Society of Cable Telecommunications Engineers

ENGINEERING COMMITTEE
(Data Standards Subcommittee)

AMERICAN NATIONAL STANDARD

ANSI/SCTE 135-1 2008

DOCSIS 3.0 Part 1: Physical Layer Specification

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1 SCOPE

1.1 Introduction and Purpose

This specification is part of the DOCSIS® family of specifications. In particular, this specification is part of a series of specifications that defines the third generation of high-speed data-over-cable systems. This specification was developed for the benefit of the cable industry, and includes 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. The other technology option is based on the corresponding European multi-program television distribution. Both options have the same status, notwithstanding that the document structure does not reflect this equal priority. The first of these options is defined in Sections 5 and 6, whereas the second is defined by replacing the content of those sections with the content of Annex B. Correspondingly, [ITU-T J.83-B] and [CEA-542-B] apply only to the first option, and [EN 300 429] only to the second. Compliance with this document requires compliance with the one or the other of these implementations, not with both. It is not required that equipment built to one option shall interoperate with equipment built to the other.

These optional physical-layer technologies allow operators flexibility in mandated areas of operation, including any frequency planning, EMC (electromagnetic compatibility), and safety requirements. For example, the 6 MHz downstream based option defined in Sections 5 and 6 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] and [FCC76] are relevant to North America and [EG 201 212], [EN 50083-1], [EN 50083-2], [EN 50083-7], [EN 50083-10], [EN 60950-1], [EN 61000-6-1], and [EN 61000-6-3] are relevant to the European Union.

Backwards compatibility with earlier versions of that technology [DOCSIS RFI 2.0] is only ensured within the same technology options referred to above and not between the two options.

1.2 Background

1.2.1 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 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 CM of 100 miles in each direction, 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 in each direction, although this would typically be limited to 15 miles.

At a propagation velocity in fiber of approximately 1.5 ns/ft, 100 miles of fiber in each direction results in a round-trip delay of approximately 1.6 ms.

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1.2.2 Network and System Architecture

1.2.2.1 The DOCSIS Network

The elements that participate in the provisioning of DOCSIS services are shown in the following figure:

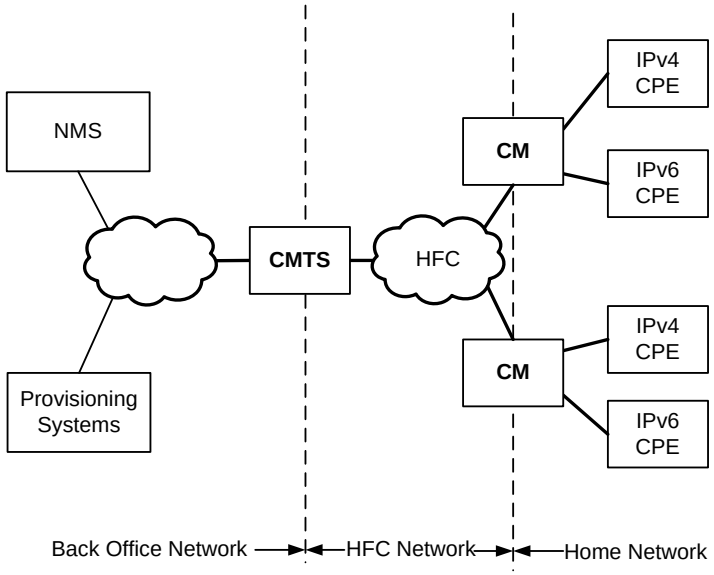

Figure 1-1 - The DOCSIS Network

The CM connects to the operator's HFC network and to a home network, bridging packets between them. Many CPEs' devices can connect to the CMs' LAN interfaces. CPE devices can be embedded with the CM in a single device, or they can be separate standalone devices, as shown in Figure 1-1. CPE devices may use IPv4, IPv6 or both forms of IP addressing. Examples of typical CPE devices are home routers, set-top devices, personal computers, etc.

The CMTS connects the operator's back office and core network with the HFC network. Its main function is to forward packets between these two domains, and between upstream and downstream channels on the HFC network.

Various applications are used to provide back office configuration and other support to the devices on the DOCSIS network. These applications use IPv4 and/or IPv6 as appropriate to the particular operator's deployment. The following applications include:

Provisioning Systems:

- The DHCP servers provide the CM with initial configuration information, including the device IP address(es), when the CM boots.
- The Config File server is used to download configuration files to CMs when they boot. Configuration files are in binary format and permit the configuration of the CM's parameters.
- The Software Download server is used to download software upgrades to the CM.
- The Time Protocol server provides Time Protocol clients, typically CMs, with the current time of day.
- Certificate Revocation server provides certificate status.

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NMS:

- The SNMP Manager allows the operator to configure and monitor SNMP Agents, typically the CM and the CMTS.
- The Syslog server collects messages pertaining to the operation of devices.
- The IPDR Collector server allows the operator to collect bulk statistics in an efficient manner.

1.2.3 Service Goals

As cable operators have widely deployed high-speed data services on cable television systems, the demand for bandwidth has increased. Additionally, networks have scaled to such a degree that IPv4 address constraints are becoming a burden on network operations. To this end, it was decided to add new features to the DOCSIS specification for the purpose of increasing channel capacity, enhancing network security, expanding addressability of network elements, and deploying new service offerings.

The DOCSIS system allows transparent bi-directional transfer of Internet Protocol (IP) traffic, between the cable system head-end and customer locations, over an all-coaxial or hybrid-fiber/coax (HFC) cable network. This is shown in simplified form in Figure 1-2.

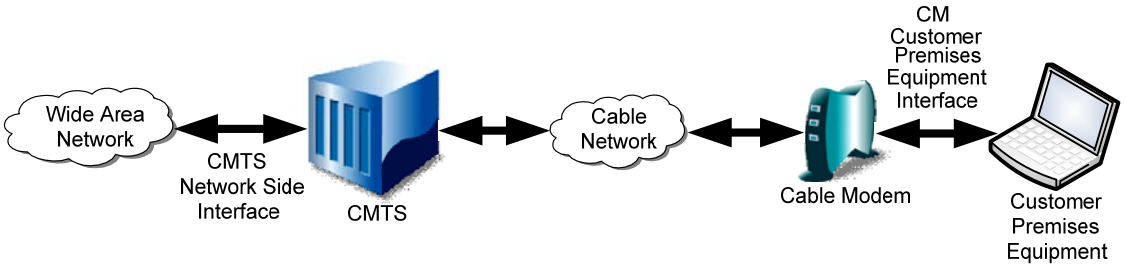

Figure 1-2 - Transparent IP Traffic Through the Data-Over-Cable System

1.2.4 Statement of Compatibility

This document specifies an interface, commonly referred to as DOCSIS 3.0, which is the third generation of the interface, commonly referred to as DOCSIS 1.x and 2.0. DOCSIS 3.0 MUST be backward- and forward-compatible with equipment built to the previous specifications. DOCSIS 3.0-compliant CMs MUST interoperate seamlessly with DOCSIS 2.0 and DOCSIS 1.x CMTSs, albeit in the 2.0 and 1.x modes, as the case may be. DOCSIS 3.0-compliant CMTSs MUST seamlessly support DOCSIS 2.0 and DOCSIS 1.x CMs.

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1.2.5 Reference Architecture

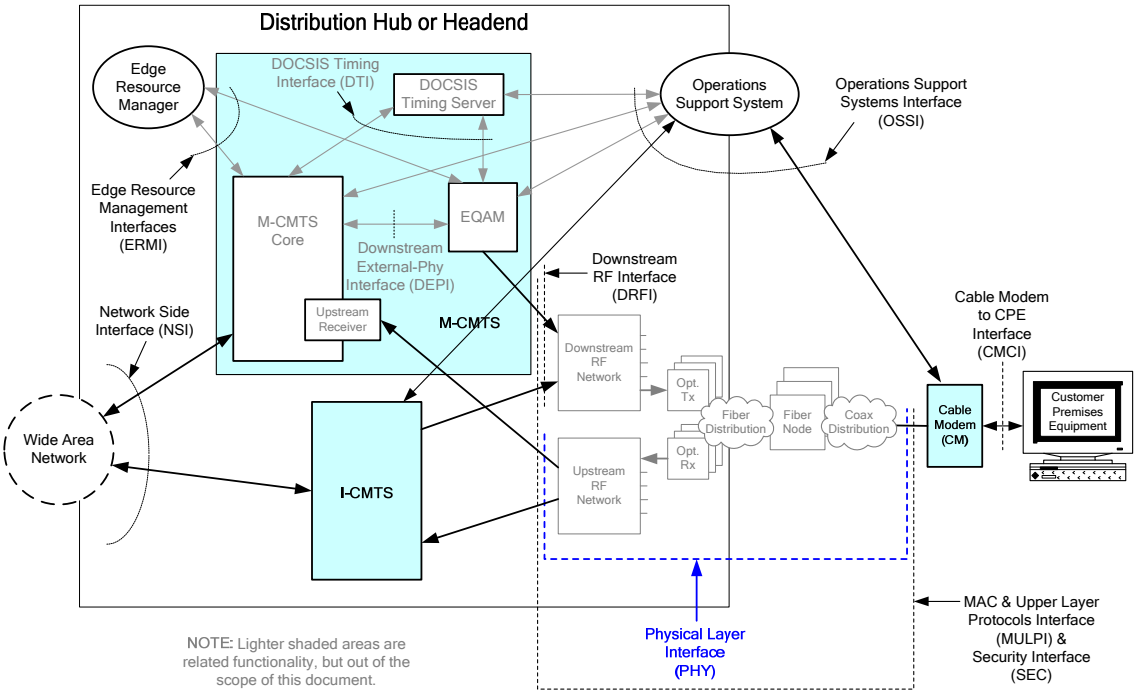

Figure 1-3 - Data-over-Cable Reference Architecture

The reference architecture for data-over-cable services and interfaces is shown in Figure 1-3.

1.2.6 DOCSIS 3.0 Documents

A list of the specifications in the DOCSIS 3.0 series is provided in Table 1-1. For further information, please refer to http://www.cablemodem.com.

Table 1-1 - DOCSIS 3.0 Series of Specifications

Designation	Title
SCTE 135-1	DOCSIS 3.0 Part 1: Physical Layer specification
SCTE 135-2	DOCSIS 3.0 Part 2: Media Access Control (MAC) and Upper Layer Protocols
SCTE 135-3	DOCSIS 3.0 Part 3: Security services
SCTE 135-4	DOCSIS 3.0 Part 4: Operations Support System Interface

This specification defines the interface for the physical layer.

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1.3 Requirements

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

"MUST"	This word means that the item is an absolute requirement of this specification.
"MUST NOT"	This phrase means that the item is an absolute prohibition of this specification.
"SHOULD"	This word means that there may exist valid reasons in particular circumstances to ignore this item, but the full implications should be understood and the case carefully weighed before choosing a different course.
"SHOULD NOT"	This phrase means that there may exist valid reasons in particular circumstances when the listed behavior is acceptable or even useful, but the full implications should be understood and the case carefully weighed before implementing any behavior described with this label.
"MAY"	This word means that this item is truly optional. One vendor may choose to include the item because a particular marketplace requires it or because it enhances the product, for example; another vendor may omit the same item.

This document defines many features and parameters, and a valid range for each parameter is usually specified. Equipment (CM and CMTS) requirements are always explicitly stated. Equipment must comply with all mandatory (MUST and MUST NOT) requirements to be considered compliant with this specification. Support of non-mandatory features and parameter values is optional.

1.4 Conventions

In this specification the following convention applies any time a bit field is displayed in a figure. The bit field should be interpreted by reading the figure from left to right, then, top to bottom, with the MSB being the first bit read and the LSB being the last bit read.

1.5 Organization of Document

Section 1 provides an overview of the DOCSIS 3.0 series of specifications including the DOCSIS reference architecture and statement of compatibility.

Section 2 includes a list of normative and informative references used within this specification.

Section 3 defines the terms used throughout this specification.

Section 4 defines the acronyms used throughout this specification.

Section 5 provides a technical overview and lists the DOCSIS 3.0 key features for the functional area of this specification.

Section 6 defines the interface requirements and the performance requirements for the CM downstream and upstream physical layer, and for the CMTS upstream physical layer.

Annex A describes the timing requirements for the CM and CMTS for supporting business services with cable systems using DOCSIS.

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Annex B contains the PHY requirements for the European technology option for DOCSIS.

Annex C contains the MPEG header synchronization and recovery requirements.

Appendix I presents an illustrative example of the DOCSIS upstream programmable preamble superstring.

Appendix II presents an algorithmic description of the subsymbol mapping for S-CDMA framing.

Appendix III describes the impact of temperature and wind loading on timing variation of the signaling across a cable plant, and the tolerances and impacts on the DOCSIS communications system to such variations.

Appendix IV contains example calculations for reporting from the CM to the CMTS the number of upstream active channels of various bandwidths supported by the CM.

Appendix V provides an explanation of the power control algorithm with multiple upstream channels.

Appendix VI provides examples illustrating the calculation of the CM noise power limits for the upstream when more than one channel is bursting.

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2 REFERENCES

2.1 Normative References

The following documents contain provisions, which, through reference in this text, constitute provisions of this standard. Intellectual property rights may be required to implement these references. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreement based on this standard are encouraged to investigate the possibility of applying the most recent editions of the documents listed below. Unless the title of a referenced document contains a specific release date or version, it is assumed that the most recently available version is to be used.

[CEA-542-B]	CEA-542-B: CEA Standard: Cable Television Channel Identification Plan," July 2003.
[DRFI]	SCTE 133, Downstream Radio Frequency Interface
[DTI]	SCTE 137-1, DOCSIS Timing Interface
[EG 201 212]	ETSI EG 201 212 V1.2.1: Electrical safety; Classification of interfaces for equipment to be connected to telecommunication networks, November 1998.
[EN 300 429]	ETSI EN 300 429 V1.2.1: Digital Video Broadcasting (DVB); Framing structure, channel coding and modulation for cable systems, April 1998.
[EN 50083-1]	CENELEC EN 50083-1: Cable networks for television signals, sound signals and interactive services -- Part 1: Safety requirements, 2002.
[EN 50083-10]	CENELEC EN 50083-10: Cable networks for television signals, sound signals and interactive services -- Part 10: System performance for return paths, March 2002.
[EN 50083-2]	CENELEC EN 50083-2: Cable networks for television signals, sound signals and interactive services -- Part 2: Electromagnetic compatibility for equipment, 2005.
[EN 50083-7]	CENELEC EN 50083-7: Cable networks for television signals, sound signals and interactive services -- Part 7: System performance, April 1996.
[EN 60950-1]	CENELEC EN 60950-1: Information technology equipment - Safety -- Part 1: General requirements, December 2001.
[EN 61000-6-1]	CENELEC EN 61000-6-4: Electromagnetic compatibility (EMC) -- Part 6-1: Generic standards - Immunity for residential, commercial and light-industrial environments, October 2001.
[EN 61000-6-3]	CENELEC EN 61000-6-3: Electromagnetic compatibility (EMC) -- Part 6-3: Generic standards - Emission standard for residential, commercial and light-industrial environments, 2003.
[FCC15]	Code of Federal Regulations, Title 47, Part 15, October 2005.
[FCC76]	Code of Federal Regulations, Title 47, Part 76, October 2005.
[ISO 13818]	ISO/IEC 13818-1, Information Technology – Generic Coding Of Moving Pictures And Associated Audio Systems Recommendation H.222.0, February 2000.
[ISO/IEC-61169-24]	ISO/IEC-61169-24, Radio-frequency connectors - Part 24: Sectional specification - Radio frequency coaxial connectors with screw coupling, typically for use in 75 ohm cable distribution systems (type F), 2001.
[ITU-T J.83-B]	Annex B to ITU-T Rec. J.83 (4/97), Digital multi-program systems for television sound and data services for cable distribution.
[MULPI]	SCTE 135-2, DOCSIS 3.0 Part 2: Media Access Control (MAC) and Upper Layer Protocols
[OSSI3.0]	SCTE 135-4, DOCSIS 3.0 Part 4: Operations Support System Interface Specification

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[DOCSIS RFI 2.0]	SCTE 79-1, DOCSIS 2.0 Part 1: Radio Frequency Interface
[SCTE 02]	ANSI/SCTE 02, Specification for "F" Port, Female Indoor, 2006.
[TEI]	SCTE 136-2, Business Services over DOCSIS Part 2: Cable Modem TDM Emulation Interface

2.2 Informative References

[CableLabs1]	Digital Transmission Characterization of Cable Television Systems, Cable Television Laboratories, Inc., November 1994. URL: http://www.cablelabs.com/downloads/digital_transmission.pdf
[NCTA]	NCTA Recommended Practices for measurements on Cable Television Systems – National Cable Television Association, Washington DC, 2nd Edition, revised October 1993.

2.3 Reference Acquisition

Cable Television Laboratories, Inc., http://www.cablelabs.com/

CENELEC: European Committee for Electro-technical Standardization, http://www.cenelec.org

EIA: Electronic Industries Alliance, http://www.eia.org/new_contact/

ETSI: European Telecommunications Standards Institute,
http://www.etsi.org/services_products/freestandard/home.htm

Internet Engineering Task Force (IETF), http://www.ietf.org/html/

ISO: International Organization for Standardization (ISO), http://www.iso.org/iso/en/xsite/contact/contact.html

ITU: International Telecommunications Union (ITU), http://www.itu.int/home/contact/index.html

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3 TERMS AND DEFINITIONS

This specification uses the following terms:

Active Codes	The set of spreading codes which carry information in an S-CDMA upstream. The complementary set, the unused codes, are idle and are not transmitted. Reducing the number of active codes below the maximum value of 128 may provide advantages including more robust operation in the presence of colored noise.
Allocation	A group of contiguous mini-slots in a MAP which constitutes a single transmit opportunity.
Availability	In cable television systems, availability is the long-term ratio of the actual RF channel operation time to scheduled RF channel operation time (expressed as a percent value) and is based on a bit error rate (BER) assumption.
Bandwidth Allocation Map (MAP)	The MAC Management Message that the CMTS uses to allocate transmission opportunities to cable modems (MAP).
Bit Error Rate (BER)	The percentage of bits that have errors relative to the total number of bits received in a transmission, usually expressed as ten to a negative power.
Burst	A single continuous RF signal from the upstream transmitter, from transmitter on to transmitter off.
Cable Modem (CM)	A modulator-demodulator at subscriber locations intended for use in conveying data communications on a cable television system. (CM).
Cable Modem Termination System (CMTS)	Cable modem termination system, located at the cable television system head-end or distribution hub, which provides complementary functionality to the cable modems to enable data connectivity to a wide-area network.
Capture Bandwidth (CBW)	The sum of the Tuning Bands in the TB List in MHz.
Carrier Hum Modulation	The peak-to-peak magnitude of the amplitude distortion relative to the RF carrier signal level due to the fundamental and low-order harmonics of the power-supply frequency.
Carrier-to-Noise Ratio (C/N) (CNR)	The ratio of signal power to noise power in the defined measurement bandwidth. For digital modulation, CNR = E_s/N_o, the energy-per-symbol to noise-density ratio; the signal power is measured in the occupied bandwidth, and the noise power is normalized to the modulation-rate bandwidth. For video, the measurement bandwidth is 4 MHz (C/N).
Channel	(See RF Channel.)
Channel Bonding	A logical process that combines the data packets received on multiple independent channels into one higher-speed data stream. Channel bonding can be implemented independently on upstream channels or downstream channels.
Chip	Each of the 128 bits comprising the S-CDMA spreading codes.
Chip Rate	The rate at which individual chips of the S-CDMA spreading codes are transmitted. (1280 to 5120 kHz). E_s/N_o.
Codeword	An element of an error-correcting code used to detect and correct transmission errors.
Codeword Error Rate	The ratio of the number of uncorrectable code words to the total number of code words sent without errors, with corrected errors and with uncorrectable errors.
Composite Second Order Beat (CSO)	The peak of the average level of distortion products due to second order nonlinearities in cable system equipment.

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Composite Triple Beat (CTB)	The peak of the average level of distortion components due to third-order nonlinearities in cable system equipment.
Cross-modulation	A form of television signal distortion where modulation from one or more television channels is imposed on another channel or channels.
Customer Premises Equipment (CPE)	Equipment at the end user's premises; may be provided by the end user or the service provider.
Decibel-Millivolt (dBmV)	A dB measurement system wherein 0 dBmV is defined as 1 millivolt over 75 ohms.
Decibels (dB)	A unit to measure the relative levels of current, voltage or power. An increase of 3 dB indicates a doubling of power, an increase of 10 dB indicates a 10x increase in power, and an increase of 20 dB indicates a 100x increase in power.
Demodulator Module	A physical entity in the CM that demodulates a block of one or more contiguous channels of a single bandwidth (6 MHz or 8 MHz) within the output from a single tuner.
Distribution Hub	A location in a cable television network which performs the functions of a head-end for customers in its immediate area, and which receives some or all of its television program material from a Master Head-end in the same metropolitan or regional area.
DOCSIS 1.x	Abbreviation for "DOCSIS 1.0 or 1.1." DOCSIS stands for Data-Over-Cable Service Interface Specifications.
DOCSIS 2.0 Mode	A CM operates in this mode when: 1) Multiple Transmit Channel (MTC) Mode is disabled; 2) the Enable 2.0 Mode configuration setting in the REG-RSP is set to 1 (Enable) explicitly or by default; and 3) it operates on at least one upstream channel using the burst descriptors associated with IUC 9, 10, and 11 as opposed to IUC 5 and 6. A CM is enabled for DOCSIS 2.0 Mode when the Enable 2.0 Mode configuration setting in the REG-RSP is set to 1 (Enable). A CM may be enabled for DOCSIS 2.0 Mode but may not be operating in DOCSIS 2.0 Mode. When a CM has MTC Mode enabled, the CM is not considered to be in DOCSIS 2.0 Mode even if some of the upstream channels it is using are operating with post-1.1 DOCSIS physical layer mechanisms. Therefore, "DOCSIS 2.0 Mode" does not have relevance for a CM operating in MTC Mode.
Downstream	In cable television, the direction of transmission from the head-end to the subscriber.
Downstream Channel	Physical layer characteristics and MAC layer parameters and functions associated to a DOCSIS forward channel.
Dynamic Host Configuration Protocol (DHCP)	An Internet protocol used for assigning network-layer (IP) addresses.
Dynamic Range	The ratio between the greatest signal power that can be transmitted over a multichannel analog transmission system without exceeding distortion or other performance limits, and the least signal power that can be utilized without exceeding noise, error rate or other performance limits.
Dynamic Range Window (DRW)	A 12 dB range defining the maximum power difference between multiple transmitters in a CM in Multiple Transmit Channel mode.
Electronic Industries Alliance (EIA)	A voluntary body of manufacturers which, among other activities, prepares and publishes standards.

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Extended Upstream Frequency Range	An optional upstream frequency range over which a CM may be capable of transmitting. In the technology option that uses 6 MHz downstream channelization, this is 5-85 MHz. In the technology option that uses 8 MHz downstream channelization, no Extended Upstream Frequency Range is defined.
F Connector (F conn)	A male F-connector is the final piece of hardware (familiar to subscribers) on a drop cable. It is cylindrical with a center pin sticking out that plugs into the female F-connector on a set-top box, cable ready TV or VCR.
Floor	A mathematical function that returns the highest-valued integer that is less than or equal to a given value.
Forward Channel	The direction of RF signal flow away from the head-end toward the end user; equivalent to Downstream.
Forward Error Correction (FEC)	FEC enables the receiver to detect and fix errors to packets without the need for the transmitter to retransmit packets.
Frame	See MAC frame, S-CDMA frame, and MPEG frame.
Frequency Division Multiple Access (FDMA)	A multiple access technology that separates users by putting each traffic channel on a discrete frequency band.
Group Delay	The difference in transmission time between the highest and lowest of several frequencies through a device, circuit or system.
Guard Band	Minimum time, measured in modulation symbols, allocated between bursts in the upstream referenced from the symbol center of the last symbol of a burst to the symbol center of the first symbol of the following burst. The guard band should be at least the duration of five symbols plus the maximum system timing error. The guard band should be at least the duration of five symbols plus the maximum system timing error.
Guard Time	Guard time, measured in modulation symbols, is similar to the guard band, except that it is measured from the end of the last symbol of one burst to the beginning of the first symbol of the preamble of an immediately following burst. Thus, the guard time is equal to the guard band – 1.
Harmonic Related Carrier (HRC)	A method of spacing television channels on a cable television system in exact 6 MHz increments, with all carrier frequencies harmonically related to a common reference.
Head-end	The central location on the cable network that is responsible for injecting broadcast video and other signals in the downstream direction. See also Master Head-End, Distribution Hub.
Header	Protocol control information located at the beginning of a protocol data unit.
Hertz (Hz)	A unit of frequency equivalent to one cycle per second. See also kilohertz (kHz) and megahertz (MHz).
Hum Modulation	Undesired modulation of the television visual carrier by the fundamental or low-order harmonics of the power supply frequency or other low-frequency disturbances.
Hybrid Fiber/Coaxial System (HFC)	A broadband bidirectional shared-media transmission system using fiber trunks between the head-end and the fiber nodes, and coaxial distribution from the fiber nodes to the customer locations.
Impulse Noise	Noise characterized by non-overlapping transient disturbances.
Incremental Related Carriers (IRC)	A method of spacing NTSC television channels on a cable television system in which all channels except 5 and 6 correspond to the standard channel plan, used to reduce composite triple beat distortions.

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Information Element	The fields that make up a MAP and define individual grants, deferred grants, etc.
International Electrotechnical Commission (IEC)	An international standards body.
International Organization for Standardization (ISO)	An international standards body, commonly known as the International Standards Organization.
Internet Engineering Task Force (IETF)	A body responsible, among other things, for developing standards used in the Internet.
Internet Protocol (IP)	The computer network protocol (analogous to written and verbal languages) that all machines on the Internet must know so that they can communicate with one another. IP is a layer 3 (network layer) protocol in the OSI model. The vast majority of IP devices today support IP version 4 (IPv4) defined in RFC-791, although support for IP version 6 (IPv6, RFC-2460) is increasing.
Internet Protocol Detail Record Service	The record formatter and exporter functions of the CMTS that creates the data record compliant to the IPDR/BSR based on the DOCSIS schemas.
Interval Usage Code (IUC)	A field in MAPs and UCDs to link burst profiles to grants.
Jitter	The fluctuation in the arrival time of a regularly scheduled event such as a clock edge or a packet in a stream of packets. Jitter is defined as fluctuations above 10 Hz.
Latency	The time taken for a signal element to pass through a device.
Layer	A subdivision of the Open System Interconnection (OSI) architecture, constituted by subsystems of the same rank.
Local Area Network (LAN)	A non-public data network in which serial transmission is used for direct data communication among data stations located on the user's premises.
Logical (Upstream) Channel	A MAC entity identified by a unique channel ID and for which bandwidth is allocated by an associated MAP message. A physical upstream channel may support multiple logical upstream channels. The associated UCD and MAP messages completely describe the logical channel.
MAC Frame	MAC header plus optional protocol data unit.
Maximum Downstream Bonded Channels (MDBC)	Maximum number of downstream bonded channels supported by the cable modem. (See Channel Bonding).
Media Access Control (MAC)	The MAC sublayer is the part of the data link layer that supports topology-dependent functions and uses the services of the Physical Layer to provide services to the Logical Link Control (LLC) sublayer. It can also be a component of a networking software stack. In the OSI 7-layer model, the Media Access Control is a part of layer 2, the data link layer.
Megahertz (MHz)	One million cycles per second.
Micro-reflections	Echoes in the forward or reverse transmission path due to impedance mismatches between the physical plant components. Micro-reflections are distinguished from discrete echoes by having a time difference (between the main signal and the echo) on the order of one microsecond. Micro-reflections cause departures from ideal amplitude and phase characteristics for the transmission channel.
Microsecond (µs)	One millionth of a second.
Microvolt (µV)	One millionth of a volt.
Millisecond (ms)	One thousandth of a second.
Millivolt (mV)	One thousandth of a volt.

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Mini-slot	A mini-slot is an integer multiple of 6.25 µs increments.
Modulation Error Ratio (MER)	MER measures the cluster variance in dB caused by the transmit waveform. It includes the effects of ISI, spurious, phase noise, and all other transmitter degradations.
Modulation Rate	The signaling rate of the upstream modulator (1280 to 5120 kHz). In S-CDMA it is the chip rate. In TDMA, it is the channel symbol rate.
Nanosecond	One millionth of a second.
National Cable Telecommunications Association (NCTA)	A voluntary association of cable television operators which, among other things, provides guidance on measurements and objectives for cable television systems in the USA.
National Television Systems Committee (NTSC)	Committee which defined the analog color television broadcast standard used today in North America.
Number of Allocated Codes	The total number of codes which a single CM uses in a single S-CDMA frame. This number is determined by the size of the grants in mini-slots and the mapping of these mini-slots to S-CDMA frames (note that a CM may receive multiple grants which are mapped to a single S-CDMA frame). The number of allocated codes can be in the range of the number of Codes per Mini-slot to the number of active codes, and may vary from frame to frame, but is constant within an S-CDMA frame.
Phase Noise	Rapid, short-term, random fluctuations in the phase of a wave, caused by time domain instabilities.
Physical Layer	Layer 1 in the Open System Interconnection (OSI) architecture; the layer that provides services to transmit bits or groups of bits over a transmission link between open systems and which entails electrical, mechanical and handshaking procedures (PHY).
Physical Media Dependent Sublayer (PMD)	A sublayer of the Physical Layer which is concerned with transmitting bits or groups of bits over particular types of transmission link between open systems and which entails electrical, mechanical and handshaking procedures (PMD).
Picosecond (ps)	One trillionth of a second.
Primary Channel	See Primary Downstream Channel.
Primary Downstream Channel	The downstream channel from which a CM derives CMTS master clock timing for upstream transmission. All other concurrently received channels are called "secondary downstream channels."
Protocol	A set of rules and formats that determines the communication behavior of layer entities in the performance of the layer functions.
Quadrature Amplitude Modulation (QAM)	A method of modulating digital signals onto a radio-frequency carrier signal involving both amplitude and phase coding.
Quadrature Phase Shift Keying (QPSK)	A method of modulating digital signals onto a radio-frequency carrier signal using four phase states to code two digital bits.
Radio Frequency (RF)	In cable television systems, electromagnetic signals in the range 5 to 1000 MHz (RF).
Radio Frequency Channel (RFC)	The frequency spectrum occupied by a signal. Usually specified by center frequency and bandwidth parameters.
Return Loss	The parameter describing the attenuation of a guided wave signal (e.g., via a coaxial cable) returned to a source by a device or medium resulting from reflections of the signal generated by the source.
Reverse Channel	The direction of signal flow towards the head-end, away from the subscriber; equivalent to Upstream.

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Root Mean Square (RMS)	A mathematical method of computing an "average" magnitude of n elements by taking the square root of the mean of the elements squared.
S-CDMA Frame	A two dimensional representation of mini-slots, where the dimensions are codes and time. An S-CDMA frame is composed of p active codes in the code dimension and K spreading intervals in the time dimension. Within the S-CDMA frame, the number of mini-slots is determined by the number of codes per mini-slot (c) and p, the number of active codes in the S-CDMA frame. Each S-CDMA frame thus contains s mini-slots, where s=p/c, and each mini-slot contains c*K information (QAM) symbols.
S-CDMA Subframe	A subframe is a vertically-smaller subset of an S-CDMA frame over which interleaving is performed, where the vertical dimension is R' codes, where R' ≤ p (the number of active codes). A subframe is generally used to constrain the interleaving region to be of a similar size to the Reed-Solomon codeword in order to provide protection from impulse noise.
Selectable Active Codes (SAC)	A methodology to determine the set of active codes and its complement, the set of unused codes. In SAC mode 1, a consecutive set of codes starting with code 0 are unused. In SAC mode 2, the active codes are selectable via a 128-bit string.
Service Identifier (SID)	A Service Flow Identifier assigned by the CMTS (in addition to a Service Flow Identifier) to an Active or Admitted Upstream Service Flow. [14 bits] (SID).
Spread Symbol	At the output of the spreader, a group of 128 chips which comprises a single S-CDMA spreading code, and is the result of spreading a single information (QAM constellation) symbol, which is referred to as a "spread symbol."
Spreader-Off S-CDMA Burst	A transmission from a single CM in a spreader-off frame on an S-CDMA channel defined by the time in which the cable modem's transmitter turns on to the time it turns off. There will generally be several spreader off bursts in a spreader-off frame.
Spreader-Off S-CDMA Frame	TDMA mini-slots on an S-CDMA channel in which the spreader is turned off. These are differentiated from TDMA bursts on a TDMA channel in that, for example, the number of mini-slots per spreader-off S-CDMA burst frame is constrained to be the same as the number of mini-slots in a spreader-on S-CDMA frame (s). This number of mini-slots will be less than the number of TDMA mini-slots in a TDMA channel over the same time interval if the number of active codes is significantly less than 128.
Spreading Codes	A family of orthogonal digital code words used in S-CDMA direct-sequence spread-spectrum modulation.
Spreading Interval	The period of a spread symbol (128 chips) is called a "spreading interval."
Standard Upstream Frequency Range	The required upstream frequency range over which a CM is to be capable of transmitting. In the technology option that uses 6 MHz downstream channelization, this is 5-42 MHz. In the technology option that uses 8 MHz downstream channelization, this is 5-65 MHz.
Sublayer	A subdivision of a layer in the Open System Interconnection (OSI) reference model.
Subscriber	(See End User).
Synchronous-Code Division Multiple Access (S-CDMA)	A multiple access physical layer technology in which different transmitters can share a channel simultaneously. The individual transmissions are kept distinct by assigning each transmission an orthogonal "code." Orthogonality is maintained by all transmitters being precisely synchronized with one another.

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Tick	6.25 µs time intervals that are the reference for upstream mini-slot definition and upstream transmission times.
Time Division Multiple Access (TDMA)	A digital technology that enables a large number of users to access, in sequence, a single radio frequency channel without interference by allocating unique time slots to each user within each channel.
Transit Delay	The time difference between the instant at which the first bit of a PDU crosses one designated boundary, and the instant at which the last bit of the same PDU crosses a second designated boundary.
Tuner Module	A physical entity in the CM that converts a block of one or more contiguous channels of a single bandwidth (6 MHz or 8 MHz) from the RF input from the cable plant to an intermediate frequency suitable for distribution to a Demodulator Module.
Tuning Band (TB)	Defines a single continuous frequency interval, in MHz, located anywhere in the downstream band (108 MHz to 870 MHz, with a CM option of tuning downstream 108 MHz to 1002 MHz).
Tuning Band List (TB List)	A list of one or more Tuning Bands supported by the CM that defines the cable modem tuning capabilities.
Type/Length/Value (TLV)	An encoding of three fields, in which the first field indicates the type of element, the second the length of the element, and the third field the value of the element.
Upstream	The direction from the subscriber location toward the head-end.
Upstream Channel	Physical layer characteristics and MAC layer parameters and functions associated to a DOCSIS reverse channel.
Upstream Channel Descriptor (UCD)	The MAC Management Message used to communicate the characteristics of the upstream physical layer to the cable modems.

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4 ABBREVIATIONS AND ACRONYMS

This specification uses the following abbreviations:

ANSI	American National Standards Institute
AWGN	Additive White Gaussian Noise
BER	Bit Error Rate
CableLabs	Cable Television Laboratories
CBW	Capture Bandwidth
CENELEC	European Committee for Electrotechnical Standardization
CL	CableLabs
CM	Cable Modem
CMTS	Cable Modem Termination System
CNR	Carrier-to-Noise Ratio
C/N	Carrier-to-Noise Ratio
CPE	Customer Premises Equipment
CRC	Cyclic Redundancy Check
CSO	Composite Second Order Composite Second Order Beat
CTB	Composite Triple Beat
CW	Continuous Wave
dB	Decibel
DBC-REQ	Dynamic Bonding Change Request MAC Message
dBc	Decibels relative to carrier power
DHCP	Dynamic Host Configuration Protocol
DOCSIS	Data-Over-Cable Service Interface Specifications
DOCSIS 1.x	Data-Over-Cable Service Interface Specifications version 1.0 or 1.1
DRFI	Downstream Radio Frequency Interface
DRW	Dynamic Range Window
DS	Downstream
DTI	DOCSIS Timing Interface
EC	Errors Corrected
EIA	Electronic Industries Association
ETSI	European Telecommunications Standards Institute
EU	Errors Uncorrectable
FCC	Federal Communications Commission
FDMA	Frequency Division Multiple Access
FEC	Forward Error Correction
FC	Frame Control
FM	Frequency Modulation
GF	Galois Field
HFC	Hybrid Fiber-Coaxial

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HRC	Harmonic Related Carrier
I	In-phase modulation component
ICMP	Internet Control Message Protocol
IE	Information Element
IEC	International Electrotechnical Commission
IETF	Internet Engineering Task Force
IP	Internet Protocol
IPDR	Internet Protocol Detail Record
IPv4	Internet Protocol version 4
IPv6	Internet Protocol version 6
IRC	Incremental Related Carrier(s)
ISO	International Standards Organization
ITU	International Telecommunications Union
ITU-T	Telecommunication Standardization Sector of the International Telecommunication Union
IUC	Interval Usage Code
LAN	Local Area Network
LFSR	Linear Feedback Shift Register
LLC	Logical Link Control
LSB	Least Significant Bit
MAC	Media Access Control
M-CMTS	Modular Cable Modem Termination System
MDBC	Maximum Downstream Bonded Channels
MDD	MAC Domain Descriptor
MER	Modulation Error Ratio
MIB	Management Information Base
M/N	Relationship of integer numbers M,N that represents the ratio of the downstream symbol clock rate to the DOCSIS master clock rate
MPEG	Moving Picture Experts Group
MSB	Most Significant Bit
MSC	Maximum Scheduled Codes
MTC	Multiple Transmit Channel
MULPI	MAC and Upper Layer Protocols Interface
NA	Number of active codes
NACO	Network Access Control Object
NCTA	National Cable & Telecommunications Association
NMS	Network Management System
ns	Nanosecond
NTSC	National Television Systems Committee
OCAP	Open Cable Application Platform
OSI	Open Systems Interconnection
PAL	Phase Alternating Line

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PAR	Peak to Average Ratio
PDU	Protocol Data Unit
PHY	Physical Layer
PLL	Phase-Locked Loop
PMD	Physical Media Dependent sublayer
PRS	Primary Reference Source
Q	Quadrature modulation component
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
RCC	Receive Channel Configuration
RCP	Receive Channel Profile
REG-REQ	Registration Request MAC Message
RF	Radio Frequency
RFC	Request For Comments
RFI	Radio Frequency Interface
RM	Receive Module
RMS	Root Mean Square
RNG-RSP	Ranging Response MAC Message
RS	Symbol rate
SAC	Selectable Active Codes
S-CDMA	Synchronous Code Division Multiple Access
SCTE	Society of Cable Telecommunications Engineers
SECAM	Séquentiel couleur à mémoire (Sequential color with memory)
SID	Service Identifier
SNMP	Simple Network Management Protocol
STD	Standard Channel Plan
TB	Tuning Band
TCS	Transmit Channel Set
TDM	Time Division Multiplexing
TDMA	Time Division Multiple Access
TE-CMTS	Time Division Multiplexing Emulation Cable Modem Termination System
TEI	TDM Emulation Interface
TLV	Type/Length/Value
TV	Television
TCM	Trellis Code Modulation
TSP	Time Division Multiplexing Service Processor
UCD	Upstream Channel Descriptor
UGS	Unsolicited Grant Service
XOR	Exclusive Or

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5 FUNCTIONAL ASSUMPTIONS

This section describes the characteristics of a cable television plant, assumed to be for the purpose of operating a data-over-cable system. It is not a description of CMTS or CM parameters. The data-over-cable system MUST be interoperable within the environment described in this section.

Whenever a 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.

5.1 Equipment Assumptions

5.1.1 Frequency Plan

In the downstream direction, the cable system is assumed to have a pass band with a lower edge of either 54 MHz or 108 MHz, and an upper edge that is implementation-dependent but is typically in the range of 300 to 1002 MHz. Within that pass band, NTSC analog television signals in 6 MHz channels are assumed present on the standard, HRC or IRC frequency plans of [CEA-542-B], as well as other narrowband and wideband digital signals.

In the upstream direction, the cable system may have a 5-30 MHz, 5-42 MHz or 5-85 MHz pass band. NTSC analog television signals in 6 MHz channels may be present, as well as other signals.

5.1.2 Compatibility with Other Services

The CM and CMTS MUST coexist with any services on the cable network.

In particular,

CM and CMTS MUST be interoperable in the cable spectrum assigned for CMTS and CM interoperation while the balance of the cable spectrum is occupied by any combination of television and other signals; and

CM and CMTS 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.

Harmful interference is understood as:

- No measurable degradation (highest level of compatibility),
- No degradation below the perceptible level of impairments for all services (standard or medium level of compatibility), or
- No degradation below the minimal standards accepted by the industry (for example, FCC for analog video services) or other service provider (minimal level of compatibility).

5.1.3 Fault Isolation Impact on Other Users

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

For the interpretation of harmful impact, see Section 5.1.2 above.

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5.1.4 Cable System Terminal Devices

The CM MUST meet and preferably exceed all applicable regulations for Cable System Termination Devices and Cable Ready Consumer Equipment as defined in FCC Part 15 [FCC15] and Part 76 [FCC76]. None of these specific requirements may be used to relax any of the specifications contained elsewhere within this document.

5.2 RF Channel Assumptions

The data-over-cable system, configured with at least one set of defined physical-layer parameters (e.g., modulation, interleaver depth, etc.) from the range of configurable settings described in this specification, MUST be interoperable on cable networks having characteristics defined in this section. This is accomplished in such a manner that the forward error correction provides for equivalent operation in a cable system both with and without the impaired channel characteristics, described below.

5.2.1 Transmission Downstream

The RF channel transmission characteristics of the cable network in the downstream direction are described in Table 5-1. These numbers assume total average power of a digital signal in a 6 MHz channel bandwidth for carrier levels unless indicated otherwise. For impairment levels, the numbers in Table 5-1 assume average power in a bandwidth in which the impairment levels are measured in a standard manner for a cable TV system. For analog signal levels, the numbers in Table 5-1 assume peak envelope power in a 6 MHz channel bandwidth. All conditions are present concurrently. No combination of the following parameters will exceed any stated interface limit defined elsewhere in this specification.

Table 5-1 - Assumed Downstream RF Channel Transmission Characteristics

Parameter	Value
Frequency range	Cable system normal downstream operating range is from 50 MHz to 1002 MHz. However, the values in this table apply only at frequencies ≥ 108 MHz (including Pre-3.0 DOCSIS modes).
RF channel spacing (design bandwidth)	6 MHz
Transit delay from head-end to most distant customer	≤ 0.800 ms (typically much less)
Carrier-to-noise ratio in a 6 MHz band	Not less than 35 dB[1,2]
Carrier-to-Composite triple beat distortion ratio	Not less than 41 dB[1,2]
Carrier-to-Composite second order distortion ratio	Not less than 41 dB[1,2]
Carrier-to-Cross-modulation ratio	Not less than 41 dB[1,2]
Carrier-to-any other discrete interference (ingress)	Not less than 41 dB[1,2]
Amplitude ripple	3 dB within the design bandwidth[1]
Group delay ripple in the spectrum occupied by the CMTS	75 ns within the design bandwidth[1]
Micro-reflections bound for dominant echo	-10 dBc @ ≤ 0.5 µs -15 dBc @ ≤ 1.0 µs -20 dBc @ ≤ 1.5 µs -30 dBc @ > 1.5 µs[1]
Carrier hum modulation	Not greater than -26 dBc (5%)[1]
Burst noise	Not longer than 25 µs at a 10 Hz average rate[1]

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Parameter	Value
Maximum analog video carrier level at the CM input	17 dBmV
Maximum number of analog carriers	121

1. Measurement methods defined in [NCTA] or [CableLabs1].
2. Measured relative to a QAM signal that is equal to the nominal video level in the plant.

5.2.2 Transmission Upstream

The RF channel transmission characteristics of the cable network in the upstream direction are described in Table 5-2. No combination of the following parameters will exceed any stated interface limit defined elsewhere in this specification. Transmission is from the CM output at the customer location to the head-end.

Table 5-2 - Assumed Upstream RF Channel Transmission Characteristics

Parameter	Value
Frequency range	5 to 42 MHz edge to edge or 5 to 85 MHz edge to edge
Transit delay from head-end to most distant customer	≤ 0.800 ms (typically much less)
Carrier-to-interference plus ingress (the sum of noise, distortion, common-path distortion and cross modulation and the sum of discrete and broadband ingress signals, impulse noise excluded) ratio	Not less than 25 dB[1]
Carrier hum modulation	Not greater than -23 dBc (7.0%)
Burst noise	Not longer than 10 µs at a 1 KHz average rate for most cases[2,3]
Amplitude ripple across upstream operating frequency range	0.5 dB/MHz
Group delay ripple across upstream operating frequency range	200 ns/MHz
Micro-reflections – single echo	-10 dBc @ ≤ 0.5 µs -20 dBc @ ≤ 1.0 µs -30 dBc @ > 1.0 µs
Seasonal and diurnal reverse gain (loss) variation	Not greater than 14 dB min to max

1. 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 10 dBc. The ratios are guaranteed only within the digital carrier channels.
2. Amplitude and frequency characteristics sufficiently strong to partially or wholly mask the data carrier.
3. Impulse noise levels more prevalent at lower frequencies (<15 MHz).

5.2.2.1 Availability

Typical cable network availability is considerably greater than 99%.

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5.3 Transmission Levels

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.

5.4 Frequency Inversion

There will be no frequency inversion in the transmission path in either the downstream or the 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.

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6 PHYSICAL MEDIA DEPENDENT SUBLAYER SPECIFICATION

6.1 Scope

This section applies to the first technology option referred to in Section 1.1. For the second option, refer to Annex B.

This specification defines the electrical characteristics and signal processing operations 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.

6.2 Upstream

6.2.1 Overview

The upstream Physical Media Dependent (PMD) sublayer uses an FDMA/TDMA (herein called TDMA mode) or FDMA/TDMA/S-CDMA (herein called S-CDMA mode) burst type format, which provides six modulation rates and multiple modulation formats. The use of TDMA or S-CDMA mode is configured by the CMTS via MAC messaging.

FDMA (frequency division multiple access) indicates that multiple RF channels are assigned in the upstream band. A CM transmits on one or more RF channels and may be reconfigured to change channels.

A CM MUST support at least four active upstream channels (which are referred to as the Transmit Channel Set for that CM).

The CM reports its maximum number of upstream channels capability, and certain other of its capability characteristics, to the CMTS (Section 6.2.25).

The CM MUST be able to operate each channel in the Transmit Channel Set, simultaneously, anywhere in the upstream band, subject to restrictions on transmit power across the channels and on reconfiguration of certain transmit properties (see Sections 6.2.19 and 6.2.20, and subsections of each). The CMTS MUST be capable of assigning and receiving each RF channel anywhere in the upstream band. The CMTS MUST set the number of assigned channels and assigned channels' center frequency, and all other channel attributes. The CMTS MAY change the number of assigned channels and the channel attributes. Each RF channel has its own set of UCD parameters as defined in [MULPI].

TDMA (time division multiple access) indicates that upstream transmissions have a burst nature. A given RF channel is shared by multiple CMs via the dynamic assignment of time slots. S-CDMA (synchronous code division multiple access) indicates that multiple CMs can transmit simultaneously on the same RF channel and during the same TDMA time slot, while being separated by different orthogonal codes.

In this document, the following naming conventions are used. For TDMA, the term "modulation rate" refers to the RF channel symbol rate (160 to 5120 ksym/s). For S-CDMA, the term "modulation rate" refers to the "chip rate," which is the rate (1280 to 5120 kHz) of the individual elements (chips) of the S-CDMA spreading code. Modulation rates are represented in units of "Hz" denoting the number of symbols per second in TDMA mode or the number of chips per second in S-CDMA mode. The "modulation interval" is the symbol period (TDMA mode) or chip period (S-CDMA mode) and is the reciprocal of the modulation rate. At the output of the spreader, a group of 128 chips which comprise a single S-CDMA spreading code, and are the result of spreading a single information (QAM constellation) symbol is referred to as a "spread symbol." The period of a spread symbol (128 chips) is called a

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"spreading interval." A "burst" is a physical RF transmission that contains a single preamble plus data, and (in the absence of preceding and following bursts) exhibits RF energy ramp-up and ramp-down.

In some cases logical zeros or logical ones are used to pad data blocks; this indicates data with zero-valued or one-valued binary bits, which result in non-zero transmitted RF energy. In other cases a numerical zero is used; this denotes, for example, symbols which result in zero transmitted RF energy (after ramp-up and ramp-down are taken into account).

The modulation format includes pulse shaping for spectral efficiency, is carrier-frequency agile, and has selectable output power level.

Each burst supports a flexible modulation order, modulation 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. In TDMA mode, 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 band 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 6.2.20.1. Maximum timing error and guard band may vary with CMTSs from different vendors. The term guard time is similar to the guard band, except that it is measured from the end of the last symbol of one burst to the beginning of the first symbol of the preamble of an immediately following burst. Thus, the guard time is equal to the guard band – 1.

The PMD sublayer also supports a synchronous mode of transmission when using S-CDMA, wherein ramp-down of one burst MAY completely overlap the ramp-up of the following burst, so that the transmitted envelope is never zero. There is no guard time for transmission on S-CDMA channels. The system timing of the S-CDMA transmissions from the various CMs MUST provide adequate timing accuracy so that different CMs do not appreciably interfere with each other. S-CDMA utilizes precise synchronization so that multiple CMs can transmit simultaneously.

The upstream modulator is part of the cable modem which interfaces with the cable network. The modulator contains the electrical-level modulation function and the digital signal-processing function; the latter provides the FEC, preamble prepend, symbol mapping, and other processing steps.

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

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, may provide 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. 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

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in each codeword. For every upstream burst, the CMTS has a prior knowledge of the exact burst length in modulation intervals (see Sections 6.2.5.1, 6.2.5.2, 6.2.6, 6.2.20, and [MULPI], in the MAC Service ID section).

6.2.2 Signal Processing Requirements

The signal processing order for each burst packet type MUST be compatible with the sequence shown in Figure 6-1. For TDMA mode, the signal processing order for each burst packet type MUST follow the order of steps in Figure 6-2. For S-CDMA mode, the signal processing order for each burst packet type MUST follow the order of steps in Figure 6-3.

The blocks used only in S-CDMA consist of a TCM encoder, S-CDMA framer, and S-CDMA spreader. The TCM encoder provides trellis modulation encoding of data symbols and is described in Section 6.2.9. The S-CDMA framer maps mini-slots into code resources, provides interleaving of data symbols, and is described in Section 6.2.11.2. The S-CDMA spreader spreads S-CDMA framed symbols for transmission and is described in Section 6.2.15, "S-CDMA Spreader."

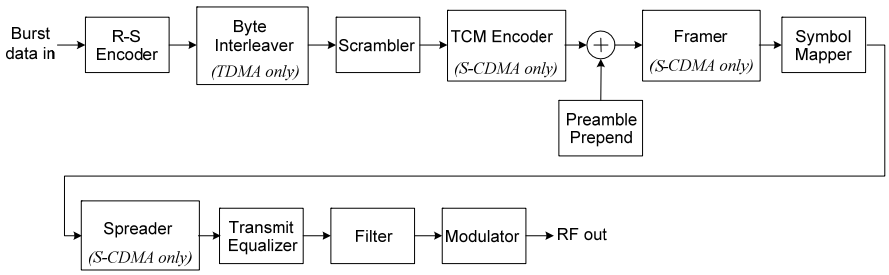

Figure 6-1 - Upstream Signal-Processing Sequence

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	Packet Stream Input ⇓
Block the Data	Separate Packet into Information Blocks (=data bytes in one codeword) ⇓
R-S Encode	R-S (Reed-Solomon) Encode each Information Block, using shortened codeword for last block if needed. R-S FEC can be turned off. ⇓
Byte Interleave	R-S Byte Interleave. R-S Byte interleaver can be turned off. ⇓
Scramble	Scramble (see Figure 6-8) ⇓
Preamble Prepend	Prepend Preamble Symbols ⇓
Symbol Map	Map the Data Stream into Modulator Symbols ⇓
Transmit Equalize	Pre-Equalize the Symbol Stream ⇓
Filter	Filter Symbol Stream for Spectral Shaping ⇓
Modulate	Modulate at Precise Times (QPSK; 8 QAM; 16 QAM; 32 QAM; 64 QAM) ⇓
	Output RF Waveform Bursts ⇓

Figure 6-2 - TDMA Upstream Transmission Processing

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	Packet Stream Input ⇓
Block the Data	Separate Packet into Information Blocks (=data bytes in one codeword) ⇓
R-S Encode	R-S (Reed-Solomon) Encode each Information Block, using shortened codeword for last block if needed. R-S FEC can be turned off. ⇓
Scramble	Scramble (see Figure 6-8) ⇓
TCM Encode	TCM (Trellis Coded Modulation) Encode the bytes. TCM can be turned off. ⇓
Preamble Prepend	Prepend Preamble Symbols ⇓
S-CDMA Framer	Frame and Interleave the Data into Mini-slots. ⇓
Symbol Map	Map the Data Stream into Modulator Symbols ⇓
S-CDMA Spreader	Spread the Symbols. For spreader-off bursts on S-CDMA channels, spreader can be turned off. ⇓
Transmit Equalize	Pre-Equalize the Signal Stream ⇓
Filter	Filter Signal for Spectral Shaping ⇓
Modulate	Modulate at Precise Times (QPSK; 8 QAM; 16 QAM; 32 QAM; 64 QAM; 128 QAM/TCM only). ⇓
	Output RF Waveform Bursts

Figure 6-3 - S-CDMA Upstream Transmission Processing

6.2.3 Modulation Formats

The upstream modulator MUST provide QPSK and 16 QAM differential encoded modulations for TDMA.

The upstream modulator MUST provide QPSK, 8 QAM, 16 QAM, 32 QAM, and 64 QAM modulations for TDMA and S-CDMA channels.

The upstream modulator MUST provide QPSK, 8 QAM, 16 QAM, 32 QAM, 64 QAM, and 128 QAM TCM encoded modulations for S-CDMA channels.

The upstream demodulator MAY support QPSK, and 16 QAM differential modulation for TDMA.

The upstream demodulator MUST support QPSK, 16 QAM, and 64 QAM modulations for TDMA and S-CDMA channels.

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The upstream demodulator MAY support 8 QAM and 32 QAM modulation for TDMA and S-CDMA channels.

The upstream demodulator MAY support QPSK, 8 QAM, 16 QAM, 32 QAM, 64 QAM, and 128 QAM TCM encoded modulations for S-CDMA channels.

6.2.4 R-S Encode

6.2.4.1 R-S Encode Modes

The upstream modulator MUST be able to provide the following selections: Reed-Solomon codes over GF(256) with T = 1 to 16 or no R-S coding.

The following Reed-Solomon generator polynomial MUST be supported:

$$g(x) = (x+\alpha^0)\,(x+\alpha^1)...(x+\alpha^{2T-1})$$

where the primitive element alpha is 0x02 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 code words 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 minimum uncoded word size MUST be 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 Sections 6.2.5.1.3 and 6.2.6.

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

6.2.4.2 R-S 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: The MAC byte-to-serial upstream convention calls for the byte LSB to be mapped into the first bit of the serial bit stream.

6.2.5 Upstream R-S Frame Structure for DOCSIS 3.0 Multiple Transmit Channel mode Enabled

This section applies to CMs operating in DOCSIS 3.0 Multiple Transmit Channel mode enabled in the upstream direction.

Figure 6-4 shows two examples of the R-S 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 code words. Example 1 illustrates the fixed codeword-length mode, and Example 2 illustrates the shortened last codeword mode. These modes are defined in Section 6.2.5.1.

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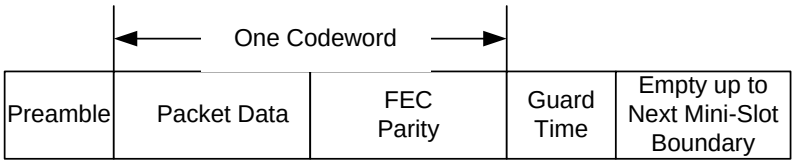
Example 1. Packet length = number of information bytes in codeword = k



Example 2. Packet length = k + remaining information bytes in 2nd codeword = k + k' ≤ k + k" ≤ 2k

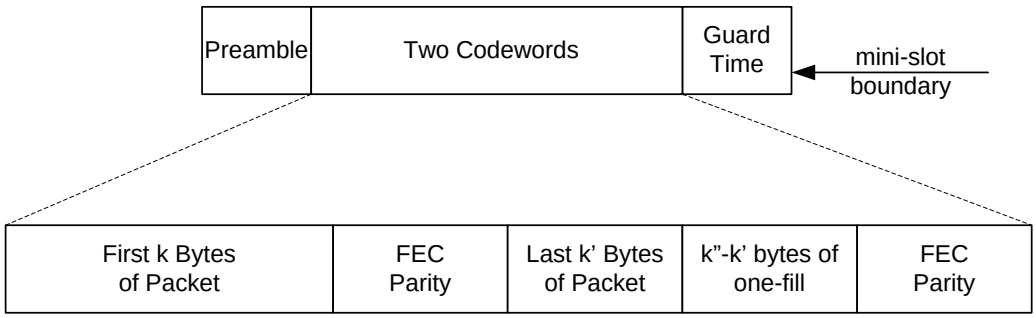


Figure 6-4 - Example Frame Structures with Flexible Burst Length Mode, DOCSIS 3.0 Operation

6.2.5.1 R-S Codeword Length

When R-S FEC is enabled, the CM operates in either fix-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 intent of the following sections is to define rules and conventions such that the CMTS PHY knows what to expect regarding the R-S FEC framing in both fixed codeword length and shortened last codeword modes. Shortened last codeword mode MUST NOT be used for Initial Maintenance (broadcast or unicast).

6.2.5.1.1 Burst Size

For an allocation of mini-slots (in both contention and non-contention regions), the requirements of Sections 6.2.5.1.2 and 6.2.5.1.3 apply to a burst transmitted in that allocation. Regardless of the size of the allocation, the size of the burst MUST be as specified in Table 6-1 below.

Table 6-1 - Burst Size

IUC	Burst Size
1, 3	Minimum number of mini-slots required for message transmission including burst overhead. Burst overhead includes pre-amble, R-S parity bytes, TCM return-to-zero bits, and guard time if applicable.
2	Number of mini-slots specified in the Well-Known Multicast SID.
4-6, 9-11	Number of mini-slots allocated.

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6.2.5.1.2 Fixed Codeword Length

With the fixed-length code words, after all the data are encoded, one-fill MUST occur in this codeword if necessary to reach the assigned k data bytes per codeword. Additionally, one-fill MUST continue up to the point when no additional fixed-length code words can be inserted before the end of the burst specified in Table 6-1 above, accounting for preamble, FEC parity, return-to-zero bits, and guard-time symbols (if any).

6.2.5.1.3 Shortened Last Codeword

As shown in Figure 6-4, let k' = the number of information bytes that remain after partitioning the information bytes of the burst into full-length (k burst data bytes) code words. 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 one-fill bytes in the shortened last codeword. In shortened codeword mode, the CM MUST 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 code words MUST 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 MUST one-fill data if necessary up to the Burst Size specified in Table 6-1 above accounting for preamble, FEC parity, return-to-zero bits and guard-time symbols (if any). Therefore, in many cases, only k" - k' one-fill bytes are necessary with $16 \leq k'' \leq k$ and $k' \leq k''$.

Generally, the CM MUST one-fill data until the point when no additional fixed-length code words can be inserted before the end of the burst specified in Table 6-1 above, accounting for preamble, FEC parity, return-to-zero bits, and guard-time symbols (if any). Then, if possible, a shortened last codeword of one-fill MUST be inserted to fit into the last mini-slot.

If, after one-fill of additional code words with k information bytes, there are less than 16 bytes remaining before the end of the burst specified in Table 6-1 above, accounting for preamble, FEC parity, return-to-zero bits and guard-time symbols (if any), then the CM MUST NOT create this last shortened codeword.

6.2.5.2 R-S FEC Disabled

When T = 0 (no FEC parity bytes), the CM MUST one-fill in full bytes to the end of the burst specified in Section 6.2.5.1.1 above, accounting for preamble, return-to-zero bits, and guard-time symbols (if any).

6.2.6 Upstream R-S Frame Structure for DOCSIS 3.0 Multiple Transmit Channel mode Not Enabled

When Multiple Transmit Channel mode is not enabled, all requirements in Section 6.2.5 for R-S frame structure in Multiple Transmit Channel Operation apply, except that zero-fill MUST be used instead of one-fill in Sections 6.2.5.1.2, 6.2.5.1.3, 6.2.5.2, and in Figure 6-4.

6.2.7 TDMA Byte Interleaver

R-S codeword interleaving in a byte (R-S symbol) format MUST be performed after R-S encoding on a TDMA channel. The byte interleaver changes the order of the bytes at the R-S encoder output, i.e., it performs an operation of byte permutation. At the receiver side, the original order of bytes is restored prior to the R-S decoding. Therefore, if some consecutive bytes were corrupted by burst noise, they are spread between various R-S code words, averaging the number of erroneous bytes in each codeword. The interleaver is a block interleaver type, i.e., the permutation is achieved by filling a table row-wise (one row per R-S codeword), and reading it column-wise. The total memory size allocated for the table is 2048 bytes.

The byte interleaver is disabled when the R-S encoder is turned off (T = 0).

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6.2.7.1 Byte Interleaver Parameters

The interleaver operating parameters described in Table 6-2 determine the operation of the interleaver for every burst.

Table 6-2 - Interleaver Operating Parameters

Parameter	Definition	Allowed Values
N_r	Interleaver Width (R-S Codeword Length, k+2*T)	18 to 255
I_r	Interleaver Depth	0 - Dynamic Mode 1 - No Interleaving 2 to floor(2048/N_r) - Fixed Mode
B_r	Interleaver Block Size	2*N_r to 2048
N_f	Packet Size (in bytes, including FEC)	≥18 bytes

The CMTS and CM MUST use the interleaver parameters within the allowed values in Table 6-2 with the following additional restrictions:

1. N_r and I_r MUST be chosen such that $N_r I_r \leq 2048$ (in other words, for a given N_r, the maximal value of I_r is $I_{r,max}$=floor(2048/N_r)).
2. N_r MUST be identical to the R-S codeword length (ie, k+2T).
3. B_r is effective only when I_r=0. This mode is called dynamic mode.
4. When I_r=1, interleaving is disabled.

N_r, I_r, and B_r are specified in the burst profile, and N_f is implied in the MAP message.

6.2.7.2 Interleaver Operating Modes

The interleaver MUST support both an operating mode in which the block size is fixed, as well as a dynamic mode in which the interleaver depth is determined based on the burst size.

6.2.7.2.1 Fixed Mode

The R-S encoded data bytes of the packet are first divided into interleaver blocks of $N_r I_r$ bytes (ie, blocks of I_r R-S code words each). The size of the last interleaver block may be smaller when the packet length is not an integer multiple of $N_r I_r$. Each interleaver block is interleaved separately.

Each interleaver block is filled into a table with I_r rows and N_r columns. The data is written row by row (from left to right). Therefore, each row corresponds to one R-S codeword. The bytes are read column by column (from top to bottom). The interleaver operation is demonstrated in Figure 6-5.

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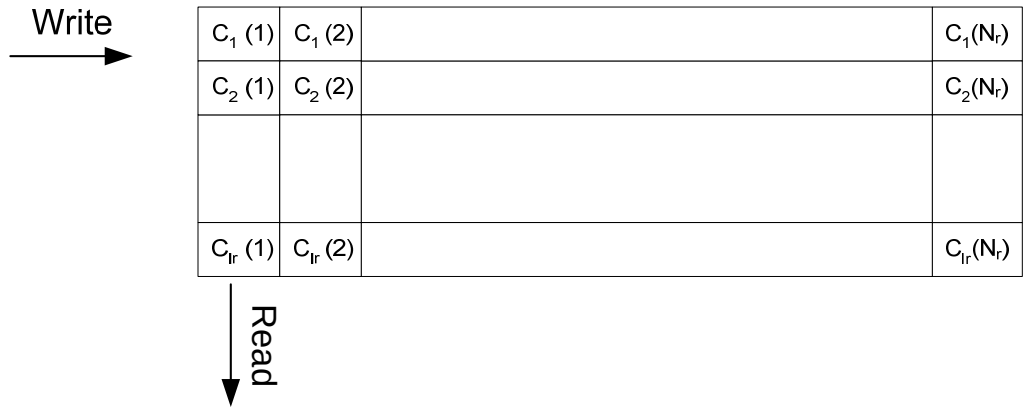
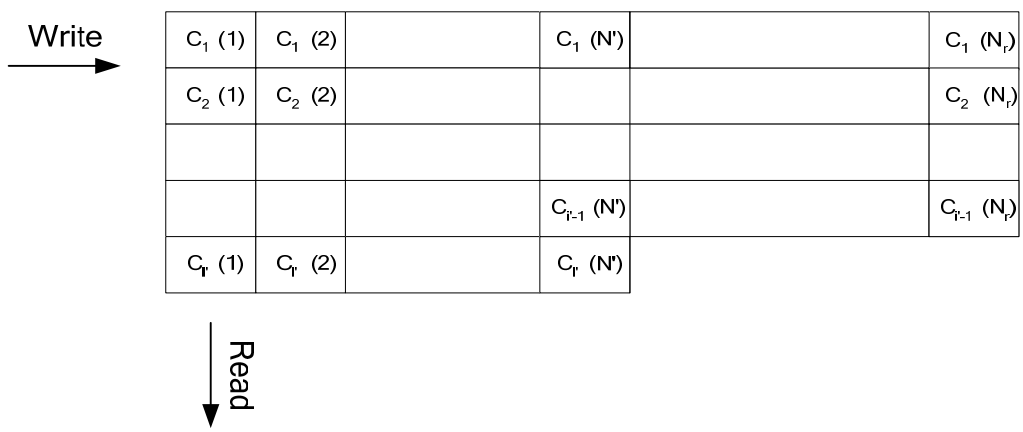


Input sequence: $C_1(1),...C_1(N_r),C_2(1),....C_2(N_r),C_3(1).....C_{I_r}(N_r)$
Output sequence: $C_1(1),C_2(1)...C_{I_r}(1),C_1(2),....C_{I_r}(2),C_1(3).....C_{I_r}(N_r)$

Figure 6-5 - Byte Interleaver Operation

The last interleaver block might have fewer rows than I_r. If the shortened last codeword mode is applied, then the last row might have fewer elements than N_r. In these cases, the interleaver table is read column by column, skipping the empty elements of the table. The interleaver operation for the last interleaver block is demonstrated in Figure 6-6.



Input sequence: $C_1(1),...C_1(N_r),C_2(1),....C_2(N_r),C_3(1).....C_{I'}(1).....C_{I'}(N')$
Output sequence:
$C_1(1),C_2(1)...C_{I'}(1),C_1(2)...C_{I'}(2)...C_1(N')...C_{I'}(N'),C_1(N'+1)....C_{I'-1}(N'+1),C_1(N'+2)...C_{i'-1}(N'+2)...C_1(N_r)...C_{I'-1}(N_r)$

Figure 6-6 - Interleaver Operation for Last Interleaver Block (with Shortened Last Codeword)

6.2.7.2.2 Dynamic Mode

In the fixed mode, the interleaving depth of the last interleaving block of a packet (I' in Figure 6-6) may be as small as one, resulting in low burst noise robustness for this block. In the dynamic mode, the depths of the interleaver blocks are chosen such that all blocks have approximately the same depth to achieve nearly optimal burst noise robustness (for the given block size).

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The R-S encoded data bytes of the packet are first divided into N_s^0 interleaver blocks. The size of the ith interleaver block is $N_r * I_r^{(i)}$ bytes (ie, a block of $I_r^{(i)}$ R-S code words). The size of the last interleaver block may be smaller in the shortened last codeword mode. Each interleaver block is interleaved separately (see the equations for N_s^0 and $I_r^{(i)}$ in Section 6.2.7.2.2.1).

The ith interleaver block is filled into a table with $I_r^{(i)}$ rows and N_r columns. The data is written row-wise (from left to right). Therefore, each row corresponds to one R-S codeword. The bytes are read column-wise (from top to bottom). The interleaver operation is demonstrated in Figure 6-5 (except that there are $I_r^{(i)}$ rows instead of I_r).

If the shortened last codeword mode is applied, then the last row might have fewer elements than N_r. In this case, the interleaver table is read column by column, skipping the empty elements of the table. The interleaver operation for the last interleaver block is demonstrated in Figure 6-6 (except that there are $I_r^{(N_s^0)}$ rows instead of I').

6.2.7.2.2.1 Dynamic Mode Calculations

Dynamic mode calculations are illustrated below.

N_s^0 and $I_r^{(i)}$ are determined by the following equations:

Total number of interleaver rows: $I_{tot}^0 = ceil(N_f / N_r)$.

Maximal number of rows per segment: $I_{r,\max} = floor(B_r / N_r)$.

Number of segments: $N_s^0 = ceil(I_{tot}^0 / I_{r,\max})$

Interleaver depth of first block: $I_r^1 = floor(I_{tot}^0 / N_s^0)$

No. of blocks with depth of I_r^1: $M = N_s^0 \cdot (I_r^1 + 1) - I_{tot}^0$

Then for segment *i*, $I_r^{(i)}$ is calculated as follows ($i = 1 \ldots N_s^0$):

$$I_r^{(i)} = \begin{cases} I_r^1, & i = 1,\ldots,M \\ I_r^1 + 1, & i = M+1,\ldots,N_s^0 \end{cases}$$

Figure 6-7 - T Mode Calculations

6.2.8 Scrambler (Randomizer)

The upstream modulator MUST implement a scrambler (shown in Figure 6-8) where the 15-bit seed value is 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).

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

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

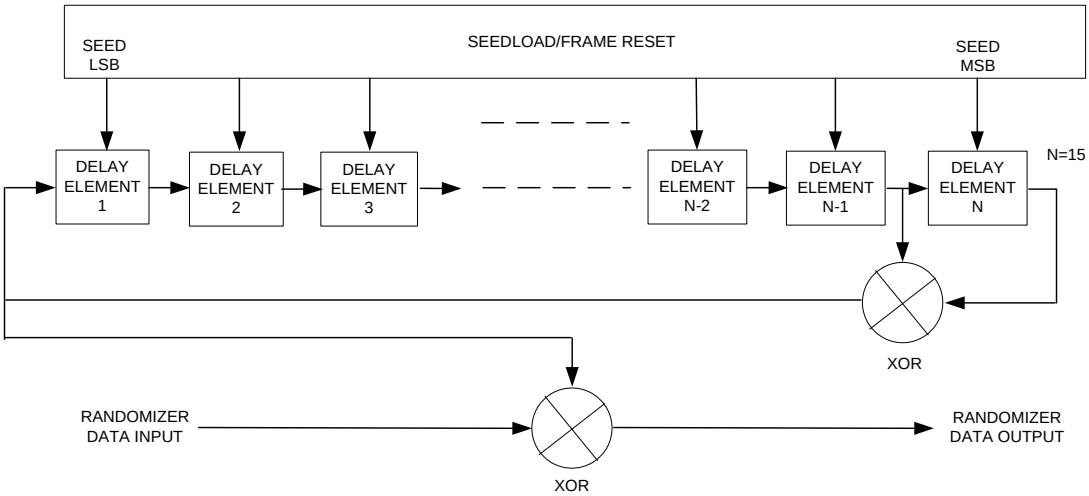

Figure 6-8 - Scrambler Structure

6.2.9 TCM Encoder

R-S symbol interleaving is commonly included between the TCM and R-S blocks to preserve coding gain in the presence of bursts of errors produced at the output of the TCM decoder. This interleaver was not included in the original baseline S-CDMA proposal to reduce memory requirements at the expense of coding gain.

In S-CDMA mode, the CM MUST support trellis coded modulation for transmission of m = 1, 2, 3, 4, 5, and 6 bits per symbol with QPSK0, 8 QAM, 16 QAM, 32 QAM, 64 QAM, and 128 QAM constellations, respectively. Support of TCM in the CMTS is optional.

Figure 6-9 shows the employed 8-state TCM encoder. The encoding operation causes a mapping of m input bits into m+1 output bits for input into the symbol mapping block. The systematic convolutional encoder adds the coded bit $x^1 = s^0$ to the input bits i^m, i^3, i^2, i^1. For m = 1, only input bit i^1 is used ($i^2 = 0$), and encoding is reduced to rate-1/2 coding.

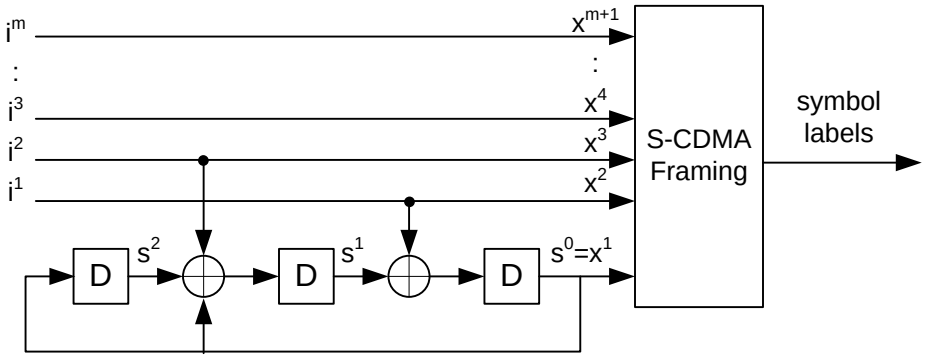

Figure 6-9 - Convolutional encoder

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The initial state of the TCM encoder MUST be the zero state. The zero state MUST be reached again with the last encoded symbol.

To return to the zero state from all possible Trellis paths, if m = 1 (QPSK) three tail symbols ($n_t = 3$) MUST be generated with input bit i^1 set to $i^1 = s^1$. By inspection of Figure 6-9, after three symbols the state bits s^2, s^1, and $s^0 = x^1$ will be zero. Tail symbols are extra symbols, which carry no information.

If m = 2, to return to the zero state from all possible Trellis paths, two tail symbols (n_t=2) MUST be generated. The input bits $i^2 i^1$ MUST be set such that the zero state is reached after two symbols. If the first symbol is set to $i^2 = 0$, $i^1 = s^1$, and the second (final) symbol to $i^2 = s^2$, $i^1 = s^1$ after these two symbols the state bits s^2, s^1, and $s^0 = x^1$ will be zero.

If $m \geq 3$, the uncoded bits $i^m,..,i^3$ MUST be used for information encoding, when this is possible. Otherwise, uncoded bits MUST be set to zero. The number of tail symbols carrying no information depends on the ending conditions and can vary between zero and two ($0 \leq n_t \leq 2$).

6.2.9.1 Byte to TCM Symbol Mapping

The mapping of bytes to TCM symbols is done such that each byte is mapped entirely to the uncoded bits $i^m,...,i^3$, or entirely to the convolutional encoder input bits i^2 i^1. The decision is made sequentially for each byte using the rule that the byte assignment should lead to the shortest packet of symbols including tail symbols, if the current byte were the last byte to be encoded. This rule results in the repetitive patterns of byte assignments to label bits shown in Figure 6-10 for m=1 to 6. In the figure bit i^m is at the top and bit i^1 is at the bottom.

The MSB (i^m) MUST be the first bit in the serial data fed into the uncoded input bits (ie, i^m to i^3). The MSB (i^2) MUST be the first bit in the serial data fed into the coded input bits.

Figure 6-11 illustrates the byte assignments for Trellis-coded 64 QAM modulation by two examples. Notice that bytes are assigned in a repetitive pattern of five bytes. In the first example, N_f is divisible by five. In this case two tail symbols are appended. In the second example, N_f is not divisible by five and no tail symbols are required. The bits needed for returning to the zero state are available in symbols still carrying information.

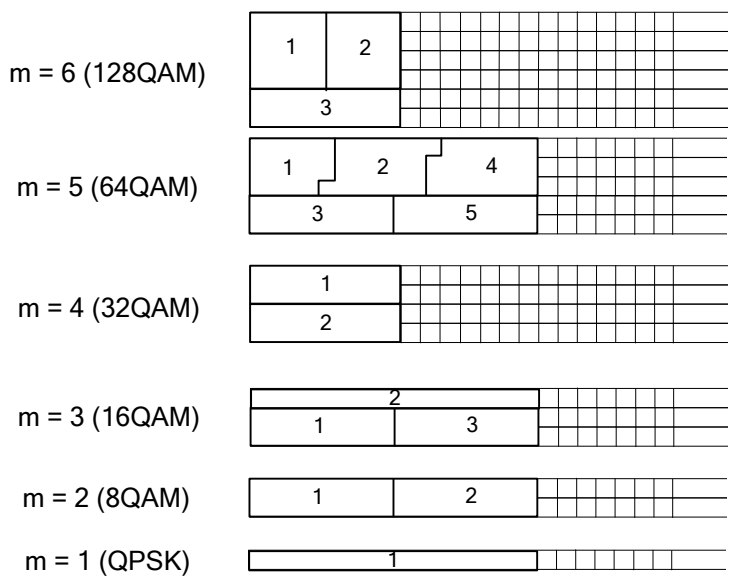

Figure 6-10 - Repetitive Patterns of Byte Mapping to Symbol Map Bits for TCM

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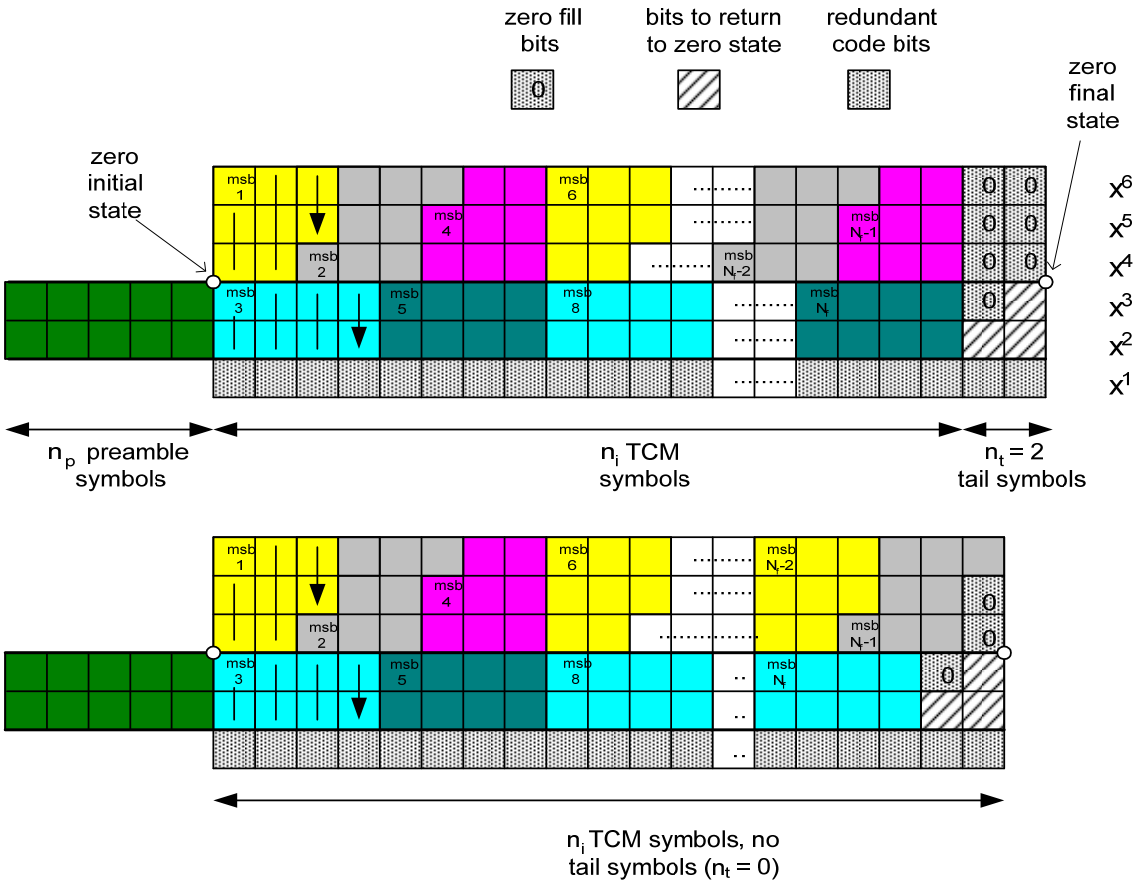

Figure 6-11 - Example Byte to Bit Assignment for 64 QAM

The CM MUST place the return-to-zero bits right after the last TCM-coded data sub-symbol, that is, the last coded sub-symbol corresponding to the parity bytes of the last shortened or fixed R-S codeword including any zero-filled (for operation not in MTC Mode) or one-filled (for operation in MTC Mode) R-S code words in the grant. The rest of the TCM-coded bits MUST be filled with zeros.

Figure 6-12 illustrates the placing of return-to-zero bits for 64 QAM when the last transmitted byte is #1. The first two pairs of x^2 and x^3 are the return to zero bits, and the last empty coded pair is zero-filled or one-filled.

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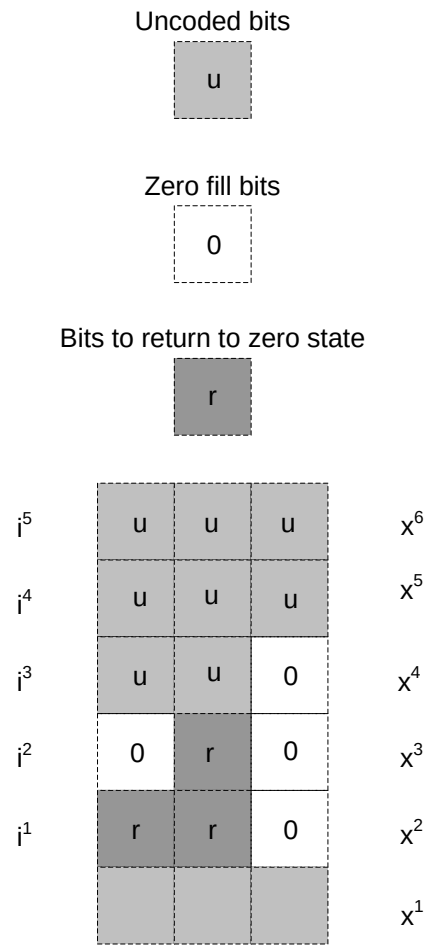

Figure 6-12 - Example of return to zero bits followed by "0"

6.2.10 Preamble Prepend

The upstream PMD sublayer MUST support a variable-length preamble field that is prepended to the data after it has been randomized, Reed-Solomon encoded, and TCM encoded.

The first bit of the Preamble Pattern is the first bit into the symbol mapper (see Section 6.2.14). The first bit of the Preamble Pattern is designated by the Preamble Value Offset. The preamble is interleaved by the framer in S-CDMA mode.

The preamble sequence MUST be programmable. For DOCSIS 2.0/3.0 bursts (bursts encoded using a Type 5 burst descriptor), the preamble MUST use the QPSK0 or QPSK1 constellation (per Figure 6-20 and Figure 6-21) with preamble length 0, 2, 4, 6,..., or 1536 bits (maximum 768 QPSK symbols). For DOCSIS 1.x compatible bursts (Type 4 burst descriptor) that use QPSK modulation, the preamble and data MUST use the QPSK0 constellation with preamble length 0, 2, 4, 6,..., or 1024 bits (maximum 512 QPSK symbols). For DOCSIS 1.x compatible bursts (Type 4 burst descriptor) that use 16 QAM modulation, the preamble and data MUST use the 16 QAM constellation with preamble length 0, 4, 8, 12,..., or 1024 bits (maximum 256 16 QAM symbols).

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

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6.2.11 Modulation Rates

6.2.11.1 DOCSIS 3.0 Modulation Rates

In TDMA and S-CDMA modes, the CM upstream modulator MUST provide all modulations at 1280, 2560 and 5120 kHz.

In TDMA and S-CDMA modes, the CMTS upstream demodulator MUST be able to support demodulation at 1280, 2560 and 5120 kHz.

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.

The modulation rate for each upstream channel is defined in an Upstream Channel Descriptor (UCD) MAC message. All CMs using that upstream channel MUST use the defined modulation rate for upstream transmissions.

6.2.11.2 Backward Compatibility Modulation Rates

Operating with a DOCSIS 1.x or DOCSIS 2.0 CMTS, or with a CMTS operating in one of these modes, in TDMA and S-CDMA modes, the CM upstream modulator MUST provide all modulations at 1280, 2560 and 5120 kHz.

In addition, with such pre-3.0-DOCSIS CMTS operation, for TDMA mode, the CM upstream modulator MAY provide all modulations at 160, 320 and 640 kHz.

In pre-3.0-DOCSIS CMTS operation, for both TDMA and S-CDMA modes, the CMTS upstream demodulator MUST be able to support demodulation at 1280, 2560, and 5120 kHz. In pre-3.0-DOCSIS CMTS operation, for TDMA mode, the CMTS upstream demodulator MAY support demodulation at 160, 320, and 640 kHz.

6.2.12 S-CDMA Framer and Interleaver

6.2.12.1 S-CDMA Framing Considerations

The S-CDMA mode of the PHY layer accepts data presented to it for transmission from the MAC layer. This data is presented as bursts of *n* mini-slots. These bursts are mapped within the PHY layer to a combination of spreading codes and time slots, in order to exploit the multi-dimensional spreading of information by the S-CDMA mode.

There are various adjustable parameters in the upstream channel parameters and upstream burst attributes that allow controlling the mini-slot to physical layer mapping, as well as tuning the channel to accommodate a variety of channel conditions, noise characteristics, capacities, reliability levels, and latency requirements.

When operating in S-CDMA mode, data is transmitted in two dimensions: codes and time. For this reason, data to be transmitted is grouped into two-dimensional rectangular frames prior to transmission.

At the physical layer, data is sent over an array of up to 128 spreading codes. There is a programmable number of *spreading intervals* per frame, as shown in Figure 6-13 below. A *spreading interval* is the time required to transmit one symbol per code across all 128 codes in S-CDMA mode. Note that the specific codes which are used and the details of the spreading operation are described in detail in Section 6.2.15.

A burst from a particular CM may be transmitted on two or more codes in one or more frames. A frame may contain bursts transmitted simultaneously from multiple CMs (each on a separate subset of the codes) as defined by the MAP message.

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6.2.12.2 Mini-slot Numbering

In normal operation, the MAC will request the PHY to transmit a burst of length *n* mini-slots, starting at mini-slot *m*, as defined by the MAP. All CMs and the CMTS MUST have a common protocol of how mini-slots are numbered, and how they are mapped onto the physical layer framing structure. This common protocol is obtained from information in the SYNC and Upstream Channel Descriptor (UCD) messages.

Mini-slots are mapped onto frames starting at the first active code, are numbered sequentially through the remainder of the frame, and then wrap to the next sequential frame (see Section 6.2.12.2.2 for mini-slot numbering examples). Mini-slots are mapped onto a group of consecutive codes.

The CMTS and the CMs require a common protocol for mini-slot numbering. For operation on a TDMA channel, this is achieved solely through recovery of the timestamp. Since the time duration of an S-CDMA frame is not necessarily a power-of-2 multiple of the 10.24 MHz reference, the timestamp rollover (at 2^{32} counts) is not necessarily at an S-CDMA frame boundary. Therefore, an additional synchronization step is required.

The CMTS is required to identify frame boundaries relative to the timestamp counter on a periodic basis. This is called the *timestamp snapshot* and has to be sent in the UCD for each upstream S-CDMA channel.

The CMTS is required to maintain a frame counter and a mini-slot counter. The CMTS has to sample these values along with the timestamp, on a frame boundary, as shown in Figure 6-13 below. The CMTS is required to obtain a new sample prior to sending each UCD message.

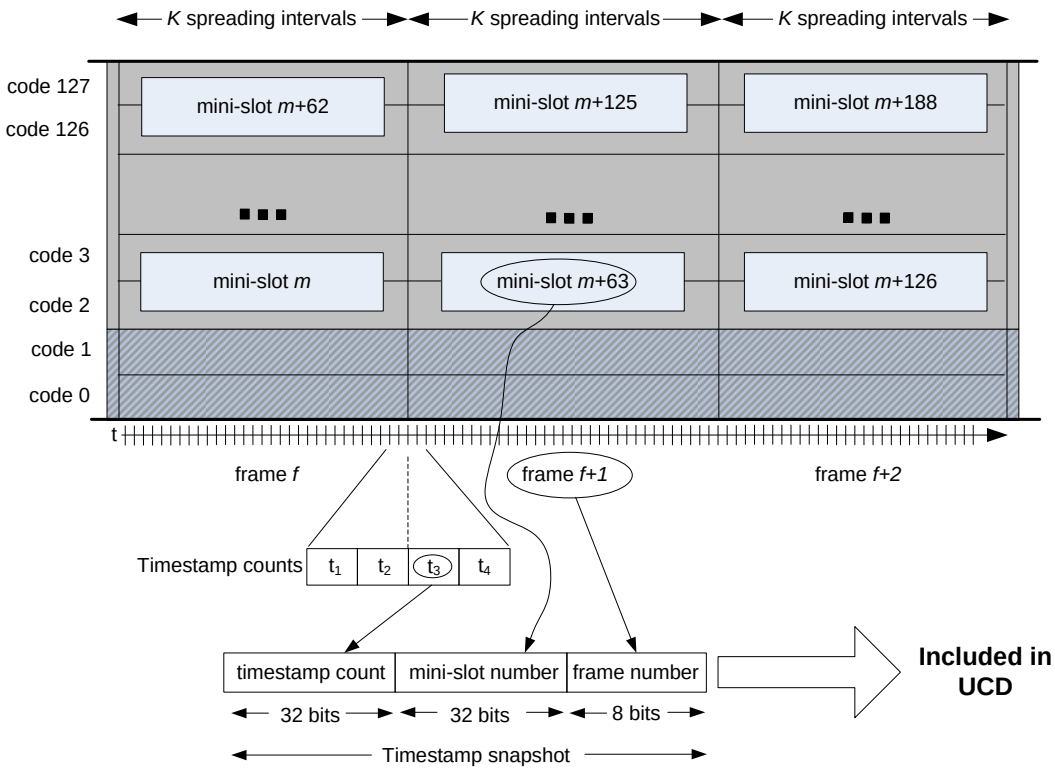

Figure 6-13 - Timestamp Snapshot

Each CM MUST maintain a timestamp counter, mini-slot counter, and frame counter functionally identical to the CMTS.

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From the UCD message, the CM receives the CMTS timestamp snapshot and parameters from which it can calculate the number of time counts per S-CDMA frame. Using modulo arithmetic, the CM can then calculate accurate values for timestamp, mini-slot, and frame counters at any point into the future.

The CM can then update its local mini-slot and frame counters at an appropriate timestamp counter value. At this point, the CM representation of mini-slots and frames are aligned with those in the CMTS.

The CMTS and CM MUST implement a 32-bit timestamp counter, a 32-bit mini-slot counter, and an 8-bit frame counter, as follows:

- The mini-slot counter MUST contain the value of the first mini-slot of the frame when it is sampled. It MAY be incremented by the number of mini-slots per frame, once per frame interval. The mini-slot counter will use all 32 bits and mini-slot numbers will, therefore, range from 0 to 2^{32}-1.
- The only specified function for the frame counter is to reset the code hopping sequence at the frame 0 (modulo-256) boundary, as defined in Section 6.2.15.1.

The frame structure above relates to the entire upstream and not necessarily to the transmission from a single CM. The codes are resources which are allocated to CMs over each S-CDMA frame. The assignment of codes to CMs is performed by the framer as it assigns a burst of symbols a particular order in the two-dimensional matrix of codes and time. This symbol sequencing is described in detail in Section 6.2.13.

6.2.12.2.1 Mini-slot Numbering Parameters in UCD

There are three parameters specified in the UCD that define mini-slot mapping: *spreading intervals per frame*, *codes per mini-slot*, and *number of active codes*.

Spreading intervals per frame

The number of *spreading intervals per frame*, K, (along with the signaling rate), $1/T_s$, define the time duration of an S-CDMA frame, T_{fr}:

$$T_{fr} = K * 128 * T_s$$

Note that the code length in the above equation is always 128, regardless of how many codes are currently active.

The valid range of the *spreading intervals per frame* parameter is 1 to 32.

Codes per mini-slot

In conjunction with the spreading intervals per frame parameter, the codes per mini-slot (C_{ms}) parameter defines the total number of symbols per mini-slot and, therefore, the mini-slot capacity. The mini-slot capacity, S_{ms}, is given in symbols by the following expression:

$$S_{ms} = K * C_{ms}$$

The lower limit on mini-slot capacity is 16 symbols. However, the mini-slot also has to be large enough to allow the transmission of the largest-sized data PDU (including physical layer overhead) in 255 mini-slots. The maximum mini-slot capacity in symbols is given by the product of the maximum number of spreading intervals per frame and the maximum number of codes per mini-slot (32x32 = 1024 symbols). The valid range of the *codes per mini-slot* parameter is 2 to 32.

Selectable Active Codes (SAC)

The number of active codes parameter N_a allows the number of codes used to carry data to be less than or equal to 128. When $N_a < 128$, the active codes may be chosen using the following two modes.

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Selectable Active Codes Mode 1: The low-numbered codes starting with code 0 are not used, as shown below in Figure 6-15 (an example of 126 active codes and code hopping off).

Selectable Active Codes Mode 2: The active codes are selectable via a 128-bit string. The first element in the string corresponds to code 0 (the all-ones code). A "1" element in the string indicates an active code, and a "0" indicates an unused code.

There are several reasons why it may be desirable to reduce the number of active codes:

- Code 0 does not have the same spreading properties as the other codes and, therefore, under certain colored noise conditions, will degrade performance.
- In extremely noisy plant conditions, a reduction in the number of active codes (along with the corresponding increase in power per code for the remaining codes) can allow reliable operation at reduced capacities. Reduction in active codes from 128 to 64 results in a 3 dB improvement in SNR.
- The number of mini-slots per S-CDMA frame MUST be an integer. Therefore the codes per mini-slot and number of active codes parameters MUST be chosen to result in an integral number of mini-slots per frame.

When $N_a \geq 64$, the S-CDMA frame consists of more than 1 mini-slot, since the number of codes per mini-slot is in the range 2 to 32. This implies that N_a is non-prime. The prime numbers between 64 and 128 are {67, 71, 73, 79, 83, 89, 97, 101, 103, 107, 109, 113, and 127}.

The CM MUST support any non-prime number of active codes in the range $64 \leq N_a \leq 128$. The CM MUST support Selectable Active Codes Mode 1. The CM SHOULD support Selectable Active Codes Mode 2.

The CMTS MUST support 126 and 128 active codes. The CMTS MUST support Selectable Active Codes Mode 1. The CMTS MAY support Selectable Active Codes Mode 2.

6.2.12.2.2 Mini-slot Numbering Examples

A typical mini-slot numbering example with $N_a = 128$ active codes and code hopping off is shown in Figure 6-14. In this example, there are two codes per mini-slot defined. The number of codes per mini-slot is an adjustable parameter (via the UCD) to allow flexibility in determining the effective capacity of each mini-slot.

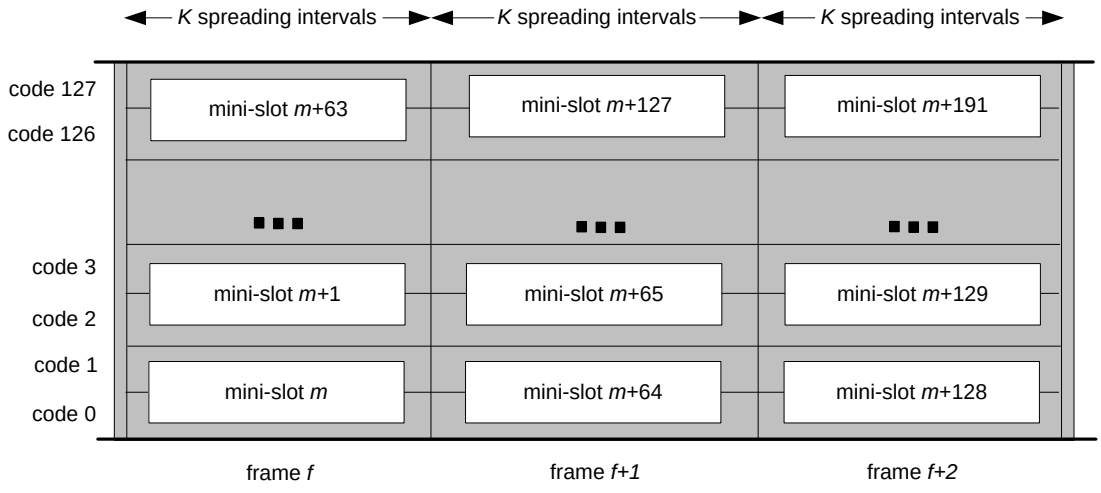

Figure 6-14 - Mini-slot Mapping with Two Codes per mini-slot, 128 Active Codes

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