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**Modular Headend Architecture Part 1: DOCSIS Timing
Interface**

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1 SCOPE

1.1 Introduction and Overview

The requirements for timing and synchronization of the DOCSIS system come from the following areas:

- Existing DOCSIS Specification & ATP Requirements
- Remote PHY System Requirements
- Implementation Requirements
- Emerging Services like T-Services and wireless

These requirements place definitions and constraints on the use of the 10.24 MHz DOCSIS master clock and the DOCSIS timestamp, which is delivered in the SYNC message. The DOCSIS standard [RFI2] originally envisioned the M-CMTS Core, EQAMs, and upstream receive functions on one assembly, fed with a common clock. The timestamp counter resided in the M-CMTS Core function.

The M-CMTS™ Remote PHY architecture may result in three components: the M-CMTS CORE, the upstream receiver, and the EQAM being located in a different chassis, and potentially at different physical locations. As a system, the three components comply with the DOCSIS standard [RFI2] and any existing CMTS equipment.

The DOCSIS Timing Protocol (DTI) defined in this document supports the accurate and robust transport of the DTI server 10.24 MHz master clock, 32-bit DOCSIS timestamp, and Time of Day, to the DTI client within the DOCSIS M-CMTS cable network. The DTI protocol is structured to minimize the complexity and cost of the DTI client clocks, and the per port cost of the shared server function while supporting all S-CDMA and TDMA timing requirements.

1.1.1 System Requirements

The DTI system requirements refer to the DOCSIS timing requirements as outlined in the DOCSIS standard [RFI2]. These requirements are presented independent of the CMTS architecture.

The sections of the DOCSIS standard [RFI2] that are of interest are:

- 6.2.11.2 Mini-slot Numbering
- 6.2.21.8.2 Chip Timing Jitter for Synchronous Operation
- 6.3.7 CMTS Timestamp Jitter
- 6.3.8 CMTS Clock Generation
- 6.3.9 CMTS Downstream Symbol Clock Jitter for Synchronous Operation
- 6.3.10 CMTS Downstream Symbol Clock Drift for Synchronous Operation
- 9.3 Timing and Synchronization

1.1.2 T-Services Consideration

To maintain compatibility with the T-Service synchronization hierarchy, the DTI Server clock operates with the specifications detailed in section 7.1, which integrate both the DOCSIS timing system requirements and the existing legacy synchronization network clock consistent with [G.812] and [T1.101]. This is done to ensure that the CM supporting T-Services can derive its clocking and meet [G.823] or [G.824] jitter and wander requirements for both traffic bearing and synchronization bearing transport clock sources.

Support of T-Services will require that the master clock and the downstream symbol clock be locked and upstream and downstream clocks be coherent.

1.1.3 Modular Implementation Requirements

The M-CMTS CORE element:

- Uses the DTI server master clock for creating a timestamp
- Uses the timestamp for MAP generation

The Edge QAM element:

- Uses the DTI server master clock for symbol rate generation
- Uses the timestamp for inserting and/or correcting SYNC messages

The Upstream receive element:

- Uses the timestamp and/or S-CDMA frame and the MAP for determining when to look for the start of a receive burst
- Uses a clock locked to the master clock for reception of symbols in S-CDMA mode

1.1.4 Architecture

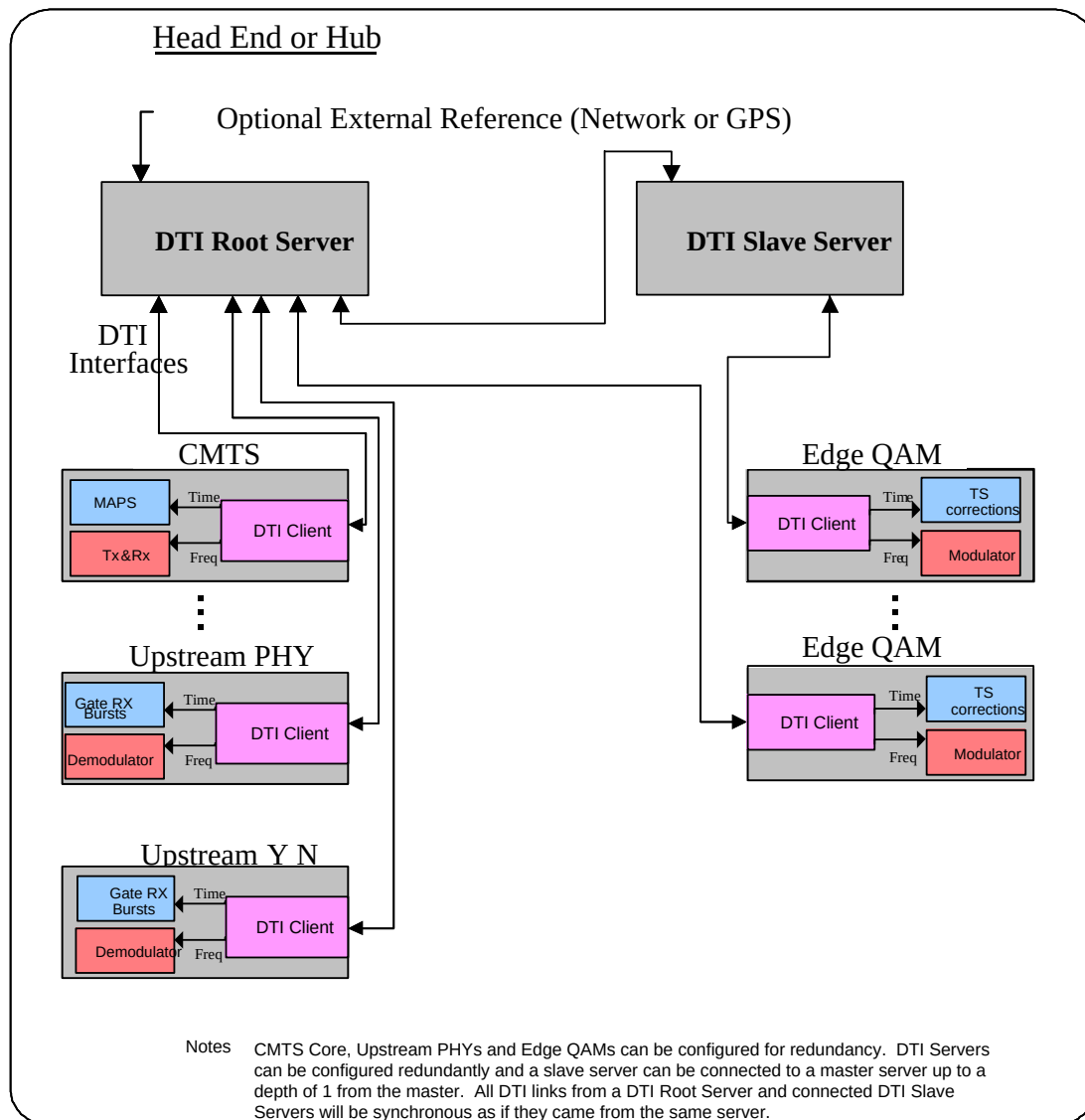


Figure 1-1 - Timing Architecture

Figure 1-1 shows frequency and timing distribution examples for both headend and Hub. The DTI Server establishes the reference for the timing distribution network and synchronizes all connected DTI Clients via point-to-point connections between the server and each client. A single protocol initiated by the DTI server permits the client to perform frequency and time synchronization. As shown, upstream receive, Edge QAMs, and the M-CMTS CORE may have different uses for the synchronized frequency and time, but utilize a common client function.

The DTI protocol and server-client interactions are described in detail in Sections 6 and 0. The essential characteristics are:

- The DTI server initiates the protocol, which the DTI client uses to establish its time and frequency synchronization.
- Using a ping-pong scheme, the client always immediately replies to the DTI server when it receives a transmission from the DTI server. The server uses this response to auto-compensate any delays with the effect that the client becomes precisely synchronized to the server.

- The server-to-client-to-server handshake continually repeats, assuring that a tight synchronization can be maintained.

The DTI protocol and components support accurate and robust transport of the server 10.24 MHz master clock and 32-bit DOCSIS timestamp to the client within a node or building. The protocol is structured to minimize the complexity and cost of the client clocks and the per port cost of the shared server function while supporting all the DOCSIS S-CDMA, TDMA, and future T-Services timing requirements in a modular system.

The high accuracy (<5 ns) and high stability (<1 ns timing jitter budget) is achieved by using a simple ping-pong layer 2 timing protocol over a single twisted pair connection using common passive PHY components in both directions. This structure provides delay reciprocity so that all cable delay processing can be performed in the server. The client's role in delay correction is to provide a fixed delay response to the server frame and to use the cable advance supplied by the server to advance the local 10 kHz DTI frame clock to correct for cable delay.

To ensure reliable transport and client clock operation, the client clock is required to report the current phase error of its local clock (frame clock) with respect to the delay-corrected server frame clock. This measurement is reported to the server at the 10 kHz frame rate. The server's role is to process this measurement data and verify the client's timing operation. This protocol supports real-time detection and mitigation of client clock faults.

The DTI client can be realized with a single digital component, a simple PHY and a low cost local oscillator, as holdover and filtering are supported in the shared server. A common definition of the DTI high-speed clock is necessary to ensure compatibility between all DOCSIS DTI client components.

1.1.5 Synchronization Needed for T-Services Deployment

The deployment of T-Services compliant with the existing Telco T1/E1 standards will require both synchronization and traceability to a common external clock source. In this case, if a cable modem supporting T-Services is connected to an M-CMTS EQAM, the cable modem will need to be synchronized with the DTI Server operating with an external T-Service reference.

1.2 Requirements

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

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

2 REFERENCES

2.1 Normative References

The following documents contain provisions, which, through reference in this text, constitute provisions of this standard. 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.

[RFI2]	ANSI/SCTE 79-1 2016 DOCSIS 2.0 Part 1: Radio Frequency Interface
[G.812]	ITU-T Recommendation. Gr.812, Timing Requirements of slave clocks suitable for use as node clocks in synchronization networks, June 1998.
[G.823]	ITU-T Recommendation. Gr. 823, The control of jitter and wander within digital networks which are based on the 2048 kbit/s hierarchy, March 2000.
[G.824]	ITU-T Recommendation. Gr. 824, The control of jitter and wander within digital networks which are based on the 1544 kbit/s hierarchy, March 2000.
[GR1244]	Telcordia, Clocks for the Synchronization Network: Common Generic Requirements, December 2000.
[IEEE 802.3]	IEEE Std. 802.3-2002, Part3: Carrier Sense Multiple Access with Collision Detection (CSMA/CD) access method and physical layer specifications, March 8, 2002.
[T1.101]	ANSI T1.101, Synchronization Interface Standard T1.101-1999, September 7, 1999.

2.2 Informative References

This specification uses the following informative references.

[DEPI]	SCTE 137-2 2017, DOCSIS Downstream External PHY Interface.
[ERMI]	SCTE 137-4 2017, Edge Resource Manager Interface.
[MOSSI]	SCTE 137-3 2017, M-CMTS Operations Support System Interface.

2.3 Reference Acquisition

- American Institute of Electrical Engineers, Internet: <http://www.ieee.org/portal/site>
- American National Standards Institute, Internet: <http://webstore.ansi.org>
- International Telecommunications Union (ITU), Internet: <http://www.itu.int>
- Internet Engineering Task Force (IETF), Internet: www.ietf.org
- Telcordia Technologies, Internet: <http://telecom-info.telcordia.com>

3 TERMS AND DEFINITIONS

This specification uses the following terms:

bridging mode	A short-term operating condition of the DTI clock where the DTI client has recently lost its controlling input and is using stored data, acquired while in normal or fast mode operation, to control its output. While in bridging the degree of deviation of the output is deemed to be such that DTI client clock is still performing within normal or acceptable limits. If an outage period persists the DTI client clock will transition to the holdover mode indicating that the DTI client clock output may be degraded.
DTI Minimum Clock oscillator	An oscillator that supports all the client clock performance requirements with holdover limited to the minimum bridging time. A non-ovenized oscillator can be used to support this oscillator category.
fast mode	An operating condition of a clock in which it is locked to an external reference and is using time constants, which are reduced to quickly bring the local oscillator's frequency into approximate agreement with the synchronization reference frequency.
free-run mode	An operating condition of a DTI clock whose output signals are internally controlled by the DTI server. The clock has never had, or has lost, external reference input and has no access to stored data that was acquired from a previously connected external reference during the time after the last power cycle. Free-run ends when the clock output is influenced by an external reference or the process to achieve lock to an external reference. Free-run may provide needed stability when external reference has been lost or not equipped.
geoid	The equipotential surface of the Earth's gravity field which best fits, in a least squares sense, global mean sea level.
holdover mode	An operating condition of a DTI clock that has lost its controlling input and is using stored data, acquired while in normal or fast mode operation, to control its output. The stored data is filtered to minimize the effects of short-term variations and to establish a predictor of oscillator behavior during the reference outage. This permits the output deviation from normal operation to be minimized.
Maximum time interval error (MTIE)	For a sequence of time delay samples x_i, MTIE at observation time (S) is: $MTIE(S) = \max_{j=1}^{N-n+1} \left[\max_{i=j}^{n+j-1} (x_i) - \min_{i=j}^{n+j-1} (x_i) \right]$ MTIE Measurement: where: τ_0 = sample period N = number of samples in the sequence $n = \lceil S/\tau_0 \rceil + 1$ S = observation time x_i = time delay sample
normal mode	An operating condition of a clock in which the output signals are controlled by an external input reference. The expected mode and state permits each clock within a distribution to have the same long-term average frequency and time. Clocks in this mode are referred to as locked, meaning that they are in tight relationship with the DTI root clock. A DTI server clock in a fault free free-run mode will be considered in normal mode
Root DTI Server:	The DTI server that is the source of traceable time and frequency for all subtending DTI servers and clients in a building.

4 ABBREVIATIONS

This specification uses the following abbreviations:

(EQAM), Edge QAM	A network element which receives MPEG-TS frames over a network interface such as Ethernet, and modulates them onto QAM carriers for use on a HFC plant.
CM	Cable Modem
CMTS	Cable Modem Termination System
CRC	Cyclic Redundancy Check
DEPI	Downstream External PHY Interface
DOCSIS®	Data-Over-Cable Service Interface Specifications
DS	Downstream
DTI	DOCSIS Timing Interface
DTS	32-bit DOCSIS Time Stamp
ERMI	Edge Resource Manager Interface
GE	Gigabit Ethernet (1 Gbps)
IE	Information Element. An element of a MAP message.
IP	Internet Protocol
MAC	Media Access Control. Used to refer to the layer 2 element of the system, which would include DOCSIS framing and signaling.
M-CMTS	Modular CMTS
MPEG	Motion Picture Experts Group
MPEG-TS	Motion Picture Experts Group Transport Stream
MTIE	Maximum Time Interval Error
PCR	Program Clock Reference
PHY	Physical Layer. Used to refer to the downstream QAM transmitters and the upstream burst demodulators (receiver).
PID	Packet Identifier used in MPEG-TS
PUSI	Payload Unit Start Indicator
QAM	Quadrature Amplitude Modulation

S-CDMA	Synchronous Code Division Multiple Access
TBD	To Be Determined (or To Be Deferred)
TDM	Time Division Multiplexing
TDMA	Time Division Multiple Access
T-Services	Legacy T1 or T3 voice and/or data transport
UDP	User Datagram Protocol
US	Upstream
UTC	Coordinated Universal Time; also known as Greenwich Mean Time (GMT) or Zulu time

5 PHYSICAL LAYER REQUIREMENTS

This section is normative and specifies the physical layer requirements of the DTI protocol.

5.1 Introduction

The DTI link comprises the connection between a DTI Server and various other elements, such as M-CMTS CORE, EQAM and US Receivers collocated in the node that derive their clocking (time and frequency) from the DTI Server. Since the link resembles an Ethernet (802.3) 10BaseT link, it is advantageous to leverage the availability and cost effectiveness of this standard. This document defines the differences between the DOCSIS Timing Interface and a conventional 802.3-10BaseT interface. Table 5–1 indicates the similarity between the two links.

Table 5–1 - Physical Layer Comparisons

Characteristic	Ethernet 802.3-10BaseT	DOCSIS Timing Interface
Data Rate (Mbps)	10	5.12
Accuracy	Free-running; 100 ppm	Traceable to Master Clock
Transmission mode(s)	Full/half Duplex ⁽¹⁾	Ping-Pong ⁽¹⁾
Topology	Star ⁽²⁾	Star ⁽²⁾
Maximum Segment Length	100 m	200 m
Media	UTP	UTP
Signaling method	Baseband	Baseband
Modulation	Manchester	Manchester

Table Notes:

1. Conventional Ethernet 802.3 transceivers use separate wire pairs for transmission in the two directions. The DTI uses a ping-pong scheme whereby the same pair is used for transmission in both directions. This ensures the maximal reciprocity, minimizing the asymmetry in transmission delay between the two directions and minimizes crosstalk.
2. Conventional Ethernet installations utilize a star-wiring configuration where the "common" point is a switch or hub. In the DTI scenario the common point is the DTI Server.

The governing standard for Ethernet (physical layer) is [IEEE 802.3]. The physical layer specifications (primarily section 14 of the standard) are applicable here.

5.2 Physical Connector Description

The DTI Server, as well as the DTI Client, **MUST** have an RJ-45 (female) connector for each DTI link. This permits conventional Ethernet cabling techniques to be applied. See [IEEE 802.3] section 14.5.1. One distinction is that the DTI utilizes a single pair for transmission in both directions. Therefore a crossover function is not required. Contacts 1 and 2, labeled "SIG+" and "SIG–" will be used for the ping-pong transmission.

The cable interconnect **MUST** be as defined in Table 5–2.

Table 5–2 - DTI RJ45 Interconnect

RJ45 Pin Number	Signal	Comment
1	SIG+	10BaseT Compliant
2	SIG–	10BaseT Compliant
3	NC	
4	NC	

RJ45 Pin Number	Signal	Comment
5	NC	
6	NC	
7	NC	
8	NC	

5.3 Cable Requirements

The DTI MUST operate normally over a maximum of 200 meters of UTP cable rated at category 5E or better.

5.4 Electrical Description

5.4.1 Impedance

The termination impedance MUST be 100 ohms. The differential output impedance as measured on the TD circuit MUST be compliant with [IEEE 802.3] section 14.3.1.2.2. The transmitter impedance balance, or the ratio of common-mode to differential-mode impedance balance of the TD circuit MUST exceed $29 - 17 \log_{10}(f/10)$ dB, where f is the frequency in MHz, over the frequency range 1.0 MHz to 20 MHz (see [IEEE 802.3] section 14.3.1.2.4).

5.4.2 Isolation

There MUST be isolation between the physical layer circuits, including frame ground, and all leads including those not used by the DTI link. The isolation requirement follows [IEEE 802.3] section 14.3.1.

5.4.3 EMI Considerations

The DTI link will comply with applicable local and national codes for limitation of electromagnetic interference.

5.4.4 Signal Strength (voltage)

The per symbol peak differential voltage on the SIG± signals at the DTI Server, when terminated in a 100 Ω resistive load MUST be between 2.2 Vpp (Volts peak-to-peak) and 2.8 Vpp for all data sequences. For an all-ones Manchester-encoded pattern, any even harmonic measured on the TD circuit MUST be at least 27 dB below the fundamental. The magnitude of the total common-mode output voltage MUST be less than 50 mV peak.

5.4.5 Common-mode rejection

Given application of common-mode voltage of 15 V peak ~10 MHz sine wave (see [IEEE 802.3] section 14.3.1.2.6) the differential-mode voltage MUST NOT change by more than 100 mV for all data sequences. The edge jitter introduced MUST be less than 3 ns.

5.4.6 Signal Description

The transmission between the DTI Server and the DTI client MUST be ping-pong in nature, using the same pair of wires for transmission in both directions. The data pattern MUST be Manchester encoded with an underlying bit-rate of 5.12 Mbps, locked to the DTI Master Clock.

6 DOCSIS TIMING PROTOCOL

This section is normative. See Section 1.1 for an informational description of the DTI protocol.

6.1 DTI Timing Entities

The DTI protocol is supported by two terminated entities.

1. DTI Server
2. DTI Client

DTI Server and Client functional entities are part of M-CMTS architecture. The DOCSIS Client function is structured to permit a low cost client clock function within all EQAMs, upstream receivers, and M-CMTS CORE entities.

The DTI Server **SHOULD** support multiple client functions to support scalable growth of DTI port capacity within a node or building.

The DTI Server **MUST** support an SNMP management interface, IP addressing, and use RJ45 connectors.

DTI server in a single building **MAY** consist of active and backup servers components in a common shelf and/or DTI servers in subtending shelves.

A DTI server **MAY** support at least one of the following two capabilities:

1. Operation as a subtending server.
2. Provide DTI outputs capable of supporting DTI subtending servers.

The following accuracy requirements may be confirmed with a delay-calibrated client. A delay-calibrated client provides sufficient measurement points to determine current calibrated delay bias.

All DTI root server outputs **MUST** meet a 1.25 ns accuracy requirement when tested with a delay calibrated client with respect to the DTI root server master clock test port with correction for test port group delay.

All DTI subtending server outputs **MUST** meet a 2.5 ns accuracy requirement when tested with a delay calibrated client with respect to the DTI root server master clock test port with correction for test port group delay.

A DTI output that can support a subtending DTI server **MUST** meet a 1.25 ns accuracy requirement when tested with delay-calibrated client under normal operating conditions. An M-CMTS EQAM, M-CMTS CORE or a separate upstream receiver **MUST** support at least one DTI client interface.

A DTI server in slave mode is intended to only accept a DTI input from a root server.

An M-CMTS device **MAY** support multiple DTI clients if protection for a DTI interconnect cable loss is desired.

If an M-CMTS device has more than one DTI client, it **MUST** not switch to a protection client as a result of a loss of DTI input until a minimum timeout of 500 ms.

6.2 DTI Timing Structure

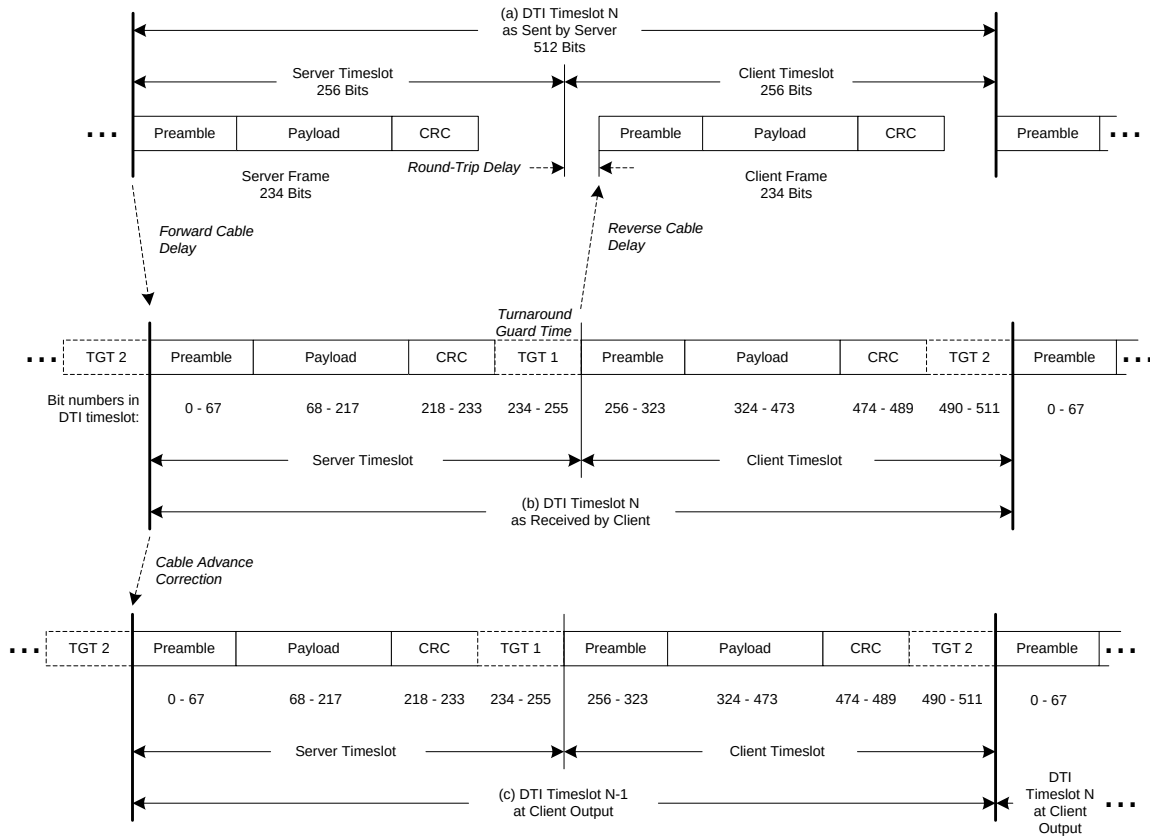


Figure 6-1 - DTI Protocol Timing Structure

Figure 6-1 defines the structure of the DOCSIS Timing Protocol as (a) sent by the Server, (b) received by the Client after the cable delay, and (c) output at the Client Test Port after the cable advance correction. The highest-level structure is the DTI Timeslot. A DTI Timeslot occupies 1024 master clock (10.24 MHz) periods spanning $1/10 \text{ kHz} = 100 \text{ us}$. A bit period consists of two consecutive master clock counts starting with an even count, resulting in 512 bit periods in a DTI timeslot. The timeslot is synchronized to the DOCSIS 32-bit timestamp (DTS), such that the current bit period of a timeslot is the integer, as follows:

$$\text{current_bit_count} = \text{floor}[(\text{DTS mod } 1024)/2]$$

The Client's received DTI Timeslot timing is offset from the Server's DTI Timeslot timing by the cable propagation delay (plus any group and logic delays). Since the Client when in steady state tracks the Server, the Client counts off a continuous succession of bit slots timed on its own 5.12 MHz bit clock, repeating DTI Timeslots seamlessly modulo 512 bits. The Client always receives the first preamble bit from the Server in bit slot 0. When it transmits, the Client MUST transmit the first bit of its preamble in bit slot 256.

The DTI protocol is ping-pong in nature. The Server and Client share the line using time division duplexing (TDD), one transmitting while the other receives. The DTI timeslot is divided into two equal intervals, the Server Timeslot and Client Timeslot. Layer 2 communication protocol data units (PDUs) are termed Frames. Both Server and Client Frames are 234 bits in length, and each is followed by a 22 bit Turnaround Guard Time (TGT). The purpose of TGT1, located after the Server Frame, is to allow time for the Client to complete its CRC processing and perform receive/transmit switching on the line after receipt of the Server Frame. The purpose of TGT2, located after the Client Frame, is to provide for the round-trip delay of the cable, ensuring that the Client Frame has been received by the Server before the Server begins transmitting the next Server Frame, including time for the Server to perform

receive/transmit switching on the line after receipt of the Client Frame. Each TGT provides approximately 4.3 μ s of guard time, which well exceeds the maximum round-trip delay for 200 m cable of approximately 2 μ s.

At the Client output, the DTI Frame timing is adjusted earlier in time by the cable advance correction sent by the Server, in order to align the Client output frame timing closely with the Server frame timing. To allow for causality, the data received during the previous frame is buffered and output by the Client after the CRC check has completed.

6.3 Traceability of DOCSIS Timestamp

Time of Coincidence (TOC) is an important concept to understand the relationship of any DTI Timestamp (DTS) 32-bit counter to GPS system time. GPS system time began on January 6, 1980. GPS receivers will provide a 32-bit gpssec timestamp that was zero at the January 6 start epoch. The gpssec is a 32-bit timestamp counter that is incremented every second. The DTS is also a 32-bit timestamp counter that is incremented every 10.24 MHz master clock. The objective is to map the current GPS system time to the current DOCSIS Timestamp in a coherent manner.

By definition, the DTS can be assigned the value of zero at the same January 6, 1980 start epoch. At the next second, the DOCSIS timestamp will advance 10,000 timeslots with 1024 master clocks per timeslot, so the DTS should be 10240000.

The TOC is the next integer gpssec when the DTS will be exactly zero. This will occur every 262144 seconds (~ every 3 days)¹. If a reset to zero process were used to synchronize every DTS counter in a server then it would require up to 3 days to align a server at start-up. The approach is to generate an initial value for DTS by a mapping function so that the alignment can occur on any one second boundary.

The mapping function from gpssec to DTS MUST be:

$$\text{DTS} = 2^{10} * [10,000 * (\text{gpssec} \bmod 262144)] \bmod 2^{22}$$

Or,

The mapping function from gpssec to DTS MUST be:

$$\text{DTS} = [2^{10} * \{10,000 * (\text{gpssec} \bmod 262144)\}] \bmod 2^{32}$$

The four time-of-day setting modes are:

1. GPS
2. User Time Set
3. Default Time Set
4. Network Timing Protocol (NTP) version 4 or greater

The GPS traceability mode provides the most precise time setting capability. Regardless of the Time of Day mode, the DTI server MUST convert time of day information to the equivalent gpssec value.

The user time set permits a user to enter an approximate time of day setting through either a local or remote user interface. The default time set operation, if selected, will establish a coarse time of day setting after a reset or power cycle. The time of day is based on the current value of the real time clock in the server.

The NTP time set mode if supported will allow the DTI server to establish a time setting via the NTP protocol as currently configured in the DTI server. If NTP time mode is supported, the DTI server MUST support NTP version 3 or higher.

The DTI server MUST support a means to configure the time of day setting modes of User Time Set, Default Time Set, NTP or GPS.

¹ The gpssec timescale will rollover every 136 years. Since there are exactly 16,384 TOC events between rollovers, there is no disruption of the DTS.

6.3.1 GPS Frequency Mode

In order to provide continuity in the DTI timebase when transitioning from free run mode or network mode to GPS mode, an intermediate state, "GPS frequency mode," is defined. When the DTI server transitions from free run or network mode to GPS frequency mode, the DTI server's 10.24 MHz output frequency is adjusted smoothly so as to track the GPS system frequency, while maintaining continuity of the DTI time counters. The system may remain in GPS frequency mode for an extended period of time. If and when the DTI server transitions from GPS frequency mode to GPS mode, the DTI time counters are realigned to GPS time; this may be done in a discontinuous manner during a scheduled maintenance period.

When transitioning from free-run or network mode to GPS mode, the DTI server **MUST** enter the GPS frequency mode first.

In GPS frequency mode the DTI server **MUST** maintain the existing time setting mode and validity state unless changed as a result of user time setting input.

The DTI server **MUST** support a user input to schedule a transition time from GPS frequency mode to GPS mode.

The DTI server operating in normal lock in GPS frequency mode **MUST** meet the same MTIE requirements as in GPS mode.

During the transition from free-run to GPS frequency mode normal lock, all DTI server free run requirements **MUST** be met.

During the transition from normal lock network to GPS frequency mode normal lock, all DTI server normal lock network MTIE requirements **MUST** be met.

Under extended GPS holdover conditions it is possible to enter the degraded MTIE region of performance. The DTI server needs to support a graceful recovery from this state if it should arise. The following requirement applies:

When recovery from a GPS degraded condition, the DTI server **MUST** support the ability to slew the frequency to accommodate at least 1 ms of offset over a recovery period of less than 24 hours without exceeding the free run performance limits.

In user mode and default mode there are no requirements to adjust the DTI timescale and TOD output after the initial time setting. The DTI time services are for local use only and not traceable to GPS system time.

If the DTI server supports frequency adjustment of the timescale in NTP mode, the vendor **SHOULD** specify the time accuracy performance under vendor defined NTP configuration(s).

If the DTI server supports frequency adjustment of the timescale in NTP mode, the DTI server output performance requirements **MUST** meet the performance requirement of the system operation mode (freerun or network).

If frequency adjustment of the timescale in NTP mode needs to be suspending to prevent degradation of output, the DTI server **MUST** report this condition.

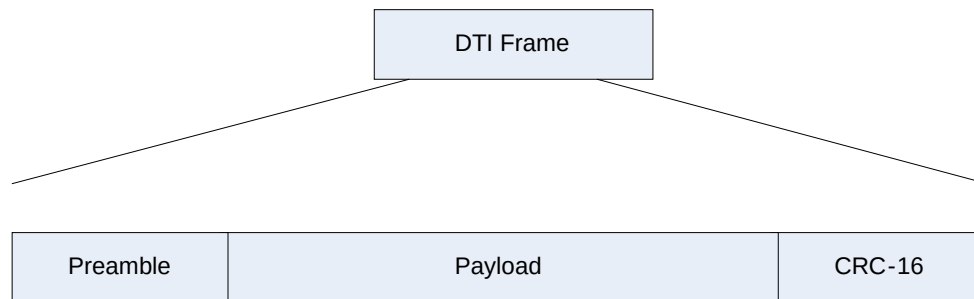
If the user requests a transition from user or default time setting to NTP after warmup, the DTI server **MAY** reject the request if the transition would degrade the output performance.

6.4 DTI Frame Structure Requirements

The DTI frame structure **MUST** consist of a preamble followed by the payload and finally by a 16 bit CRC as shown in Figure 6–2. The length of the DTI frame, including the preamble and the CRC **MUST** be 234 bits. The CRC **MUST** be calculated only on the payload bits. The rising edge of the 10 kHz DTI frame clock **MUST** be aligned with the leading edge of the first bit of the preamble of the DTI server. The client digital clock recovery circuit **MUST** be tolerant to missing clocks since any bit error in the frame will prevent the CRC OK flag in the client CRC checker from being asserted.

6.4.1 Conventions for this Specification

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 from top to bottom, with the MSB being the first bit so read and the LSB being the last bit so read. The DTI frames are transmitted most significant element first. Within bit fields, the most significant bit **MUST** always be transmitted on the wire first. There are nine bit fields that constitute a frame in each direction. Fields **MUST** transmit in numerical order from lower to highest value (see Table 6–1 and Table 6–2 for field order).



DTI Frame Structure

Figure 6–2 - DTI Frame Structure

6.4.2 SERVER TO CLIENT

The frame structure in the server to client direction **MUST** operate as shown below in Table 6–1.

Table 6–1 - DTI Server Frame Structure

DTI Server Frame Structure			
FIELD	NAME	SIZE (Bits)	DESCRIPTION
1	PREAMBLE	68	Preamble of 0xAAAA AAAA AAAA AAAA 9 prior to Manchester encoding
2	DEVICE TYPE	8	Byte describing type of server.
3	SERVER STATUS FLAGS	8	8 flag bits identifying server status.
4	DOCSIS UPPER TIMESTAMP	22	22 Most Significant Bits of the DTS
5	TIME OF DAY	10	Field supports serial TOD message over multiple frames.
6	CABLE ADVANCE	24	Integer and Fractional Cable Advance
7	PATH TRACEABILITY FIELD	10	Field supports serial Path Traceability Message over multiple frames.
8	RESERVED	68	All bits set to one.
9	CRC16	16	16 bit CRC, which covers all bits except preamble.
	Total Payload Bits	234	

In the server to client direction, the DTI frame structure details are as follows.

6.4.2.1.1 Preamble

The 68-bit preamble is used to align the digital clock recovery circuit on the client and to locate the bit transitions in the Manchester coding that contain information. 0x9 "1001" pattern at the end of the preamble locates the beginning of the payload.

6.4.2.1.2 Device type

The 8-bit device type field is used to identify the type of server and its timing source. The bits in this field **MUST** be assigned as shown below:

Bits 7:5 External Timing Source (for root server)

- 000: Server has no external timing source
- 001: Server is receiving external time and frequency from GPS
- 010: Server is receiving timing from a network
- 011: Server is receiving external frequency only from GPS (no time)
- 111: Reserved

Bit 4:3 Server Hop Count

- 00: Server is the root DTI Server for the office distribution
- 01: Server is directly connected to root DTI server.
- 10-11: Reserved

Bits 2:0 Root Server Clock Type:

- 000: Server clock is ITU type I
- 001: Server clock is ITU type II
- 010: Server clock is ITU type III
- 011: Server clock is ANSI T1.101 ST3 (back-up operation only)
- 100-111 reserved

6.4.2.1.3 Server Status Flags

This 8-bit field is used to send the server status to a client. The information in this field relates to the DTI Server transmitting the DTI protocol. The bits **MUST** be assigned as shown below:

Bit 7: Reserved

Bit 6: Client Performance Stable

This bit, when set to 1, indicates that the server verifies the client phase error measurement is within acceptable operating performance.

Bit 5: Cable Advance

This bit, when set to 1, indicates that the cable delay has been calculated and that the value in the cable advance field is valid.

Bit 4: Holdover mode

This bit, when set to 1, indicates that the server has lost its timing reference and is in holdover.

Bit 3: Normal mode

This bit, when set to 1, indicates that the clock is stable, has locked on to the timing reference, and is compliant with the appropriate clock standard.

Bit 2: Fast mode

This bit, when set to 1, indicates that the clock is using a short time constant. A shorter time constant is used in the clock circuit to shorten the initial lock time when the server first powers up or receives a reference for the first time.

Bit 1: Freerun mode

This bit, when set to 1, indicates that the server is operating with output frequency that has not been influenced by local external reference signals.

Bit 0: Warmup

This bit is set to 1 to indicate that the reference oscillator has not stabilized yet.

6.4.2.1.4 DOCSIS Upper Time Stamp

These 22 bits MUST contain the most significant portion of the DOCSIS 32-bit timestamp, which is the portion of the timestamp that remains constant for an entire DTI Frame period (1/10 kHz = 100 us). These bits are used to load and/or monitor the upper 22 bits of the 32-bit DOCSIS timestamp counter in the client. The 10 least significant bits of the DOCSIS timestamp counter in the client represent the number of 10.24 MHz clocks since the beginning of the DTI Frame. Together, these two fields create the entire 32-bit DOCSIS timestamp.

6.4.2.1.5 Time of Day

The Time of Day (TOD) message provides time in binary format and optionally in ASCII format, each with 1-second resolution. The gpssec time and leap second are sent in binary format. When in verbose mode, calendar time in ASCII format is also sent, including a modified Julian date and local date/time information. The TOD message is transmitted at a rate of 10 bits (one byte of payload and two control bits) per DTI frame, and is subcommutated to span multiple DTI frames. The first control bit indicates that the location of the pulse per second will be coincident with the beginning of the next frame. The second control bit is a data valid flag which applies to the payload byte. The data valid flag may be used to stop and start the subcommutated byte stream. When the data valid flag is 0, the payload byte MUST contain all ones. When the data valid flag, is 1, the payload byte MUST contain the next serial byte in the TOD message. The TOD message corresponding to a given PPS count MUST start transmission one or more frames after the frame where the PPS flag bit has been set, and complete transmission within 100 ms. The bit assignments for the 10-bit TOD message field in each DTI frame MUST be as follows:

Bit 9: PPS flag

This bit MUST be set to '1' when the beginning of the next frame is coincident with the DTI server pulse per second². The asserted "1" indicates that the next DTI server frame PPS flag position bit is the on-time mark for PPS information just transferred during the last one second period. ³The PPS flag bit is asserted in every 10,000th frame.

Bit 8: Data Valid bit

This bit is set to '1' to indicate that the data in the payload byte (following eight bits) contains valid data.

² The Pulse Per Second is free-running except in GPS mode where it aligned to the GPS 1PPS.

Bit 7-0:

This field contains the subcommutated TOD payload byte, which MUST be in accordance with Table 6–2.

Table 6–2 - TOD subcommutated message format

Byte Number	Length	Type	Format	Name	Description
1	1	Binary	See TOD Status Field description below this table.	TOD Status	
2-5	4	Binary		gpssec	32-bit gpssec timestamp (MSB is most significant byte is zero)
6	1	Binary		Leap Seconds	Cumulative leap seconds between gpssec and UTC
7	1	7-bit ASCII	ASCII "*" (0x2A) denotes Valid TODCalendar Time ASCII "!" (0x21) denotes Invalid Calendar TimeTOD	TOD Calendar Time Valid	
8-12	5	7-bit ASCII	MMMMM Where M is [0-9] ASCII	MJD	Modified Julian Date (number of days since November 17,1958)
13	1	7-bit ASCII	ASCII Decimal Point "." (0x2E)		
14-23	10	7-bit ASCII	Year/Month/Day Year::[0000-9999] Month:[1-12] Day:[1-31]	Date	Local Date
24	1	7-bit ASCII	ASCII Decimal Point "." (0x2E)		
25-32	8	7-bit ASCII	Hour:Min:Sec Hour:[00-23] Min:[00-59] Sec:[00-60] ⁴	Time	Local Time
33	1	7-bit ASCII	ASCII Decimal Point "." (0x2E)		
34:38	5	7-bit ASCII	SHH.F S: sign [+ , -] H: offset in hours F: [0] or ([5] for 30 minute offsets)	Time Zone Offset	Local time zone offset
39	1	7-bit ASCII	ASCII Decimal Point "." (0x2E)		
40 ⁵	1	7-bit ASCII	Leap Leap: +, 0, -	Leap Second Indicator	"+" for adding leapsecond "0" for no leapsecond "-" for subtracting leapsecond
41	1	7-bit ASCII	ASCII Carriage Return (0x0D)		

6.4.2.1.6 TOD Status Field

The 8-bit is used to report the status of the Time Of Day Message. The bits in the TOD Status Field MUST be assigned as shown below:

Bits 7: 4 Time Setting Mode

⁴ 60 second indicator may be used to indicate a leap second

- 0000: Default Time Setting Mode
- 0001: User Time Setting Mode
- 0010: NTP Time Setting Mode
- 0011: GPS Time Setting Mode
- 0100-1111: Reserved

Bit 3:2 TOD state

- 00: TOD is currently not valid
- 01: TOD is valid
- 10-11: Reserved

Bits 1:0 TOD Message Mode

- 00: Short Message Mode. Message bytes 0-5 (binary only)
- 01: Verbose Message Mode: Message includes all fields in Table 6–2
- 10-11: Reserved

The DTI server **MUST** support the Short Message Mode for TOD delivery.

The Verbose Message Mode **SHOULD** be supported by the DTI server.

If more than one TOD message mode is supported the default **MUST** be the Short Message Mode.

If more than one TOD message mode is supported the mode **SHOULD** be configurable on a port basis.

6.4.2.1.7 Cable Advance

Cable Advance is described in 7.1.2. The cable advance information **MUST** be contained in this 24-bit field. The 16 most significant bits of the cable advance **MUST** contain the integer portion of the cable advance value that is in 149.8 MHz⁶ sample clock cycles. The remaining 8 bits, the least significant byte of the cable advance, **MUST** be the fractional portion of the cable advance and is in 1/256 of a 149.8 MHz clock cycle.

6.4.2.1.8 Path Traceability Field

The path traceability field is used to transfer messages containing path information from a server to a client. A path message is a concatenated set of type, length, value (TLV) data items as defined in this section. Sub-commutating the path message over multiple DTI timeslots supports the transport of path messages. A path message slot is a 10ms time interval and **MUST** begin when the DTI upper time-stamp modulo 100 is equal to zero. By design the maximum length of a path message **MUST** be less than or equal to 64 bytes. If a message is pending, the server **MUST** assert the start of message flag within 1 ms of the start of a path message slot and **MUST** complete delivery within 9 ms of the start a path message slot. The message transmission **MUST** start coincident with the start of message flag or one frame after the start of message flag.

The DTI server **MUST** support path traceability message. For the path traceability message the maximum transfer rate **MUST** be less than or equal to one message per second. For the path traceability message the minimum transfer rate **MUST** be greater than or equal to one message every 5 seconds. The path traceability message **MUST** utilize the first path message slot after the frame where the PPS flag bit has been set.

After a path traceability message is transferred, the DTI server **MUST NOT** transmit other messages until the next 1PPS event.

The Path Traceability Field is 10-bit field that **MUST** be used to send byte oriented data to the client. The path traceability field **MUST** be filled as follows:

Bit 9: Start of Message

⁶ The 149.8 MHz high-speed clock is more precisely 10.24MHz * 512/35.

The path traceability field start of message bit MUST be set high for one frame to indicate the beginning of a status message.

Bit 8: Data Valid Bit

The path traceability field data valid bit MUST be set to '1' to indicate that the next eight data bits contain valid data. When the path traceability field data valid bit is '0', the client MUST ignore the contents of the eight data bits that follow.

Bit 7:0: Data Byte

This data byte MUST contain the serial message data bytes.

Table 6–3 - Path Traceability Message Format

Name	Type (1 byte)	Length (1 byte)	Value (variable length)
Root DTI Server IPV4 Address	1	4	IP address of Root DTI Server (highest level in tree)
Root DTI Server Output Port #	2	1	Root server output port number for this DTI interface. Output port number counting starts at 0 and goes through 255.
DTI Server IPV4 Address (if not root server)	3	4	IP address of DTI Server source DTI interface (if not root server)
DTI Server Output Port #	4	1	Server output port number for this DTI interface. Ports start counting at 0 and continue to 255.
Root DTI Server IPV6 Address	5	16	IP address of Root DTI Server (highest level in tree)
DTI Server IPV6 Address (if not root server)	6	16	IP address of Root DTI Server (highest level in tree)
Root DTI Server DTI Version ⁷	7	1	DTI version number running on Root Server
DTI Server DTI Version	8	1	DTI version number running on DTI Server (if not root server)
EOT	9	1	0x00 The EOT identifies the end of the Path Traceability Field.

If there is subtending DTI Server, the root DTI server address MUST be passed through the subtending DTI server to DTI clients. In other words, a DTI client connected to a root server through an intermediate server will have both a Root Server IP address and a Server IP address in the path traceability field. The root server MUST not transmit the non-root IP information. The path traceability field MUST follow the Type, Length, and Value sequence, as shown below, and follows the bit/byte ordering already defined.

The DTI server MAY support the path location message (Table 6–4). The path location message provides the GPS positioning information (if available) associated with the root server. Since all clients are within a maximum radial distance of 400m from the root server, this position information can support position related algorithms, routing other related applications. For the path location message the maximum transfer rate MUST be less than or equal to one message per second. For the path location message the minimum transfer rate MUST be greater than or equal to one message every 5 seconds. A subtending server MUST relay the path location message from the root to all downstream DTI client ports.

⁷ For DTI servers compliant with the first release of this standard this value shall be zero.

Table 6–4 - Path Position Message Format

Name	Type (1 byte)	Length (1 byte)	Value (variable length)
UTC Time Stamp	11	6	UTC Time of position fix "12": hh 00-23 hours "34":mm 00-59 minutes "56":ss 00-59 seconds
Latitude	12	9	"34": degree 00-90 "44": minute (integer) 00-59 "0000":minute (fractional) 0000-9999 "N": North/South N or S
Longitude	12	10	"135": degree 000-180 "44": minute (integer) 00-59 "0000":minute (fractional) 0000-9999 "E": East/West E or W
GPS Quality Indication	13	1	"0" Fix not available or invalid "1" Fix is valid
No. of satellites used for positioning	14	2	00-12
Dilution of Precision	15	5	02.34 Note 00.00 when position is interrupted or suspended
Altitude	16	9	"+" +/- sign relative to geoid 12345.6 00000.0 to 04000.0 "M" unit meters
EOT	17	1	0x00 The EOT marks the end of the Path Position Message.

6.4.2.1.9 Reserved

The remaining 68 bits MUST be reserved for future use. They will be filled with '1's until defined otherwise.

6.4.2.1.10 CRC 16

The CRC-16 field MUST contain the 16 bit CRC16 cyclic redundancy check. The CRC-16 algorithm is defined as Annex C, DTI-S CRC-16.

6.4.3 CLIENT TO SERVER

The frame structure for the client to server direction MUST operate as shown below in Table 6–5.

Table 6–5 - DTI Client Frame Structure.

DTI CLIENT FRAME STRUCTURE			
Field	Name	Size	Description
1	PREAMBLE	68	Preamble of 0xAAAA AAAA AAAA AAAA 6 prior to Manchester encoding
2	DEVICE TYPE	8	Byte describing type of client