocation with  $16 \leq k'' \leq k$  and  $k' \leq k''$ . However, note the following.

More generally, the CM is required to zero-fill data until the point when no additional fixed-length codewords can be inserted before the end of the last allocated mini-slot in the grant (accounting for FEC parity and guard-time symbols), and then, if possible, a shortened last codeword of zero-fill shall be inserted to fit into the mini-slot allocation.

If, after zero-fill of additional codewords with  $k$  information bytes, there are less than 16 bytes remaining in the allocated grant of mini-slots, accounting for parity and guard-time symbols, the CM shall not create this last shortened codeword.

#### 4.2.12 Signal Processing Requirements

The signal processing order for each burst packet type MUST be compatible with the sequence shown in Figure 4-9 and MUST follow the order of steps in Figure 4-10.

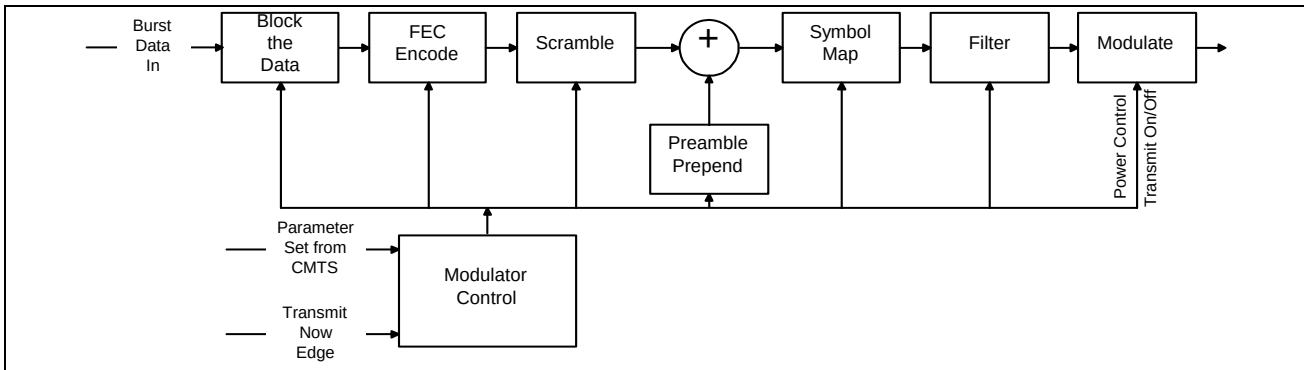
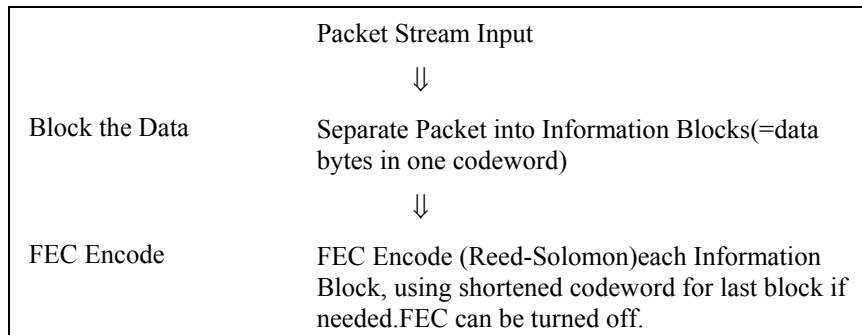


Figure 4-9. Signal-Processing Sequence



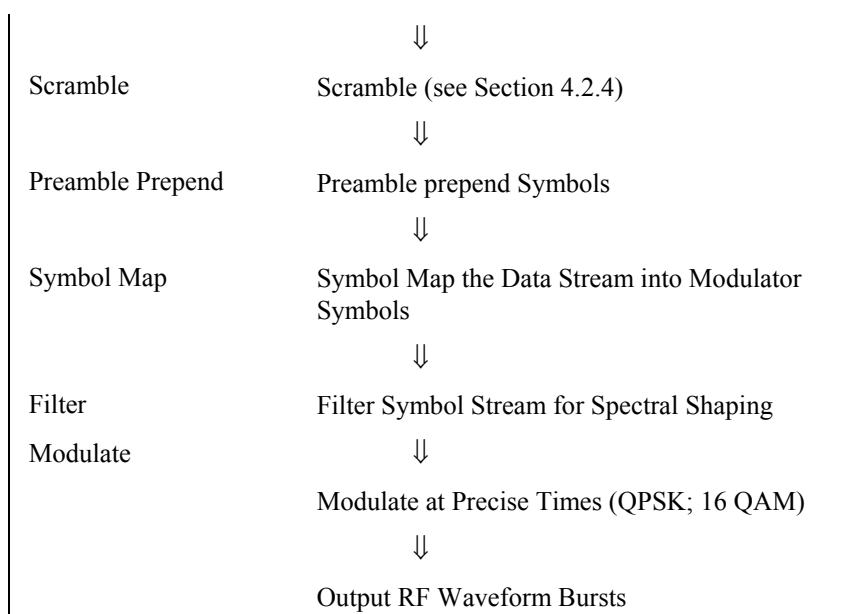


Figure 4-10. TDMA Upstream Transmission Processing

### 4.2.13 Upstream Demodulator Input Power Characteristics

The maximum total input power to the upstream demodulator MUST NOT exceed 35 dBmV in the 5-42 MHz frequency range of operation.

The intended received power in each carrier MUST be within the values shown in Table 4-9.

**Table 4-9. Maximum Range of Commanded Nominal Receive Power in Each Carrier**

| Symbol Rate<br>(ksym/sec) | Maximum Range<br>(dBmV) |
|---------------------------|-------------------------|
| 160                       | -16 to +14              |
| 320                       | -13 to +17              |
| 640                       | -10 to +20              |
| 1,280                     | -7 to +23               |
| 2,560                     | -4 to +26               |

The demodulator MUST operate within its defined performance specifications with received bursts within  $\pm 6$  dB of the nominal commanded received power.

### 4.2.14 Upstream Electrical Output from the CM

The CM MUST output an RF modulated signal with the characteristics delineated in Table 4-10.

**Table 4-10. Electrical Output from CM**

| Parameter                 | Value                    |
|---------------------------|--------------------------|
| Frequency                 | 5 to 42 MHz edge to edge |
| Level range (one channel) | +8 to +55 dBmV (16QAM)   |

|                       |                                         |
|-----------------------|-----------------------------------------|
|                       | +8 to +58 dBmV (QPSK)                   |
| Modulation Type       | QPSK and 16QAM                          |
| Symbol Rate (nominal) | 160, 320, 640, 1,280 and 2,560 ksym/sec |
| Bandwidth             | 200, 400, 800, 1,600 and 3,200 kHz      |
| Output impedance      | 75 ohms                                 |
| Output Return Loss    | > 6 dB (5-42 MHz)                       |
| Connector             | [SCTE 02 1997] or [IEC 60169-24]        |

## 4.3 Downstream

### 4.3.1 Downstream Protocol

The downstream PMD sublayer MUST conform to ITU-T Recommendations J.83, Annex B for Low-Delay Video Applications [ITU J.83-B], with the exceptions called out in Section 4.3.2.

**Note:** Any reference in this document to the transmission of television in the forward channel that is not consistent with [EN 300 429] is outside the normative scope as only [EN 300 429] is used for digital multi-program TV distribution by cable in European applications. See sec. 1 ("Scope").

### 4.3.2 Scalable Interleaving to Support Low Latency

The downstream PMD sublayer MUST support a variable-depth interleaver with the characteristics defined in Table 4-11. The table contains a subset of interleaver modes found in [ITU J.83-B].

**Table 4-11. Interleaver Characteristics**

| I<br>(Number of Taps) | J<br>(Increment) | Burst Protection<br>64QAM/256QAM | Latency<br>64QAM/256QAM |
|-----------------------|------------------|----------------------------------|-------------------------|
| 8                     | 16               | 5.9 µsec/4.1 µsec                | 0.22 msec/0.15 msec     |
| 16                    | 8                | 12 µsec/8.2 µsec                 | 0.48 msec/0.33 msec     |
| 32                    | 4                | 24 µsec/16 µsec                  | 0.98 msec/0.68 msec     |
| 64                    | 2                | 47 µsec/33 µsec                  | 2.0 msec/1.4 msec       |
| 128                   | 1                | 95 µsec/66 µsec                  | 4.0 msec/2.8 msec       |

The interleaver depth, which is coded in a 4-bit control word contained in the FEC frame synchronization trailer, always reflects the interleaving in the immediately-following frame. In addition, errors are allowed while the interleaver memory is flushed after a change in interleaving is indicated.

Refer to [ITU J.83-B] for the control bit specifications required to specify which interleaving mode is used.

### 4.3.3 Downstream Frequency Plan

The downstream frequency plan should comply with Harmonic Related Carrier (HRC), Incremental Related Carrier (IRC) or Standard (STD) North American frequency plans per [IS-6]. However, operation below a center frequency of 91 MHz is not required.

### 4.3.4 CMTS Output Electrical

The CMTS MUST output an RF modulated signal with the following characteristics defined in Table 4-12.

**Table 4-12. CMTS Output**

| Parameter                                                       | Value                                                                                                                                                                                                                                 |
|-----------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Center Frequency ( $f_c$ )                                      | 91 to 857 MHz $\pm 30$ kHz <sup>a</sup>                                                                                                                                                                                               |
| Level                                                           | Adjustable over the range 50 to 61 dBmV                                                                                                                                                                                               |
| Modulation Type                                                 | 64QAM and 256QAM                                                                                                                                                                                                                      |
| Symbol Rate (nominal)                                           |                                                                                                                                                                                                                                       |
| 64QAM                                                           | 5.056941 Msym/sec                                                                                                                                                                                                                     |
| 256QAM                                                          | 5.360537 Msym/sec                                                                                                                                                                                                                     |
| Nominal Channel Spacing                                         | 6 MHz                                                                                                                                                                                                                                 |
| Frequency response                                              |                                                                                                                                                                                                                                       |
| 64QAM                                                           | ~18% Square Root Raised Cosine shaping                                                                                                                                                                                                |
| 256QAM                                                          | ~12% Square Root Raised Cosine shaping                                                                                                                                                                                                |
| Total Discrete Spurious Inband ( $f_c \pm 3$ MHz)               | < -57dBc                                                                                                                                                                                                                              |
| Inband Spurious and Noise ( $f_c \pm 3$ MHz)                    | < -48dBc; where channel spurious and noise includes all discrete spurious, noise, carrier leakage, clock lines, synthesizer products, and other undesired transmitter products. Noise within $\pm 50$ kHz of the carrier is excluded. |
| Adjacent channel ( $f_c \pm 3.0$ MHz) to ( $f_c \pm 3.75$ MHz)  | < -58 dBc in 750 kHz                                                                                                                                                                                                                  |
| Adjacent channel ( $f_c \pm 3.75$ MHz) to ( $f_c \pm 9$ MHz)    | < -62 dBc, in 5.25 MHz, excluding up to 3 spurs, each of which must be < -60 dBc when measured in a 10 kHz band                                                                                                                       |
| Next adjacent channel ( $f_c \pm 9$ MHz) to ( $f_c \pm 15$ MHz) | Less than the greater of -65 dBc or -12dBmV in 6MHz, excluding up to three discrete spurs. The total power in the spurs must be < -60dBc when each is measured with 10 kHz bandwidth.                                                 |
| Other channels (47 MHz to 1,000 MHz)                            | < -12dBmV in each 6 MHz channel, excluding up to three discrete spurs. The total power in the spurs must be < -60dBc when each is measured with 10kHz bandwidth.                                                                      |
| Phase Noise                                                     | 1 kHz - 10 kHz: -33dBc double-sided noise power<br>10 kHz - 50 kHz: -51dBc double-sided noise power<br>50 kHz - 3 MHz: -51dBc double-sided noise power                                                                                |
| Output Impedance                                                | 75 ohms                                                                                                                                                                                                                               |
| Output Return Loss                                              | > 14 dB within an output channel up to 750 MHz;<br>> 13 dB in an output channel above 750 MHz                                                                                                                                         |
| Connector                                                       | [SCTE 02 1997] or [IEC 60169-24]                                                                                                                                                                                                      |

<sup>a</sup>  $\pm 30$  kHz includes an allowance of 25 kHz for the largest FCC frequency offset normally built into upconverters

### 4.3.5 Downstream Electrical Input to CM

The CM MUST accept an RF modulated signal with the following characteristics (Table 4-13.)

**Table 4-13. Electrical Input to CM**

| Parameter                      | Value                                                                                                        |
|--------------------------------|--------------------------------------------------------------------------------------------------------------|
| Center Frequency               | 91 to 857 MHz $\pm$ 30 kHz                                                                                   |
| Level Range (one channel)      | -15 dBmV to +15 dBmV                                                                                         |
| Modulation Type                | 64QAM and 256QAM                                                                                             |
| Symbol Rate (nominal)          | 5.056941 Msym/sec (64QAM) and 5.360537 Msym/sec (256QAM)                                                     |
| Bandwidth                      | 6 MHz (18% Square Root Raised Cosine shaping for 64QAM and 12% Square Root Raised Cosine shaping for 256QAM) |
| Total Input Power (40-900 MHz) | <30 dBmV                                                                                                     |
| Input (load) Impedance         | 75 ohms                                                                                                      |
| Input Return Loss              | > 6 dB (88-860 MHz)                                                                                          |
| Connector                      | [SCTE 02 1997] or [IEC 60169-24]                                                                             |

### 4.3.6 CM BER Performance

The bit-error-rate performance of a CM MUST be as described in this section. The requirements apply to the I = 128, J = 1 mode of interleaving.

#### 4.3.6.1 64QAM

##### 4.3.6.1.1 64QAM CM BER Performance

Implementation loss of the CM MUST be such that the CM achieves a post-FEC BER less than or equal to  $10^{-8}$  when operating at a carrier to noise ratio ( $E_s/N_o$ ) of 23.5 dB or greater.

##### 4.3.6.1.2 64QAM Image Rejection Performance

Performance as described in Section 4.3.6.1.1 MUST be met with analog or digital signal at +10 dBc in any portion of the RF band other than the adjacent channels.

##### 4.3.6.1.3 64QAM Adjacent Channel Performance

Performance as described in Section 4.3.6.1.1 MUST be met with digital signal at 0 dBc in the adjacent channels.

Performance as described in Section 4.3.6.1.1 MUST be met with analog signal at +10 dBc in the adjacent channels.

Performance as described in Section 4.3.6.1.1, with an additional 0.2-dB allowance, MUST be met with digital signal at +10 dBc in the adjacent channels.

#### 4.3.6.2 256QAM

##### 4.3.6.2.1 256QAM CM BER Performance

Implementation loss of the CM MUST be such that the CM achieves a post-FEC BER less than or equal to  $10^{-8}$  when operating at a carrier to noise ratio ( $E_s/N_o$ ) as shown below.

**Table 4-14. 256QAM CM BER Performance**

| Input Receive Signal Level         | $E_s/N_o$        |
|------------------------------------|------------------|
| -6 dBmV to +15 dBmV                | 30 dB or greater |
| Less than -6 dBmV down to -15 dBmV | 33 dB or greater |

#### 4.3.6.2.2 256QAM Image Rejection Performance

Performance as described in Section 4.3.6.2.1 MUST be met with analog or digital signal at +10 dBc in any portion of the RF band other than the adjacent channels.

#### 4.3.6.2.3 256QAM Adjacent Channel Performance

Performance as described in Section 4.3.6.2.1 MUST be met with analog or digital signal at 0 dBc in the adjacent channels.

Performance as described in Section 4.3.6.2.1, with an additional 0.5-dB allowance, MUST be met with analog signal at +10 dBc in the adjacent channels.

Performance as described in Section 4.3.6.2.1, with an additional 1.0-dB allowance, MUST be met with digital signal at +10 dBc in the adjacent channels.

### 4.3.7 CMTS Timestamp Jitter

The CMTS timestamp jitter must be less than 500 ns peak-to-peak at the output of the Downstream Transmission Convergence Sublayer. This jitter is relative to an ideal Downstream Transmission Convergence Sublayer that transfers the MPEG packet data to the Downstream Physical Media Dependent Sublayer with a perfectly continuous and smooth clock at the MPEG packet data rate. Downstream Physical Media Dependent Sublayer processing MUST NOT be considered in timestamp generation and transfer to the Downstream Physical Media Dependent Sublayer.

Thus, any two timestamps  $N1$  and  $N2$  ( $N2 > N1$ ) which were transferred to the Downstream Physical Media Dependent Sublayer at times  $T1$  and  $T2$  respectively must satisfy the following relationship:

$$|(N2-N1)f_{\text{CMTS}} - (T2-T1)| < 500 \times 10^{-9}$$

In the equation, the value of  $(N2-N1)$  is assumed to account for the effect of rollover of the timebase counter, and  $T1$  and  $T2$  represent time in seconds.  $f_{\text{CMTS}}$  is the actual frequency of the CMTS master timebase and may include a fixed frequency offset from the nominal frequency of 10.24 MHz. This frequency offset is bounded by a requirement further below in this section.

The jitter includes inaccuracy in timestamp value and the jitter in all clocks. The 500ns allocated for jitter at the Downstream Transmission Convergence Sublayer output must be reduced by any jitter that is introduced by the Downstream Physical Media Dependent Sublayer.

The CM is expected to meet the burst timing accuracy requirements in Section 4.2.6 when the time stamps contain this worst-case jitter.

**Note:** Jitter is the error (i.e., measured) relative to the CMTS Master Clock. (The CMTS Master Clock is the 10.24 MHz clock used for generating the timestamps.)

The CMTS 10.24 MHz Master Clock MUST have frequency stability of  $\pm 5$  ppm, drift rate  $\pm 10^{-8}$  per second, and edge jitter of  $\pm 10$  nsec peak-to-peak ( $\pm 5$  nsec). [The drift rate and jitter requirements on the CMTS Master Clock implies that the duration of two adjacent segments of 10,240,000 cycles will be within 30 nsec, due to 10 nsec jitter on each segment's duration, and 10 nsec due to frequency drift. Durations of other counter lengths also may be deduced: adjacent 1,024,000 segments,  $\pm 21$  nsec; 1,024,000 length segments separated by 1 10,240,000 cycles,  $\pm 30$  nsec; adjacent 102,400,000 segments,  $\pm 120$  nsec. The CMTS Master Clock MUST meet such test limits in 99% or more measurements.

## 5. DOWNSTREAM TRANSMISSION CONVERGENCE SUBLAYER

This section applies to the first technology option referred to in Section 1 (“Scope”). For the second option, refer to Appendix N.

### 5.1 Introduction

In order to improve demodulation robustness, facilitate common receiving hardware for both video and data, and provide an opportunity for the possible future multiplexing of video and data over the PMD sublayer bitstream defined in Section 4, a sublayer is interposed between the downstream PMD sublayer and the Data-Over-Cable MAC sublayer.

The downstream bitstream is defined as a continuous series of 188-byte MPEG [ITU-T H.222.0] packets. These packets consist of a 4-byte header followed by 184 bytes of payload. The header identifies the payload as belonging to the Data-Over-Cable MAC. Other values of the header may indicate other payloads. The mixture of MAC payloads and those of other services is optional and is controlled by the CMTS.

Figure 5-1 illustrates the interleaving of Data-Over-Cable (DOC) MAC bytes with other digital information (digital video in the example shown).

|              |                       |
|--------------|-----------------------|
| header=DOC   | DOC MAC payload       |
| header=video | digital video payload |
| header=video | digital video payload |
| header=DOC   | DOC MAC payload       |
| header=video | digital video payload |
| header=DOC   | DOC MAC payload       |
| header=video | digital video payload |
| header=video | digital video payload |
| header=video | digital video payload |

**Figure 5-1. Example of Interleaving MPEG Packets in Downstream**

### 5.2 MPEG Packet Format

The format of an MPEG Packet carrying DOCSIS data is shown in Figure 5-2. The packet consists of a 4-byte MPEG Header, a pointer\_field (not present in all packets) and the DOCSIS Payload.

|                          |                           |                                      |
|--------------------------|---------------------------|--------------------------------------|
| MPEG Header<br>(4 bytes) | pointer_field<br>(1 byte) | DOCSIS Payload<br>(183 or 184 bytes) |
|--------------------------|---------------------------|--------------------------------------|

**Figure 5-2. Format of an MPEG Packet**

### 5.3 MPEG Header for DOCSIS Data-Over-Cable

The format of the MPEG Transport Stream header is defined in Section 2.4 of [ITU-T H.222.0]. The particular field values that distinguish Data-Over-Cable MAC streams are defined in Table 5-1. Field names are from the ITU specification.

The MPEG Header consists of 4 bytes that begin the 188-byte MPEG Packet. The format of the header for use on a DOCSIS Data-Over-Cable PID is restricted to that shown in Table 5-1. The header format conforms to the MPEG standard, but its use is restricted in this specification to NOT ALLOW inclusion of an adaptation\_field in the MPEG packets.

**Table 5-1. MPEG Header Format for DOCSIS Data-Over-Cable Packets**

| Field                        | Length (bits) | Description                                                                                                                                                                    |
|------------------------------|---------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| sync_byte                    | 8             | 0x47; MPEG Packet Sync byte                                                                                                                                                    |
| transport_error_indicator    | 1             | Indicates an error has occurred in the reception of the packet. This bit is reset to zero by the sender, and set to one whenever an error occurs in transmission of the packet |
| payload_unit_start_indicator | 1             | A value of one indicates the presence of a pointer_field as the first byte of the payload (fifth byte of the packet)                                                           |
| transport_priority           | 1             | Reserved; set to zero                                                                                                                                                          |
| PID (see Note)               | 13            | DOCSIS Data-Over-Cable well-known PID (0x1FFE)                                                                                                                                 |
| transport_scrambling_control | 2             | Reserved, set to '00'                                                                                                                                                          |
| adaptation_field_control     | 2             | '01'; use of the adaptation_field is NOT ALLOWED on the DOCSIS PID                                                                                                             |
| continuity_counter           | 4             | Cyclic counter within this PID                                                                                                                                                 |

**Note:** In the future, additional PIDs MAY be assigned to a CM. See Section 9.3 of this document.

### 5.4 MPEG Payload for DOCSIS Data-Over-Cable

The MPEG payload portion of the MPEG packet will carry the DOCSIS MAC frames. The first byte of the MPEG payload will be a 'pointer\_field' if the payload\_unit\_start\_indicator (PUSI) of the MPEG header is set.

#### stuff\_byte

This standard defines a stuff\_byte pattern having a value (0xFF) that is used within the DOCSIS payload to fill any gaps between the DOCSIS MAC frames. This value is chosen as an unused value for the first byte of the DOCSIS MAC frame. The 'FC' byte of the MAC Header will be defined to never contain this value. (FC\_TYPE = '11' indicates a MAC-specific frame, and FC\_PARM = '11111' is not currently used and, according to this specification, is defined as an illegal value for FC\_PARM.)

#### pointer\_field

The pointer\_field is present as the fifth byte of the MPEG packet (first byte following the MPEG header) whenever the PUSI is set to one in the MPEG header. The interpretation of the pointer\_field is as follows:

The pointer\_field contains the number of bytes in this packet that immediately follow the pointer\_field that the CM decoder must skip past before looking for the beginning of an DOCSIS MAC Frame. A pointer field MUST be present if it is possible to begin a Data-Over-Cable MAC Frame in the packet, and MUST point to either:

1. the beginning of the first MAC frame to start in the packet or
2. to any stuff\_byte preceding the MAC frame.

## 5.5 Interaction with the MAC Sublayer

MAC frames may begin anywhere within an MPEG packet, MAC frames may span MPEG packets, and several MAC frames may exist within an MPEG packet.

The following figures show the format of the MPEG packets that carry DOCSIS MAC frames. In all cases, the PUSI flag indicates the presence of the pointer\_field as the first byte of the MPEG payload.

Figure 5-3 shows a MAC frame that is positioned immediately after the pointer\_field byte. In this case, pointer\_field is zero, and the DOCSIS decoder will begin searching for a valid FC byte at the byte immediately following the pointer\_field.

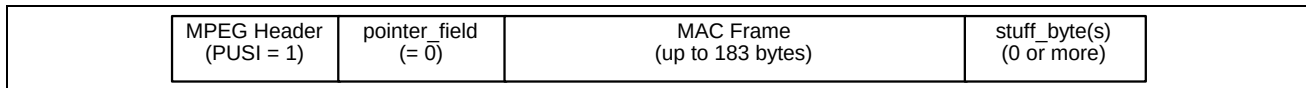


**Figure 5-3. Packet Format Where a MAC Frame Immediately Follows the pointer\_field**

Figure 5-4 shows the more general case where a MAC Frame is preceded by the tail of a previous MAC Frame and a sequence of stuffing bytes. In this case, the pointer\_field still identifies the first byte after the tail of Frame #1 (a stuff\_byte) as the position where the decoder should begin searching for a legal MAC sublayer FC value. This format allows the multiplexing operation in the CMTS to immediately insert a MAC frame that is available for transmission if that frame arrives after the MPEG header and pointer\_field have been transmitted.

In order to facilitate multiplexing of the MPEG packet stream carrying DOCSIS data with other MPEG-encoded data, the CMTS SHOULD NOT transmit MPEG packets with the DOCSIS PID which contain only stuff\_bytes in the payload area. MPEG null packets SHOULD be transmitted instead. Note that there are timing relationships implicit in the DOCSIS MAC sublayer which must also be preserved by any MPEG multiplexing operation.

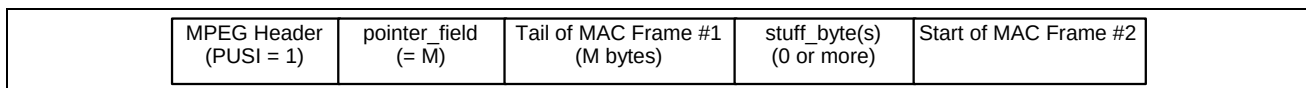


**Figure 5-4. Packet Format with MAC Frame Preceded by Stuffing Bytes**

Figure 5-5 shows that multiple MAC frames may be contained within the MPEG packet. The MAC frames may be concatenated one after the other or be separated by an optional sequence of stuffing bytes.

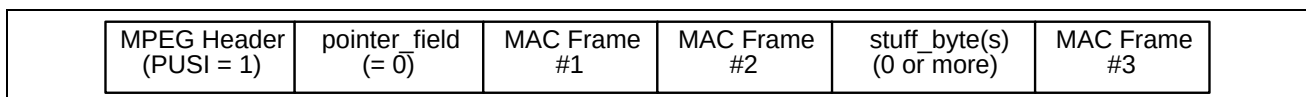


**Figure 5-5. Packet Format Showing Multiple MAC Frames in a Single Packet**

Figure 5-6 shows the case where a MAC frame spans multiple MPEG packets. In this case, the pointer\_field of the succeeding frame points to the byte following the last byte of the tail of the first frame.

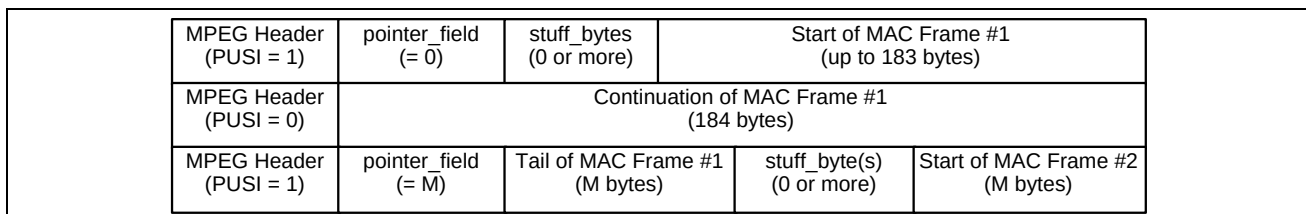


**Figure 5-6. Packet Format Where a MAC Frame Spans Multiple Packets**