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E1.59 – 2021

Entertainment Technology – Object Transform Protocol (OTP)

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The ESTA Technical Standards Program was created to serve the ESTA membership and the entertainment industry in technical standards related matters. The goal of the Program is to take a leading role regarding technology within the entertainment industry by creating standards, monitoring standards issues around the world on behalf of our members, and improving communications and safety within the industry. ESTA works closely with the technical standards efforts of other organizations within our industry, including USITT and VPLT, as well as representing the interests of ESTA members to ANSI, UL, and the NFPA. The Technical Standards Program is accredited by the American National Standards Institute.

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The Control Protocols Working Group, which authored this standard, consists of a cross section of entertainment industry professionals representing a diversity of interests. ESTA is committed to developing consensus-based standards in an open setting. Future Control Protocols Working Group projects will include updating this publication as changes in technology and experience warrant, as well as developing new standards for the benefit of the entertainment industry.

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1 Introduction

1.1 Scope

This standard describes a mechanism to transfer object transform information such as position, rotation and velocity over an IP network. It covers data format, data protocol, data addressing, and network management. It does not require real-world location or any association between multiple objects represented in the same message.

Data transmitted is intended to coordinate visual and audio elements of a production and should not be used for safety critical applications.

1.2 Overview and Architecture

This standard can be used to transfer information, such as that about an object's position, rotation, velocity, and acceleration via an IP network. To provide scalability, multiple messages may be used to encapsulate this information for a particular transmitting device.

This standard uses multicast addressing to provide a mechanism for simple one-to-many or many-to-many environments. Unicast addressing is used for responses, where required.

1.3 Appropriate Use of This Standard

This standard uses a non-reliable IP transport mechanism to stream messages from multiple sources to multiple receivers over an IP network. There is no acknowledgement and, therefore, it offers no assurance that all messages have been received.

1.4 Classes of Data Appropriate for Transmission

This standard is intended to define a method to carry lightweight object transform data and metadata over IP networks. It is designed to carry repetitive observational data from one or more producers to one or more consumers. This protocol is intended to be used to provide lighting, video, sound, and other media systems with information about objects for the purpose of live tracking and effect synchronization.

1.5 Advertisement

This standard defines mechanisms by which consumers and producers can advertise information about themselves. This includes the modules a consumer supports, the systems for which a producer provides object transform data and the names of points. This information is used for automatic configuration, bandwidth conservation and to provide useful information to the user.

1.6 Compliance

Compliance with this standard is strictly voluntary and the responsibility of the implementor. Markings and identification or other claims of compliance do not constitute certification or approval by the E1 accredited standards committee.

2 Normative References

[ASIPM] RFC 2365 Administratively Scoped IP Multicast.

This standard is maintained by the IETF.

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[CommonShowFile] ANSI E1.44 Common Show File Exchange Format For Entertainment Industry Automation Control Systems - Stage Machinery

This standard is maintained by Entertainment Services and Technology Association

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[EmbeddedRP] RFC 3956 Embedding the Rendezvous Point (RP) Address in an IPv6 Multicast Address

This standard is maintained by the IETF.

[IGMP2] RFC 2236 IGMPv2 Internet Group Management Protocol Version 2

This standard is maintained by the IETF.

[IPv6McastScope] RFC 7346 IPv6 Multicast Address Scopes

This standard is maintained by the IETF.

[ManufId] Control Protocols Working Group – Manufacturer IDs

http://tsp.esta.org/tsp/working_groups/CP/mfctrIDs.php

[MLD] RFC 2710 Multicast Listener Discovery (MLD) for IPv6

This standard is maintained by the IETF.

[NTP] RFC 5905 Network Time Protocol Version 4

This standard is maintained by the IETF.

[UDP] RFC 0768 UDP User Datagram Protocol

This standard is maintained by the IETF.

[UnicastPrefixMcast] RFC 3306 Unicast-Prefix-based IPv6 Multicast Addresses

This standard is maintained by the IETF.

[UTF-8] The Unicode Standard, Version 5.0 (Boston, MA, Addison-Wesley, 2007. ISBN 0-321-48091-0).

The Unicode Consortium.

[UUID] RFC 4122 P. Leach, M. Mealling, and R. Salz. *A Universally Unique IDentifier (UUID) URN Namespace*. July 2005.

This standard is maintained by the IETF.

3 Definitions

Octet: An eight-bit byte.

Point: The smallest, indivisible component having properties of motion. This may be the center of a complex Object, or merely one of many *Points* on it.

Object: A conceptual container composed of one or more Points. An *Object's* motion is described via the properties of the Points that make it up.

Group: A user-defined collection of one or more Points. A *Group* could describe a single Object, many Objects, or simply a set of Points with some logical association.

System: A user-defined collection of one or more *Groups. Systems* provide part of the method of partitioning network traffic.

Module: A set of properties of a Point, such as its position or rotation. The data structure of a *Module* is either defined by this standard, or it is manufacturer-specific.

System Number: Each System is assigned a unique *System Number,* identifying the System.

Group Number: Each Group is assigned a *Group Number,* identifying the Group within its System. *Group Numbers* are unique within a System. That is, anything within a single System with the same *Group Number* belongs to the same Group. In a multi-System implementation, there may be several Groups (a maximum of one per System) with the same *Group Number.*

Point Number: Each Point is assigned a *Point Number,* identifying the Point. A *Point Number* is unique within a Group. In a multi-Group System, or a multi-System implementation, there may be many Points with the same *Point Number*.

Address: The combination of System Number, Group Number, and Point Number make up the *Address* which identifies a Point.

Reference Frame: Each Point can be assigned a single *Reference Frame,* which is another Point with which it shares a kinematic relationship. Transform information for the Point is relative to the *Reference Frame*.

Time Origin: The *Time Origin* is the point in time from which a Component's timestamps are calculated (represented as 0 microseconds). Components may use a standard system such as Unix Time, the moment a Component initializes, or any other moment in time as the *Time Origin*.

Rotation: The circular movement or orientation of an object around a Point of rotation. For the purposes of OTP, *Rotation* and orientation are considered equivalent and are relative to the space defined in Section 4, or any assigned Reference Frame. There are 3 rotational axes: X,Y,Z.

Producer: A *Producer* is any network device transmitting OTP Transform Messages.

Consumer: A *Consumer* is the intended target of information from a Producer.

Component: Producers and Consumers are all OTP *Components.*

OTP Transform Message: An OTP Transform Message carries object transform information such as position and rotation. It is transmitted with the VECTOR_OTP_TRANSFORM_MESSAGE vector.

OTP Advertisement Message: An OTP Advertisement Message is any of the set of messages containing OTP Module Advertisement Messages, OTP System Advertisement Messages and OTP Name Advertisement Messages. It is transmitted with the VECTOR_OTP_ADVERTISEMENT_MESSAGE vector.

OTP Module Advertisement Message: An *OTP Module Advertisement Message* contains a packed list of the Module Identifiers of Modules supported by a Consumer. It is transmitted with the VECTOR_OTP_ADVERTISEMENT_MODULE vector.

OTP System Advertisement Message: An *OTP System Advertisement Message* contains a packed list of the System Numbers for which Producer provides object transform data. It is transmitted with the VECTOR_OTP_ADVERTISEMENT_SYSTEM vector.

OTP Name Advertisement Message: An *OTP Name Advertisement Message* contains a packed list of the Point Names and associated Addresses for a Producer. It is transmitted with the VECTOR_OTP_ADVERTISEMENT_NAME vector.

OTP Message: An *OTP Message* is any of the set of messages containing OTP Transform Messages and OTP Advertisement Messages.

OTP Folio: An *OTP Folio* is a set of OTP Messages with the same folio number. Together they make up a snapshot of information which due to its size has to be split across multiple messages.

Full Point Set: A *Full Point Set* for a Producer includes every Point for a specific System for which a Producer is currently providing transform information.

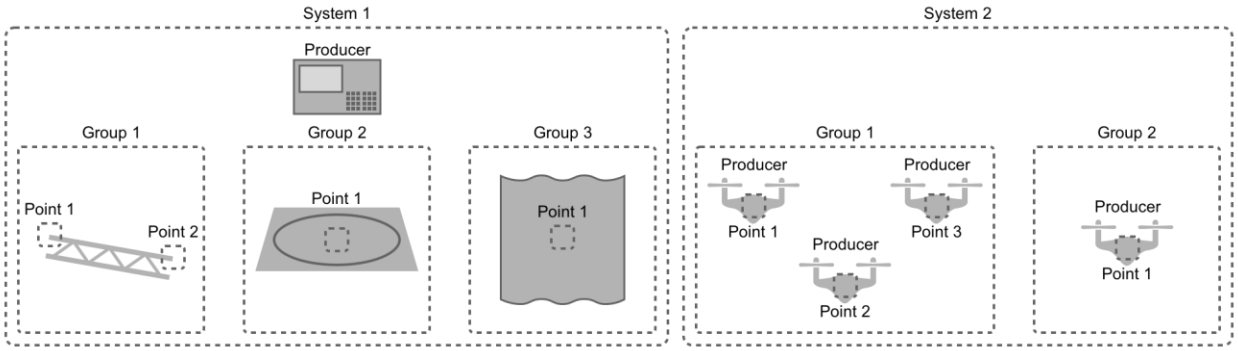

Figure 3-1: Example System, Group and Point Assignment (Informative)

4 Space

4.1 Coordinate System

To establish the coordinate system, it is first necessary to set an origin and a viewpoint. All axes are defined using these two elements as reference. Establishing the origin and viewpoint is the responsibility of the user, and outside the scope of this standard. Table 4-1 has some examples of potential origins and viewpoints for different environments.

Table 4-1: Origin and Viewpoint Examples

Space	Origin	Viewpoint
Proscenium Theatre	Downstage Center, Stage Level	Auditorium Center
Arena	Center of Arena Floor	Operating Position
TV Studio	Center of Studio Floor	Camera 1 Position

Components complying with this standard shall use a Right-Handed Z-up coordinate system as described in Table 4-2. The linear Y axis is defined for a viewer located at the viewpoint looking at the origin. Positive rotation for each axis is defined as clockwise for a viewer located at the origin and looking at that axis in a positive linear direction. Zero degrees for each axis is defined for a viewer located at the viewpoint, standing upright, and looking at the origin.

Table 4-2: Coordinate System

Axis	Linear Positive	Linear Negative	Zero Degrees
X	Right	Left	Up
Y	Far	Near	Up
Z	Up	Down	Far

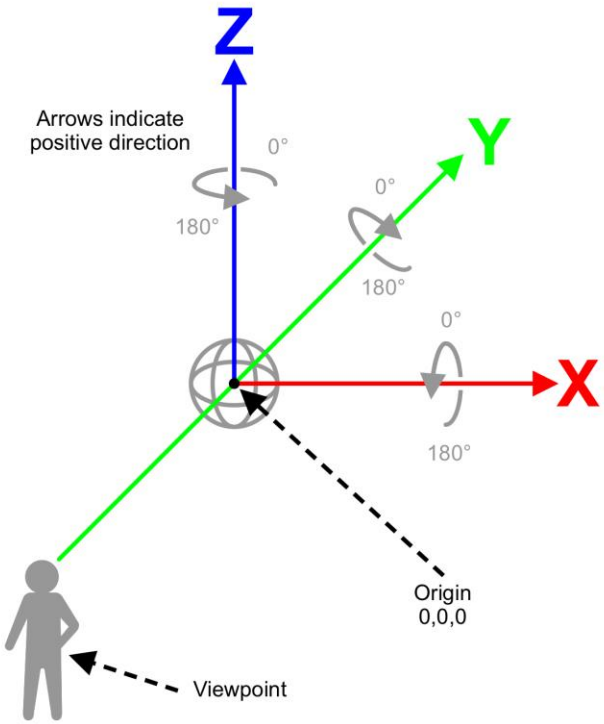

Figure 4-1: Coordinate System Illustration

4.2 Rotation Scheme

The default modules in this standard include a way to describe the rotation of a Point using Euler angles.

Implementors of this standard supporting the Rotation (Section 16.3) and Rotation Velocity/Acceleration Modules (Section 16.4) shall describe the final rotation of an object in three-dimensional space as the combination of at most three sequential rotations, each around an axis that differs from the preceding one.

Implementors shall use intrinsic rotation conforming to the Tait-Bryan ZYX convention, which is described by a rotation around the object's Z axis, followed by a rotation around the object's Y axis, and then a rotation around the object's X axis. In aeronautics, these three rotations are often described as yaw, pitch, and roll.

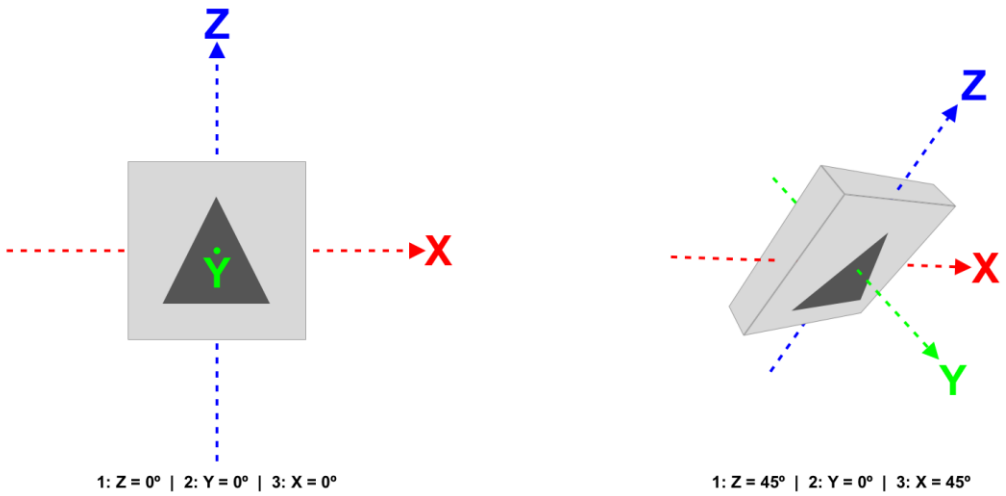

Figure 4-2: Intrinsic Tait-Bryan ZYX Example (Informative)

For further information on Euler angles and other forms of rotational notation see Appendix C.

4.3 Defining the space (Informative)

Although it is likely that Points sharing the same System Number or Group Number have some association with each other, implementors should be aware that no relationship is implied by this standard. While it is beneficial to define a single origin and viewpoint for an entire space, there is no requirement for users of this standard to do so.

When using a single origin for a space, it is strongly suggested that implementors and users of OTP refer to Section 5.3 of [CommonShowFile] which defines a common origin (datum) and rotational zero degree reference point ([CommonShowFile], Section 5.3.1.2.5).

5 OTP Structure and PDU

OTP shall use the OTP Layer as defined in Section 6. Every OTP Message shall conform to the same OTP Layer structure.

5.1 Protocol Data Unit

OTP Messages typically carry one or more Protocol Data Units, or PDUs. Each PDU contains 3 segments: Vector, Length, and Data.

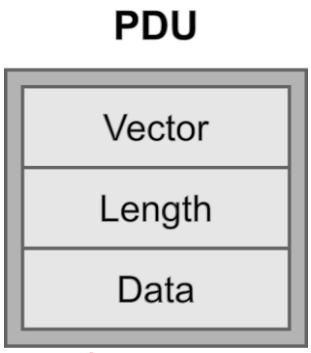

Figure 5-1: PDU

5.1.1 Vector Field

The Vector field shall be 2 octets and shall differentiate the payload of the PDU. It is a key that describes the format of the rest of the information contained in the Data field of that PDU.

5.1.2 Length Field

The length field shall be 2 octets and shall specify the length in octets of the rest of the PDU, excluding the Vector and Length fields.

5.1.3 Data Field

The Data field stores the payload of the PDU. This field may be empty, may contain additional sub-fields, or may contain entire PDUs.

6 OTP Layer

The OTP Layer carries a single PDU which is either an OTP Transform Layer PDU or an OTP Advertisement Layer PDU. Each of these top level PDUs may contain any number of nested PDUs, which in turn may carry additional nested PDUs.

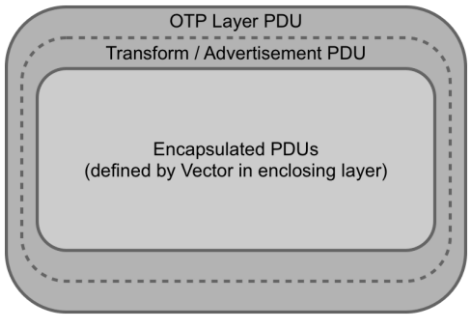

Figure 6-1 OTP Message Structure

Table 6-1: OTP Layer

Octet	Field Size	Field Name	Field Description	Field Contents
OTP Layer				
0-11	12	OTP Packet Identifier	Identifies this message as OTP	0x4f 0x54 0x50 0x2d 0x45 0x31 0x2e 0x35 0x39 0x00 0x00 0x00
12-13	2	Vector	Identifies the type of OTP data in the PDU	VECTOR_OTP_TRANSFORM_MESSAGE, VECTOR_OTP_ADVERTISEMENT_MESSAGE
14-15	2	Length	Length of message	The length of the message excluding the footer in octets, starting with octet 16.
16	1	Footer Options	Footer Options Flags	Reserved. Shall be transmitted as 0x00.
17	1	Footer Length	Length of footer	The length of the footer in octets.
18-33	16	CID	Sender's CID	Sender's unique ID.
34-37	4	Folio Number	Identifies OTP Folios	Identifier indicating which Folio this is.
38-39	2	Page	Page number	Identifier indicating which page of N this is - page numbers start at 0.
40-41	2	Last Page	Final page number	Page number of the final page to be transmitted.
42	1	Options	Options Flags	Reserved. Shall be transmitted as 0x00.
43-46	4	Reserved	Reserved	Reserved. Shall be transmitted as 0x00000000.
47-78	32	Component Name	Component Name	A human-readable [UTF-8] string identifying the Component.
…	…	Additional Fields Determined by Vector	…	...

6.1 OTP Packet Identifier

The OTP Packet Identifier shall contain the following sequence of hexadecimal characters: 0x4f 0x54 0x50 0x2d 0x45 0x31 0x2e 0x35 0x39 0x00 0x00 0x00.

Receiving Components shall discard the message if the OTP Packet Identifier is not valid.

6.2 Vector

Producers sending an OTP Transform Message shall set the OTP Layer's Vector to VECTOR_OTP_TRANSFORM_MESSAGE, indicating that the OTP Layer is wrapping an OTP Transform PDU.

Components sending an OTP Advertisement Message shall set the OTP Layer's Vector to VECTOR_OTP_ADVERTISEMENT_MESSAGE to indicate the OTP Layer is wrapping an OTP Advertisement PDU.

Receiving Components shall discard any OTP message if the vector value is not one of VECTOR_OTP_TRANSFORM_MESSAGE or VECTOR_OTP_ADVERTISEMENT_MESSAGE.

6.3 Length

The OTP Layer PDU length is computed starting with octet 16 and continuing through the last octet provided by the innermost layer (so, it is the length of the entire message, excluding the footer (See Section 6.5), minus 16, since counting begins at octet #16). Thus, messages would have total lengths in the ranges specified in Table 6-2.

Table 6-2: OTP Message Total Length

Message	Min Octets	Max Octets (not including footer)
OTP Transform Message	134*	1472
OTP System Advertisement Message	96	296
OTP Name Advertisement Message	96	1461
OTP Module Advertisement Message	99	1471

** 134 octets is the value calculated for a standard OTP Transform Message containing a single Point, and a single standard Reference Frame Module. In the case of Manufacturer-Specific Modules, this number could be as little as 128 if the payload contained but a single octet.*

6.3.1 OTP Message Maximum Length

The maximum size for an OTP Message shall be 1472 octets.

6.4 Footer Options

The Footer Options bit field is reserved for future use. Components shall transmit as 0x00. Receiving Components shall ignore this field. The footer that these flags describe is undefined and reserved for future use.

6.5 Footer Length

The Footer Length field is an 8-bit field containing the length of the footer in octets. All Components shall transmit a Footer Length of 0x00, indicating that there is no footer.

6.6 CID (Component Identifier)

The OTP Layer contains a Component Identifier (CID). This CID shall be a UUID (Universally Unique Identifier) [UUID] that is a 128-bit number that is unique across space and time, compliant with RFC 4122 [UUID]. Each piece of equipment should maintain the same CID for its entire lifetime (e.g. by storing it in read-only memory). This means that a particular Component on the network can be identified as the same entity from day to day, despite network interruptions, power down, or other disruptions. In the case of a system where volatile Components are created “on the fly,” it is acceptable to dynamically generate CIDs as required. The CID shall be transmitted in network byte order (big endian).

6.7 Folio Number

Components shall maintain a separate Folio Number counter for each type of OTP Advertisement Message they transmit (OTP Module Advertisement Message, OTP Name Advertisement Message, or OTP System Advertisement Message), and each System for which they transmit OTP Transform Messages. The Folio Number for the relevant OTP Advertisement Message type shall be incremented by one for every OTP Folio sent of that type. The Folio Number for the relevant System shall be incremented by one for every OTP Folio sent for that System.

Folio Numbers shall roll over from 0xFFFFFFFF to 0x00000000.

Components shall use the Folio Number to identify OTP Messages belonging to a single OTP Folio.

In a network environment, it is possible for messages to be received in a different order than that in which they were sent. The Folio Number, combined with the Page (See Section 6.8), allows Components or other diagnostic equipment to detect out-of-sequence or lost messages.

Components shall attempt to process all messages in the order that they are received. Components may choose to discard messages deemed not part of the current communication, or to attempt to re-order messages, using an algorithm such as the following:

CASE 1: A Component, having first received an OTP Message of type X (and System Y for OTP Transform Messages) with a Folio Number A and a Page Number M receives another OTP Message of type X (and System Y for OTP Transform Messages) with Folio Number A and a Page Number N which is not numerically one greater than M. The Component could assume that OTP Messages of type X sharing the same Folio Number A are part of the same communication, but have arrived out-of-sequence. The Component may attempt to re-order the messages, or may choose to discard the second message.

CASE 2: A Component, having first received an OTP Message of type X (and System Y for OTP Transform Messages) with Folio Number A, then receives another OTP Message of type X (and System Y for OTP Transform Messages) with Folio Number B. If, using unsigned 32-bit binary arithmetic, (A - B) falls within the range [0 - 65535], inclusive, then the message containing Folio Number B may be discarded as out-of-sequence and, in doing so, shall not be considered in the next iteration of this algorithm.

6.8 Page

It is possible that a single Producer or Consumer may need to transmit so much data that it will not fit in a single OTP Layer PDU. A single Producer may need to transmit many Point PDUs, a Consumer may support so many Modules that its List of Module Identifiers is too large, or a Producer may provide object transform data for so many Points that the List of Address Point Descriptions does not fit. In these cases, the message may be split into multiple *Pages.* Data shall not be subdivided in the middle of an entry (a Module Identifier, Address Point Description, Point PDU, etc...) and may only be split on a boundary.

The Page field is a 16-bit field indicating the page number of this OTP Message. Page numbers start at 0x0000 and shall increment by one.

6.9 Last Page

The Last Page field is a 16-bit field indicating the number of the final page to be transmitted. A set of pages carry across a complete Transform Message, List of Module Identifiers, or List of Address Point Descriptions. Page numbers start at 0x0000 and shall increment by one.

6.10 Options

The Options bit field is reserved for future use. Components shall transmit as 0x00. Receiving Components shall ignore this field.

6.11 Reserved

These octets are reserved for future use. Components shall transmit as 0x00000000. Receiving Components shall ignore this field.

6.12 Component Name

The Component Name is a user-assigned name representing the identity of a Component. There is no mechanism, other than user configuration, to ensure uniqueness of this name. The Component Name shall not exceed 32 octets. Shorter names shall be null-padded to fill out the full field length. Longer names must be truncated, and shall not break anywhere other than a rune boundary (e.g., a 33 octet name ending in the rune specified by 0xF09F92A1 would need to be truncated back to the 29th octet, and then followed by 0x000000).

7 Protocol Message Structure and Operation

All OTP Components shall support the OTP Transform Message for transportation of object transform data, the OTP Module Advertisement Message for transportation of supported Module information, and the OTP System Advertisement Message for transportation of System Number information. OTP Components should support the OTP Name Advertisement Message for transportation of human-readable Point names.

OTP uses clearly defined layering to carry transform and advertisement data. Figure 7-1 and Figure 7-2 illustrate the layering and nesting of PDUs.

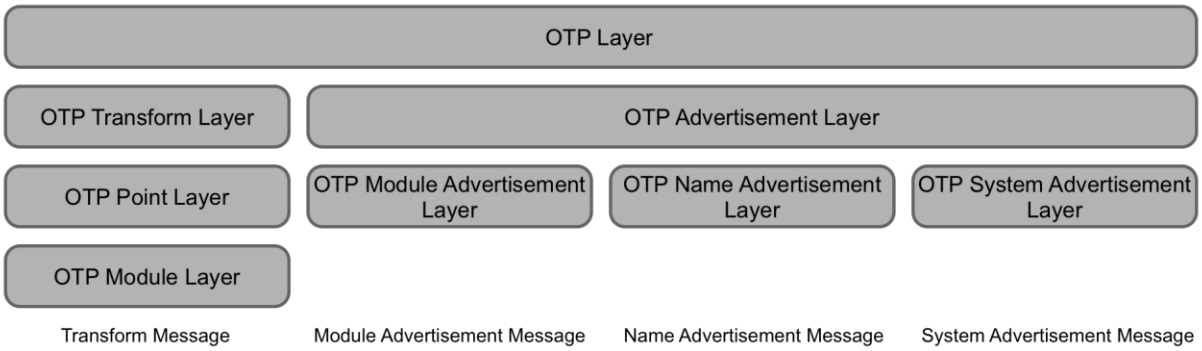

Figure 7-1: OTP Message Layering

OTP Messages shall carry either a single OTP Transform PDU or a single OTP Advertisement PDU within the data block of the OTP Layer.

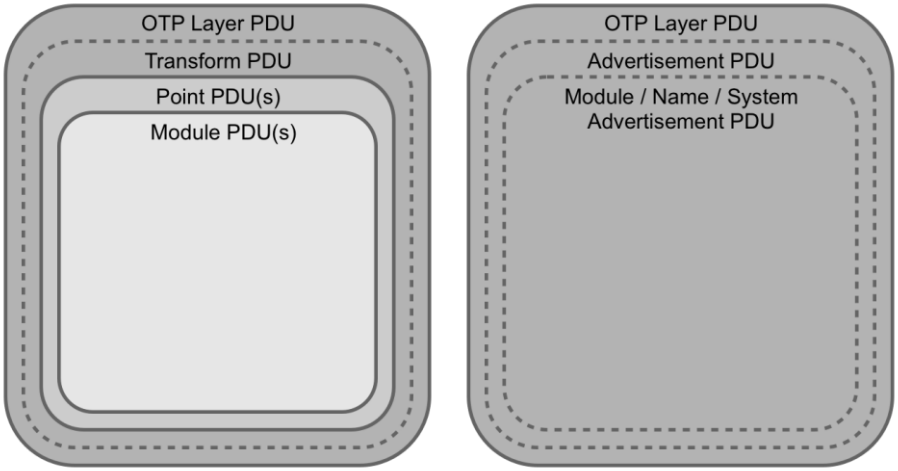

Figure 7-2: OTP Transform and Advertisement Message Layers

7.1 Transform Message

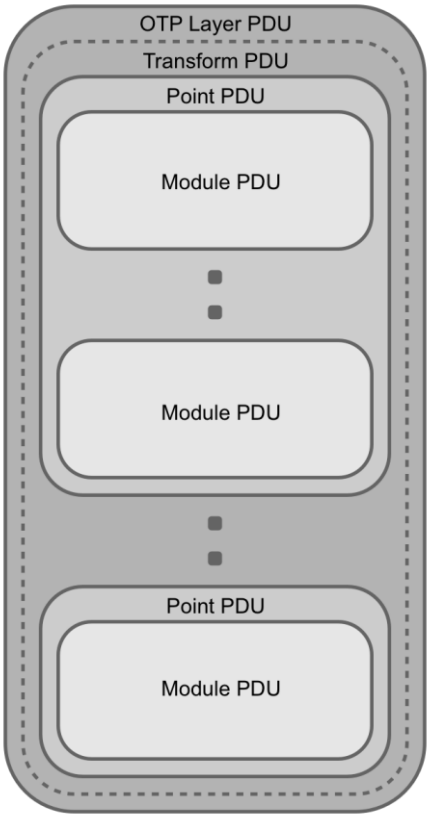

Figure 7-3: OTP Transform Message

7.1.1 Transform Message Structure

The OTP Transform Message defines an outer layer PDU wrapper containing Component information, paging information, and carrying a block of data. This data block is a single Transform PDU carrying information such as a timestamp, and carrying a block of data. This data block contains a number of Point PDUs containing information about the Point, and carrying a block of data. The Point PDU data block contains a number of Module PDUs containing information such as position or rotation. Each PDU contains a length field which equals the length of the entire PDU, including its header and data block information.

All OTP Transform Messages shall carry the vector VECTOR_OTP_TRANSFORM_MESSAGE in the OTP Layer, in order to indicate that their payload is object transform data. Table 7-1: OTP describes the OTP Transform Message format.

Table 7-1: OTP Transform Message

Octet	Field Size	Field Name	Field Description	Field Contents
OTP Layer (See Section 6)				
0-11	12	OTP Packet Identifier	Identifies this message as OTP	0x4f 0x54 0x50 0x2d 0x45 0x31 0x2e 0x35 0x39 0x00 0x00 0x00
12-13	2	Vector	Identifies OTP Layer data as OTP Transform PDU	VECTOR_OTP_TRANSFORM_MESSAGE
14-15	2	Length	Length of message	The length of the message excluding the footer in octets, starting with octet 16.
16	1	Footer Options	Footer Options Flags	Reserved. Shall be transmitted as 0x00.
17	1	Footer Length	Length of footer	The length of the footer in octets.
18-33	16	CID	Sender's CID	Sender's unique ID.
34-37	4	Folio Number	Identifies OTP Folios	Identifier indicating which Folio this is.
38-39	2	Page	Page number	Identifier indicating which page of N this is - page numbers start at 0.
40-41	2	Last Page	Final page number	Page number of the final page to be transmitted.
42	1	Options	Options Flags	Reserved. Shall be transmitted as 0x00.
43-46	4	Reserved	Reserved	Reserved. Shall be transmitted as 0x00000000.
47-78	32	Component Name	Component Name	A human-readable [UTF-8] string identifying the Component.
OTP Transform Layer (See Section 8)				
79-80	2	Vector	Identifies transform data as OTP Point PDU	VECTOR_OTP_POINT
81-82	2	Length	Length of PDU	The length of the PDU in octets.
83	1	System Number	Unique within a network, identifies this System.	The number of the System.
84-91	8	Timestamp	Microseconds since the Time Origin	Timestamp indicating the moment this message was generated.
92	1	Options	Options Flags	Bit 7 = Full Point Set
93-96	4	Reserved	Reserved	Reserved. Shall be transmitted as 0x00000000.
OTP Point Layer (See Section 9)				
…	2	Vector	Identifies Point data as OTP Module PDU	VECTOR_OTP_MODULE
…	2	Length	Length of PDU	The length of the PDU in octets.
…	1	Priority	Data priority if multiple sources for this Address	0-200, default of 100.
…	2	Group Number	Unique within a System, identifies this Group	The number of the Group.

…	4	Point Number	Unique within a Group, identifies this Point	The number of the Point.
…	8	Timestamp	Microseconds since the Time Origin	Timestamp indicating the moment this Point was sampled by the Producer.
…	1	Options	Options Flags	Reserved. Shall be transmitted as 0x00.
…	4	Reserved	Reserved	Reserved. Shall be transmitted as 0x00000000.
OTP Module Layer (See Section 10)				
…	2	Manufacturer ID	Identifies the Manufacturer ID of an encapsulated module	The Manufacturer ID for this module.
…	2	Length	Length of PDU	The length of the PDU in octets.
…	2	Module Number	Identifies the type of the module	The number of the Module.
…	…	Additional Fields Determined by Vector and Module Number	…	See Section 16.

All message contents shall be transmitted in network byte order (big endian).

7.1.2 Transform Message Operation and Timing

7.1.2.1 Identifying Points (Addressing)

The Address of a Point is constructed by combining System Number, Group Number, and Point Number. It is intended that addresses are unique within the network. Addresses shall be notated as described in Table 7-3, using a '/' to separate each number. System, Group, and Point Numbers shall be in the decimal ranges shown in Table 7-2.

Table 7-2: Address Numbering

Number	Minimum	Maximum
System	1	200
Group	1	60,000
Point	1	4,000,000,000

Table 7-3: Address Designation Examples

System Number	Group Number	Point Number	Address
1	1	1	1/1/1
1	1	2	1/1/2
1	2	3	1/2/3

7.1.2.2 Multiple Producers

It is possible for there to be multiple Producers transmitting data on the network. A single Producer shall not use the same Address to describe multiple Points, unless they represent the same point on the same physical object and are transmitted using different priorities (See Section 9.3). In multiple Producer environments where uniqueness is required, it is up to the user to ensure that there is only one Producer providing transform information for any particular Address.

Further information on the behavior of a Consumer receiving information for the same address from multiple Producers can be found in Section 9.3.

7.1.2.3 Transmission Rate

Producers shall transmit an OTP Folio of OTP Transform Messages for each System they are transmitting at a fixed rate between OTP_TRANSFORM_TIMING_MIN and OTP_TRANSFORM_TIMING_MAX. This OTP Folio shall contain either a Full Point Set, or all Points with changing OTP Module Layer data.

Producers should provide a user-definable method for setting the transmission rate within the range specified.

Prior to ceasing transmission of a particular System, Producers choosing to transmit a subset of the Full Point Set shall include each of the transmitted Points in three additional OTP Folios of OTP Transform Messages at the specified transmission rate.

Regardless of the contents of other OTP Folios, for each System being transmitted a single OTP Folio containing a Full Point Set shall always be transmitted at intervals of between OTP_TRANSFORM_FULL_POINT_SET _TIMING_MIN and OTP_TRANSFORM_FULL_POINT_SET_TIMING_MAX.

See Section 8.5 for further information on how Full Point Sets are identified.

7.1.2.4 Data Loss

A Consumer shall wait OTP_TRANSFORM_DATA_LOSS_TIMEOUT after receiving the last OTP Transform Message from a Producer before entering a data loss state. Behavior of Consumers once in data loss is beyond the scope of this standard.

7.1.2.5 Multiple Messages

Producers transmitting OTP Transform Messages shall not truncate, split, or subdivide OTP Module Layers. OTP Module Layers shall be transmitted in full within a single OTP Transform Message.

Note: Consumers may receive information about the same Point in different OTP Transform Messages within the same OTP Folio.

7.2 OTP System Advertisement Message

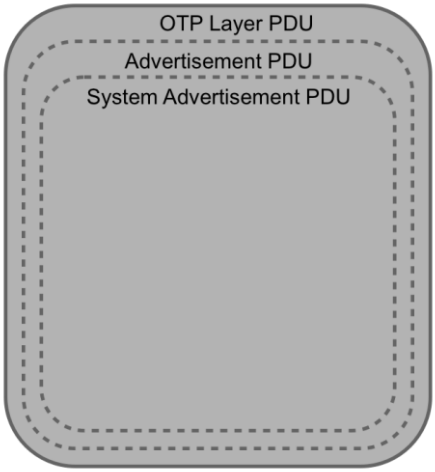

Figure 7-4: OTP System Advertisement Message

7.2.1 System Advertisement Message Structure

The OTP System Advertisement Message defines an outer layer PDU wrapper containing Component information, paging information, and a segment of data. This segment is a single Advertisement PDU which carries a segment of data. This segment is a single System Advertisement PDU containing a list of System Numbers. Each PDU contains a length field which equals the length of the entire PDU, including its header and data segment information.

All OTP System Advertisement Messages shall carry the vector VECTOR_OTP_ADVERTISEMENT_MESSAGE in the OTP Layer in order to indicate that their payload is advertisement data.

Table 7-4 describes the OTP System Advertisement Message format.

Table 7-4: OTP System Advertisement Message

Octet	Field Size	Field Name	Field Description	Field Contents
OTP Layer (See Section 6)				
0-11	12	OTP Packet Identifier	Identifies this message as OTP	0x4f 0x54 0x50 0x2d 0x45 0x31 0x2e 0x35 0x39 0x00 0x00 0x00
12-13	2	Vector	Identifies OTP Layer data as OTP Advertisement PDU	VECTOR_OTP_ADVERTISEMENT_MESSAGE
14-15	2	Length	Length of message	The length of the message excluding the footer in octets, starting with octet 16.
16	1	Footer Options	Footer Options Flags	Reserved. Shall be transmitted as 0x00.
17	1	Footer Length	Length of footer	The length of the footer in octets.
18-33	16	CID	Sender's CID	Sender's unique ID.
34-37	4	Folio Number	Identifies OTP Folios	Identifier indicating which Folio this is.

38-39	2	Page	Page number	Identifier indicating which page of N this is - page numbers start at 0.
40-41	2	Last Page	Final page number	Page number of the final page to be transmitted.
42	1	Options	Options Flags	Reserved. Shall be transmitted as 0x00.
43-46	4	Reserved	Reserved	Reserved. Shall be transmitted as 0x00000000.
47-78	32	Component Name	Component Name	A human-readable [UTF-8] string identifying the Component.
OTP Advertisement Layer (See Section 11)				
79-80	2	Vector	Identifies Advertisement data as system advertisement	VECTOR_OTP_ADVERTISEMENT_SYSTEM
81-82	2	Length	Length of PDU	The length of the PDU in octets.
83-86	4	Reserved	Reserved	Reserved. Shall be transmitted as 0x00000000.
OTP System Advertisement Layer (See Section 14)				
87-88	2	Vector	Identifies System Advertisement data as system number list	VECTOR_OTP_ADVERTISEMENT_SYSTEM_LIST
89-90	2	Length	Length of PDU	The length of the PDU in octets.
91	1	Options	Options Flags	Bit 7 = Request/Response
92-95	4	Reserved	Reserved	Reserved. Shall be transmitted as 0x00000000.
96-	0-200	List of System Numbers	Sorted list of up to 200 System Numbers	List of {System Number}.

All message contents shall be transmitted in network byte order (big endian).

7.2.2 System Advertisement Message Operation and Timing

OTP System Advertisement enables Consumers to learn the System Numbers for which a Producer is transmitting data. OTP System Advertisement is a mandatory part of this standard – all Components shall implement System Advertisement.

7.2.2.1 Consumers

OTP Consumers wishing to receive a list of System Numbers for which a Producer is currently transmitting data shall transmit an OTP System Advertisement Message with the OTP System Advertisement Layer's Options Request/Response bit set to 0.

7.2.2.2 Producers

When an OTP Producer receives an OTP System Advertisement Message with the OTP System Advertisement Layer's Options Request/Response bit set to 0, it shall transmit an OTP System Advertisement Message unicast to the source of the request, after a randomly selected delay within the range of 0 seconds – OTP_SYSTEM_ADVERTISEMENT_MAX_BACKOFF, inclusive. The message shall contain a list of all System Numbers for which the Producer is currently transmitting data.

Producers shall not transmit OTP System Advertisement Messages containing an empty List of System Numbers.

Producers shall ignore OTP System Advertisement Messages with the Request/Response bit set to 1.

7.3 OTP Name Advertisement Message

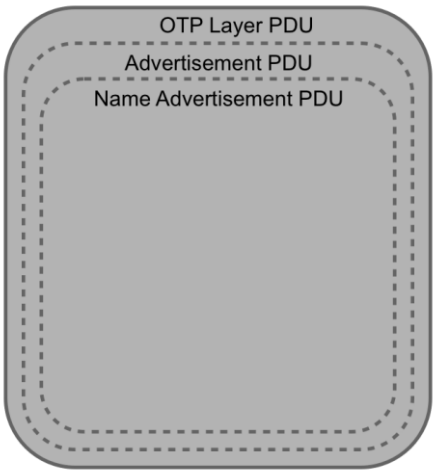

Figure 7-5: OTP Name Advertisement Message

7.3.1 Name Advertisement Message Structure

The OTP Name Advertisement Message defines an outer layer PDU wrapper containing Component information, paging information, and a segment of data. This segment is a single Advertisement PDU which carries a segment of data. This segment is a single Name Advertisement PDU containing a list of Address Point Descriptions. Each PDU contains a length field which equals the length of the entire PDU, including its header and data segment information.

All OTP Name Advertisement Messages shall carry the vector VECTOR_OTP_ADVERTISEMENT_MESSAGE in the OTP Layer, indicating that their payload is advertisement data.

Table 7-5 describes the OTP Name Advertisement Message format.

Table 7-5: OTP Name Advertisement Message

Octet	Field Size	Field Name	Field Description	Field Contents
OTP Layer (See Section 6)				
0-11	12	OTP Packet Identifier	Identifies this message as OTP	0x4f 0x54 0x50 0x2d 0x45 0x31 0x2e 0x35 0x39 0x00 0x00 0x00
12-13	2	Vector	Identifies OTP Layer data as OTP Advertisement PDU	VECTOR_OTP_ADVERTISEMENT_MESSAGE
14-15	2	Length	Length of message	The length of the message excluding the footer in octets, starting with octet 16.
16	1	Footer Options	Footer Options Flags	Reserved. Shall be transmitted as 0x00.
17	1	Footer Length	Length of footer	The length of the footer in octets.
18-33	16	CID	Sender's CID	Sender's unique ID.
34-37	4	Folio Number	Identifies OTP Folios	Identifier indicating which Folio this is.

38-39	2	Page	Page number	Identifier indicating which page of N this is - page numbers start at 0.
40-41	2	Last Page	Final page number	Page number of the final page to be transmitted.
42	1	Options	Options Flags	Reserved. Shall be transmitted as 0x00.
43-46	4	Reserved	Reserved	Reserved. Shall be transmitted as 0x00000000
47-78	32	Component Name	Component Name	A human-readable [UTF-8] string identifying the Component.
OTP Advertisement Layer (See Section 11)				
79-80	2	Vector	Identifies Advertisement data as name advertisement	VECTOR_OTP_ADVERTISEMENT_NAME
81-82	2	Length	Length of PDU	The length of the PDU in octets.
83-86	4	Reserved	Reserved	Reserved. Shall be transmitted as 0x00000000.
OTP Name Advertisement Layer (See Section 13)				
87-88	2	Vector	Identifies Name Advertisement data as name list	VECTOR_OTP_ADVERTISEMENT_NAME_LIST
89-90	2	Length	Length of PDU	The length of the PDU in octets.
91	1	Options	Options Flags	Bit 7 = Request/Response
92-95	4	Reserved	Reserved	Reserved. Shall be transmitted as 0x00000000.
96-	0-1365	List of Address Point Descriptions	Sorted list of up to 35 Address Point Descriptions	List of {Address Point Description}

All message contents shall be transmitted in network byte order (big endian).

7.3.2 Name Advertisement Message Operation and Timing

OTP Name Advertisement enables Consumers to learn human-readable names of the Points for which Producers are providing data. All Components intending to comply with OTP should implement Name Advertisement.

7.3.2.1 Consumers

OTP Consumers supporting Name Advertisement and wishing to receive a list of Address Point Descriptions shall transmit an OTP Name Advertisement Message with the OTP Name Advertisement Layer's Options Request/Response bit set to 0.

Note: As support for Name Advertisement is optional, Consumers may not receive a response to a request for Address Point Descriptions.

7.3.2.2 Producers

When an OTP Producer supporting Name Advertisement receives an OTP Name Advertisement Message with the OTP Name Advertisement Layer's Options Request/Response bit set to 0, it shall transmit an OTP Name Advertisement Message unicast to the source of the request, after a randomly selected delay,

within the range of 0 seconds – OTP_NAME_ADVERTISEMENT_MAX_BACKOFF, inclusive. The message shall contain a list of all Address Point Descriptions for which the Producer is currently providing data.

Producers shall not transmit OTP Name Advertisement Messages containing an empty List of Address Point Descriptions.

Producers shall not include more than one Address Point Description with the same Address in the List of Address Point Descriptions.

Producers shall ignore OTP Name Advertisement Messages with the Request/Response bit set to 1.

7.4 OTP Module Advertisement Message

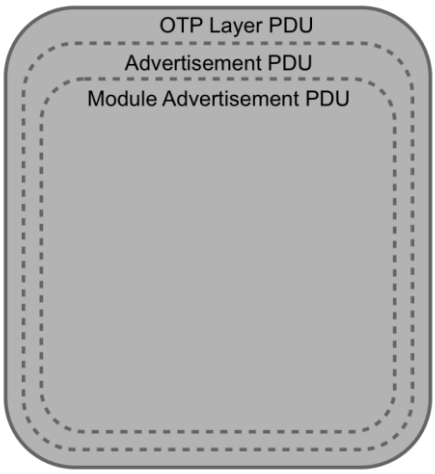

Figure 7-6: OTP Module Advertisement Message

7.4.1 Module Advertisement Message Structure

The OTP Module Advertisement Message defines an outer layer PDU wrapper containing Component information, paging information, and a segment of data. This data segment is a single Advertisement PDU which carries a segment of data. This data segment is a single Module Advertisement PDU containing a List of Module Identifiers. Each PDU contains a length field which equals the length of the entire PDU, including its header and data segment information.

All OTP Module Advertisement Messages shall carry the vector VECTOR_OTP_ADVERTISEMENT_MESSAGE in the OTP Layer in order to indicate that their payload is advertisement data.

Table 7-6 describes the OTP Module Advertisement Message format.

Table 7-6: OTP Module Advertisement Message

Octet	Field Size	Field Name	Field Description	Field Contents
OTP Layer (See Section 6)				
0-11	12	OTP Packet Identifier	Identifies this message as OTP	0x4f 0x54 0x50 0x2d 0x45 0x31 0x2e 0x35 0x39 0x00 0x00 0x00
12-13	2	Vector	Identifies OTP Layer data as OTP Advertisement PDU	VECTOR_OTP_ADVERTISEMENT_MESSAGE
14-15	2	Length	Length of message	The length of the message excluding the footer in octets, starting with octet 16.
16	1	Footer Options	Footer Options Flags	Reserved. Shall be transmitted as 0x00.
17	1	Footer Length	Length of footer	The length of the footer in octets.
18-33	16	CID	Sender's CID	Sender's unique ID.
34-37	4	Folio Number	Identifies OTP Folios	Identifier indicating which Folio this is.

38-39	2	Page	Page number	Identifier indicating which page of N this is - page numbers start at 0.
40-41	2	Last Page	Final page number	Page number of the final page to be transmitted.
42	1	Options	Options Flags	Reserved. Shall be transmitted as 0x00.
43-46	4	Reserved	Reserved	Reserved. Shall be transmitted as 0x00000000
47-78	32	Component Name	Component Name	A human-readable [UTF-8] string identifying the Component.
OTP Advertisement Layer (See Section 11)				
79-80	2	Vector	Identifies Advertisement data as module advertisement	VECTOR_OTP_ADVERTISEMENT_MODULE
81-82	2	Length	Length of PDU	The length of the PDU in octets.
83-86	4	Reserved	Reserved	Reserved. Shall be transmitted as 0x00000000.
OTP Module Advertisement Layer (See Section 12)				
87-88	2	Vector	Identifies Module Advertisement data as module list	VECTOR_OTP_ADVERTISEMENT_MODULE_LIST
89-90	2	Length	Length of PDU	The length of the PDU in octets.
91-94	4	Reserved	Reserved	Reserved. Shall be transmitted as 0x00000000.
95-	4-1376	List of Module Identifiers	Sorted list of up to 344 module identifiers	List of {Manufacturer ID + Module Number}

All message contents shall be transmitted in network byte order (big endian).

7.4.2 Module Advertisement Message Operation and Timing

OTP Module Advertisement enables Producers to learn which Modules are supported by the Consumers on a network. OTP Module Advertisement is a mandatory part of this standard – all Producers and Consumers shall support it.

Module Advertisement allows Producers to be automatically configured, and it has the potential to reduce the load on a network, if Producers only transmit Modules which can be interpreted and used by Consumers.

7.4.2.1 Consumers

Consumers shall transmit an OTP Module Advertisement Message every OTP_ADVERTISEMENT_TIMING, containing a list of all Module Identifiers the Consumer is currently interested in receiving.

A Consumer that is no longer listening for any OTP Transform Message data shall stop sending OTP Module Advertisement Messages until such time that it resumes listening for data. Consumers shall not transmit an OTP Module Advertisement Messages containing an empty List of Module Identifiers.

In the event that the List of Module Identifiers has changed within OTP_ADVERTISEMENT_TIMING, a Consumer may send up to one additional OTP Folio to advertise information, without waiting for the full time to elapse.

7.4.2.2 Producers

Producers shall transmit only the Modules (and any associated Modules listed in Table 16-1) for which they have received in an OTP Module Advertisement Message within OTP_ADVERTISEMENT_TIMEOUT.

If a Producer does not support any of the advertised Modules for a certain Point, the Producer shall not include that Point in any OTP Transform Messages it transmits.

Producers must wait OTP_ADVERTISEMENT_STARTUP_WAIT after initialization before transmitting any OTP Transform Messages.

Note: As Consumers may dynamically change which Modules they are interested in consuming, Producers should be aware that the List of Module Identifiers for a Consumer may change during a session.

8 OTP Transform Layer

Transform data only appears in OTP Transform Messages and shall not be included in OTP Advertisement Messages.

Table 8-1: OTP Transform Layer

Octet	Field Size	Field Name	Field Description	Field Contents
OTP Transform Layer				
79-80	2	Vector	Identifies transform data as OTP Point PDU	VECTOR_OTP_POINT
81-82	2	Length	Length of PDU	The length of the PDU in octets.
83	1	System Number	Unique within a network, identifies this System.	The number of the System.
84-91	8	Timestamp	Microseconds since the Time Origin	Timestamp indicating the moment this message was generated.
92	1	Options	Options Flags	Bit 7 = Full Point Set
93-96	4	Reserved	Reserved	Reserved. Shall be transmitted as 0x00000000.

8.1 Transform Layer Vector

The vector appearing in the Transform Layer Vector field shall be VECTOR_OTP_POINT. Consumers shall ignore Transform PDUs with any other vectors.

8.2 Length

The length field is a 16-bit field containing the PDU length in octets, excluding the Vector and Length fields.

8.3 System Number

The System Number is an assigned number, unique within the OTP network, that represents this system. While System Numbers shall be unique for each OTP network, there is no guarantee or expectation that they are universally unique. System numbers shall be in the decimal range of 1 through 200.

System Number 0 and System Numbers 201 through 255 are reserved for future use. Consumers shall discard any message with a System Number of 0 or 201-255.

8.4 Timestamp (Generation)

The Timestamp is the time, in microseconds since the Time Origin, that the information in this message was generated, not the time it is being sent (unless they are identical).

Note: In a system with multiple Producers, to ensure optimal functioning of this standard, it is important that OTP Components must synchronize time. Such synchronization is beyond the scope of this standard. Implementors are advised to consider techniques such as the SNTP subset of [NTP], or some other suitable method, in order to maintain consistent time in an OTP Network. If feedforward calculations are not required, or there is only a single Producer on the network, it may not be necessary to synchronize timing between Components.

8.5 Options

This bit-oriented field is used to encode flags indicating how to process the remaining data in the PDU.

Full Point Set: Bit 7 (most significant bit)

This bit, when set to 0, indicates that this Transform Layer PDU contains a subset of the Full Point Set for this Producer. When set to 1, this bit indicates that this Transform Layer PDU contains a Full Point Set from this Producer.

Bits 0 through 6 of this field are reserved for future use and shall be transmitted as 0 and ignored by Consumers.

8.6 Reserved

These octets are reserved for future use. Producers shall transmit as 0x00000000. Consumers shall ignore this field.

9 OTP Point Layer

Point data only appears in OTP Transform Messages and shall not be included in OTP Advertisement Messages.

Table 9-1: OTP Point Layer

Octet	Field Size	Field Name	Field Description	Field Contents
OTP Point Layer				
…	2	Vector	Identifies Point data as OTP Module PDU	VECTOR_OTP_MODULE
…	2	Length	Length of PDU	The length of the PDU in octets.
…	1	Priority	Data priority if multiple sources for this Address	0-200, default of 100
…	2	Group Number	Unique within a System, identifies this Group	The number of the Group.
…	4	Point Number	Unique within a Group, identifies this Point	The number of the Point.
…	8	Timestamp	Microseconds since the Time Origin	Timestamp indicating the moment this Point was sampled by the Producer.
…	1	Options	Options Flags	Reserved. Shall be transmitted as 0x00.
…	4	Reserved	Reserved	Reserved. Shall be transmitted as 0x00000000.

9.1 Point Layer Vector

The Vector in the Point Layer indicates the type of information in the Data field of the Point PDU. It shall be VECTOR_OTP_MODULE. Consumers shall ignore Point PDUs with any other vectors.

9.2 Length

The length field is a 16-bit field containing the PDU length in octets, excluding the Vector and Length fields.

9.3 Priority

A Consumer may receive Points with the same Address from multiple Producers, or indeed from a single Producer, within an OTP Folio (See Section 7.1.2.2).

The priority field is used by Consumers in selecting between multiple Points with the same Address. Priority increases with numerical value, e.g., 200 is a higher priority than 100. Consumers receiving transform information for multiple Points with the same Address shall treat the Point with the highest priority as definitive for that Address.

Priorities shall be in the decimal range 0 through 200. Priorities 201 through 255 are reserved for future use. Consumers shall discard any Point with a reserved priority. Producers that do not support variable priority shall transmit a priority of 100.

9.3.1 Multiple Points at Highest Priority

It is possible for a Consumer to receive multiple Points with the same Address at the highest active priority for that Address. When this occurs, Consumers must handle these Points in some way.

A Consumer which is only capable of processing transform information for an Address from a single Producer will encounter a *Producers Exceeded* condition when two or more Producers are transmitting Points with the same Address at the highest active priority.

Many devices are capable of combining, merging or arbitrating between the candidate Producers by some algorithm (see below), but such algorithms frequently limit the number of concurrent Producers which can be handled due to resource limitations, or encounter situations where there are still multiple candidate Producers meeting some specified condition. In these situations, a *Producers Exceeded* condition shall arise, which requires resolution.

9.3.2 Note on Merge and Arbitration Algorithms

The process of combining data from multiple Producers to produce a definitive result is called merging. A process which selects between candidate Producers based on some additional selection criteria is called arbitration.

One option for merging transform information from multiple Producers is to take the arithmetic mean of the values received from the Producers. However, Consumers may choose to apply any number of alternative merging algorithms.

In situations where it is more desirable to accept a single Producer of data, arbitration of multiple Producers using criteria such as the Component Name (See Section 6.12) may be applied.

9.3.3 Note on Resolution of Producers Exceeded Condition

Resolution is required when the number of Producers exceeds the limitations of the algorithm or of the resources available. With no merging or arbitration, this would occur when there is more than one Producer providing transform information for an Address at the highest active priority.

One resolution mechanism is to stop accepting data from any Producer. Other mechanisms may involve choosing one or more of the candidate Producers by some overload selection scheme.

Implementors are very strongly encouraged to use resolution algorithms that generate the same results from the same combination of Producers each time. Using algorithms that lead to discrepant outcomes can make *Producers Exceeded* conditions hard to detect, networks difficult to troubleshoot, and may cause unexpected output at critical times.

Consumers are strongly recommended to indicate a *Producers Exceeded* condition by some means easily detected by the user, e.g., an obvious status message on the Consumer.

9.4 Group Number

The Group Number is an assigned number, unique within a System, that represents this group. Group Numbers shall be in the decimal range 1 through 60,000. Group Numbers 0 and 60,001 through 65,535 are reserved for future use. Consumers shall discard any Point with a reserved Group Number.

9.5 Point Number

The Point Number is an assigned number, unique within a Group, that represents the Point about which information is to be conveyed in the encapsulated PDU. Point Numbers shall be in the range 1 through 4,000,000,000. Point Numbers 0 and 4,000,000,001 through 4,294,967,295 are reserved for future use. Consumers shall discard any Point with a Point Number of 0 or 4,000,000,001-4,294,967,295.

9.6 Timestamp (Sampled)

The Timestamp is the time, in microseconds since the Time Origin, that the information in this message was sampled from the Point. Unless identical to the generation time, it shall not be the same as time that this message was sent (See Section 8.4 for an informative note on time synchronization in an OTP environment).

9.7 Options

The Options field is reserved for future use. Producers shall transmit 0x00. Consumers shall ignore this field.

9.8 Reserved

These octets are reserved for future use. Producers shall transmit as 0x00000000. Consumers shall ignore this field.

10 OTP Module Layer

Module data only appears in OTP Transform Messages and shall not be included in OTP Advertisement Messages.

Producers shall not include more than one Module of the same type within a single Point PDU.

Table 10-1: OTP Module Layer

Octet	Field Size	Field Name	Field Description	Field Contents
OTP Module Layer				
…	2	Manufacturer ID	Identifies the Manufacturer ID of an encapsulated module	The Manufacturer ID for this module.
…	2	Length	Length of PDU	The length of the PDU in octets.
…	2	Module Number	Identifies the type of the module	The number of the Module.
…	…	Additional Fields Determined by Vector and Module Number	…	See Section 16.

10.1 Manufacturer ID

All standard modules shall use ESTA_MANUFACTURER_ID as the Manufacturer ID.

Manufacturers wishing to define their own Modules shall use their assigned Manufacturer ID (see [ManufId]).

Consumers shall ignore Module PDUs with Manufacturer IDs they do not support.

10.2 Length

The length field is a 16-bit field containing the PDU length in octets, excluding the Manufacturer ID and Length fields.

10.3 Module Number

The Module Number field is a 16-bit field containing the Module Number identifying the type of module contained.

Consumers shall ignore Module PDUs with Module Numbers they do not support.

10.4 Additional Fields

Additional fields for standard Modules are defined in Section 16.

11 OTP Advertisement Layer

Advertisement data only appears in OTP Advertisement Messages and shall not be included in OTP Transform Messages.

Table 11-1: OTP Advertisement Layer

Octet	Field Size	Field Name	Field Description	Field Contents
OTP Advertisement Layer				
79-80	2	Vector	Identifies the type of advertisement data in the PDU	VECTOR_OTP_ADVERTISEMENT_MODULE, VECTOR_OTP_ADVERTISEMENT_NAME, VECTOR_OTP_ADVERTISEMENT_SYSTEM
81-82	2	Length	Length of PDU	The length of the PDU in octets.
83-86	4	Reserved	Reserved	Reserved. Shall be transmitted as 0x00000000.

11.1 Advertisement Layer Vector

Consumers sending an OTP Module Advertisement Message shall set the vector to VECTOR_OTP_ADVERTISEMENT_MODULE, indicating that it contains module advertisement data.

Components sending an OTP Name Advertisement Message shall set the vector to VECTOR_OTP_ADVERTISEMENT_NAME, indicating that it contains name advertisement data.

Components sending an OTP System Advertisement Message shall set the vector to VECTOR_OTP_ADVERTISEMENT_SYSTEM, indicating that it contains system advertisement data.

Receiving Components shall discard an Advertisement Message if the vector is not one of VECTOR_OTP_ADVERTISEMENT_MODULE, VECTOR_OTP_ADVERTISEMENT_NAME, or VECTOR_OTP_ADVERTISEMENT_SYSTEM.

11.2 Length

The length field is a 16-bit field containing the PDU length in octets, excluding the Vector and Length fields.

11.3 Reserved

These octets are reserved for future use. Components shall transmit as 0x00000000. Receiving Components shall ignore this field.

12 OTP Module Advertisement Layer

Module Advertisement data only appears in OTP Module Advertisement Messages and shall not be included in OTP Transform Messages, OTP Name Advertisement Messages, or OTP System Advertisement Messages.

Table 12-1: OTP Module Advertisement Layer

Octet	Field Size	Field Name	Field Description	Field Contents
OTP Module Advertisement Layer				
87-88	2	Vector	Identifies Module Advertisement data as module list	VECTOR_OTP_ADVERTISEMENT_MODULE_LIST
89-90	2	Length	Length of PDU	The length of the PDU in octets.
91-94	4	Reserved	Reserved	Reserved. Shall be transmitted as 0x00000000.
95-	4-1376	List of Module Identifiers	Sorted list of up to 344 module identifiers	List of {Manufacturer ID + Module Number}

12.1 Module Advertisement Layer Vector

The Module Advertisement Layer's Vector shall be set to VECTOR_OTP_ADVERTISEMENT_MODULE_LIST, indicating that it contains a List of Module Identifiers.

Producers shall discard any message whose vector is not VECTOR_OTP_ADVERTISEMENT_MODULE_LIST.

12.2 Length

The length field is a 16-bit field containing the PDU length in octets, excluding the Vector and Length fields.

12.3 Reserved

These octets are reserved for future use. Consumers shall transmit as 0x00000000. Producers shall ignore this field.

12.4 List of Module Identifiers

The Module Advertisement Layer's List of Module Identifiers is a packed list of Module Identifiers, numerically sorted from the lowest tuple of {Manufacturer ID, Module Number}. Each Module Identifier shall contain a Manufacturer ID and a 16-bit Module Number. It shall enumerate all of the supported Modules of a Consumer.

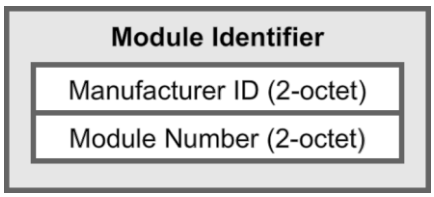

Figure 12-1: Module Identifier Structure

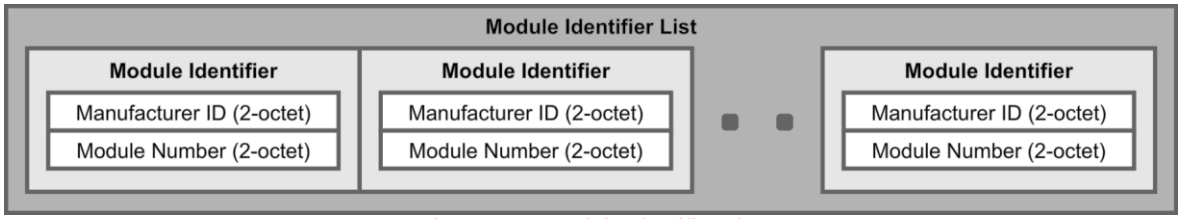

Figure 12-2: Module Identifier List

For all standard Modules defined in Section 16, the Manufacturer ID shall be set to ESTA_MANUFACTURER_ID.

13 OTP Name Advertisement Layer

Name Advertisement data only appears in OTP Name Advertisement Messages and shall not be included in OTP Transform Messages, OTP Module Advertisement Messages, or OTP System Advertisement Messages.

Table 13-1: OTP Name Advertisement Layer

Octet	Field Size	Field Name	Field Description	Field Contents
OTP Name Advertisement Layer				
87-88	2	Vector	Identifies Name Advertisement data as name list	VECTOR_OTP_ADVERTISEMENT_NAME_LIST
89-90	2	Length	Length of PDU	The length of the PDU in octets.
91	1	Options	Options Flags	Bit 7 = Request/Response
92-95	4	Reserved	Reserved	Reserved. Shall be transmitted as 0x00000000.
96-	0-1365	List of Address Point Descriptions	Sorted list of up to 35 Address Point Descriptions	List of {Address Point Description}

13.1 Name Advertisement Layer Vector

The Name Advertisement Layer's Vector shall be set to VECTOR_OTP_ADVERTISEMENT_NAME_LIST, indicating that it contains a List of Address Point Descriptions.

Receiving Components shall discard the message if the received value is not VECTOR_OTP_ADVERTISEMENT_NAME_LIST.

13.2 Length

The length field is a 16-bit field containing the PDU length in octets, excluding the Vector and Length fields.

13.3 Options

This bit-oriented field is used to encode flags indicating how to process the remaining data in the PDU.

Request/Response: Bit 7 (most significant bit)

This bit, when set to 0, indicates that this is a request for Point Names from a Consumer. When set to 1, this bit indicates this is a response to an OTP Name Advertisement Message.

Producers shall ignore OTP Name Advertisement Messages with the Request/Response bit set to 1.

Bits 0 through 6 of this field are reserved for future use and shall be transmitted as 0 and ignored by receiving Components.

13.4 Reserved

These octets are reserved for future use. They shall be transmitted as 0x00000000. Receiving Components shall ignore this field.

13.5 List of Address Point Descriptions

The Name Advertisement Layer's List of Address Point Descriptions is a packed list of Address Point Descriptions, numerically sorted from the lowest tuple of {System Number, Group Number, Point Number}.

Each Address Point Description shall contain four subfields: System Number, Group Number, Point Number, and Point Name.

Consumers transmitting a request with the Options Request/Response bit set to 0 shall transmit an empty list for this field. Producers shall ignore this field.

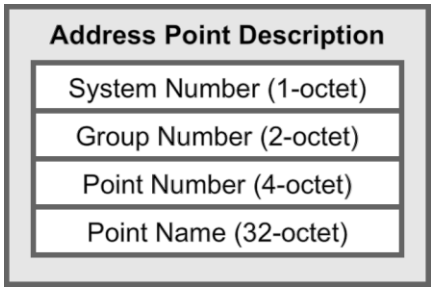

Figure 13-1: Address Point Description Structure

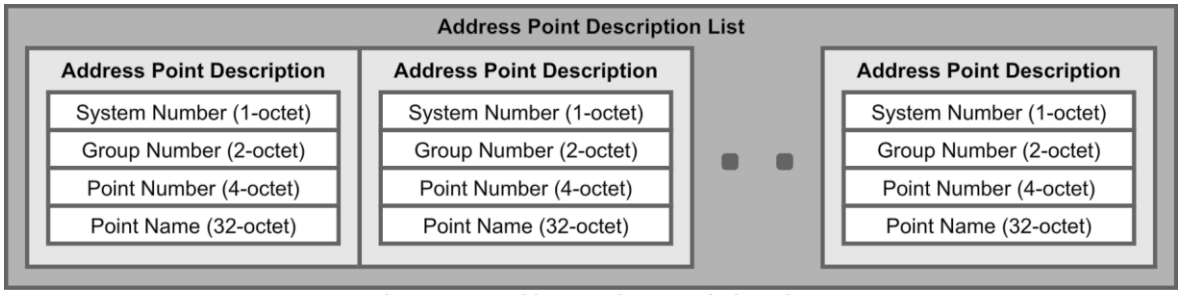

Figure 13-2: Address Point Description List

13.5.1 Point Name

The Point Name sub-field is an optional field that may contain a user-assigned name for the Point. Producers that choose not to support this field shall fill it with 0x00 characters. This field shall not exceed 32 octets. Shorter labels shall be null-padded to fill out the full field length. Longer labels must be truncated, and shall not break anywhere other than a rune boundary (e.g. a 34 octet name ending in the rune specified by 0xF09F8F97 would need to be truncated back to the 30th octet, and then followed by 0x0000).

14 OTP System Advertisement Layer

System Advertisement data only appears in OTP System Advertisement Messages and shall not be included in OTP Transform Messages, OTP Module Advertisement Messages, or OTP Name Advertisement Messages.

Table 14-1: OTP System Advertisement Layer

Octet	Field Size	Field Name	Field Description	Field Contents
OTP System Advertisement Layer				
87-88	2	Vector	Identifies System Advertisement data as system number list	VECTOR_OTP_ADVERTISEMENT_SYSTEM_LIST
89-90	2	Length	Length of PDU	The length of the PDU in octets.
91	1	Options	Options Flags	Bit 7 = Request/Response
92-95	4	Reserved	Reserved	Reserved. Shall be transmitted as 0x00000000.
96-	0-200	List of System Numbers	Sorted list of up to 200 System Numbers	List of {System Number}

14.1 System Advertisement Layer Vector

The System Advertisement Layer's Vector shall be set to VECTOR_OTP_ADVERTISEMENT_SYSTEM_LIST, indicating that it contains a List of System Numbers.

Receiving Components shall discard the message if the received value is not VECTOR_OTP_ADVERTISEMENT_SYSTEM_LIST.

14.2 Length

The length field is a 16-bit field containing the PDU length in octets, excluding the Vector and Length fields.

14.3 Options

This bit-oriented field is used to encode flags indicating how to process the remaining data in the PDU.

Request/Response: Bit 7 (most significant bit)

This bit, when set to 0, indicates that this is a request for System Numbers from a Consumer. When set to 1, this bit indicates this is a response to an OTP System Advertisement Message request.

Producers shall ignore OTP System Advertisement Messages with the Request/Response bit set to 1.

Bits 0 through 6 of this field are reserved for future use and shall be transmitted as 0 and ignored by receiving Components.

14.4 Reserved

These octets are reserved for future use. Components shall transmit as 0x00000000. Receiving Components shall ignore this field.

14.5 List of System Numbers

The System Advertisement Layer's List of System Numbers is a packed list of System Numbers, sorted numerically, starting from the lowest number. When sent by a Producer, it shall enumerate all of the System Numbers for which that Producer is transmitting data. When sent by a Consumer, this field shall be empty.

Producers shall ignore this field.

15 Operation of OTP in IPv4 and IPv6 Networks

This standard has the ability to operate over both IPv4 and IPv6 transports. Producers and Consumers shall support at least one of IPv4 or IPv6. All Components should support IPv4, and may optionally support IPv6. Components complying with this standard shall indicate, through labelling, manufacturer documentation, or other means, which IP transports they support, using the appropriate designation from Table 15-1.

Table 15-1: Component Designation

Support	Designation
IPv4	OTP-4
IPv6	OTP-6
IPv4 & IPv6	OTP-4/6

15.1 Multicast Addressing

This standard uses multicast addressing to direct OTP Messages to their specified destination(s). Where an OTP Advertisement Message requires a response, it shall be sent unicast to the source address and port of the request.

Components configured to operate simultaneously in IPv4 and IPv6 shall transmit identical OTP Messages regardless of the IP transport used, and shall not process OTP Messages differently based on their IP transport. Components seeing the same OTP Message via both IP transports shall only act on one instance of that message.

OTP Components shall only transmit multicast OTP Messages to the multicast addresses defined in Section 15.3. OTP Transform Message addressing and partitioning of multicast traffic is achieved by setting the least significant bytes of the multicast IP address to the desired System Number. Components can thus transmit and receive data for a specific System Number without prior knowledge of the network topology.

The identity of the system shall be determined by the System Number in the OTP Transform Message and shall not be assumed from the multicast address.

When operating over [UDP], the multicast destination port shall be set to OTP_PORT.

15.2 Multicast Subscription

Components supporting IPv4 shall support IGMP V2 [IGMP2] or any subsequent superset of [IGMP2]'s functionality.

Components supporting IPv6 shall support MLD V1 [MLD] or any subsequent superset of [MLD]'s functionality.

These protocols are used to communicate multicast address usage to network infrastructure.

15.3 Allocation of Multicast Addresses

15.3.1 Allocation of IPv4 Multicast Addresses

Multicast addresses are from the IPv4 Local Scope and will be managed by routers in conformance with RFC 2365 [ASIPM].

Multicast Addresses are defined as follows:

Table 15-2: IPv4 Multicast Addresses

Message	IP Address			
	Byte 1	Byte 2	Byte 3	Byte 4
OTP Transform Message	239	159	1	System Number
OTP Advertisement Message	239	159	2	1

15.3.2 Allocation of IPv6 Multicast Addresses

Multicast addresses are specified as follows:

Table 15-3: IPv6 Multicast Addressing

Message	Prefix (1 Byte)	Flags (4 bits)	Scope (4 bits)	Group ID (112 bits)
OTP Transform Message	0xff	0 R P T	0x8	00::9f:00:01:<System Number>
OTP Advertisement Message	0xff	0 R P T	0x8	00::9f:00:02:01

The multicast address prefix is fixed at 0xff.

The flags are set as follows:

0 - The high-order flag bit is reserved and shall be set to 0.

R – The R flag shall be set to 0 to indicate that a rendezvous point is not embedded ([EmbeddedRP]).

P – The P flag shall be set to 0 to indicate that the multicast address does not carry prefix information ([UnicastPrefixMcast]).

T – The T flag shall be set to 1 to indicate that this multicast address is temporary, and not a “well-known” address permanently assigned by IANA.

The scope shall be set to 0x8 to indicate Organization-Local scope (for more information on IPv6 multicast scopes, see [IPv6McastScope], Section 2).

The Group ID shall be set to 00::9f:00:01:<System Number> (i.e.: the range ff18::9f:00:01:01 – ff18::9f:00:01:c8) for OTP Transform Messages and 00::9f:00:02:01 (i.e.: ff18::9f:00:02:01) for OTP Advertisement Messages.

16 Standard Modules

These Standard Modules each define different sets of information about a Point.

There are no requirements as to what Modules a Producer may support. For any given Point, Producers may only support some Modules. For any supported Standard Module, Producers shall also support all of its Associated Modules (see Table 16-1).

Consumers may request the transmission of certain Modules using the Module Advertisement mechanism (See Section 7.4.2.1).

Modules are uniquely identified using a Module Identifier, which is composed of a Manufacturer ID and a 16-bit Module Number. For all standard Modules, the Manufacturer ID shall be set to ESTA_MANUFACTURER_ID.

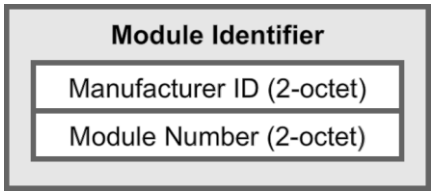

Figure 16-1: Module Identifier Structure

Table 16-1: Standard Module Types

Module	Number Value	Associated Module(s)
Position	0x0001	
Position Velocity/Acceleration	0x0002	Position
Rotation	0x0003	
Rotation Velocity/Acceleration	0x0004	Rotation
Scale	0x0005	
Reference Frame	0x0006	

All Modules defined in OTP shall be transmitted in network byte order (big endian) and use unsigned integers, except where indicated.

16.1 Position Module

This data structure contains the current position of a Point in all three linear directions.

Table 16-2: Position Module

Octet	Field Size	Field Name	Field Description	Field Value
Module Data				
0	1	Options	Options Flags	Bit 7 = Scaling
1-4	4 Signed	X	The X location of the Point in µm or mm	-2,147,483,648 – 2,147,483,647
5-8	4 Signed	Y	The Y location of the Point in µm or mm	-2,147,483,648 – 2,147,483,647
9-12	4 Signed	Z	The Z location of the Point in µm or mm	-2,147,483,648 – 2,147,483,647

16.1.1 Options

This bit-oriented field is used to encode flags indicating how the data in other fields is encoded.

Scaling: Bit 7 (most significant bit)

This bit, when set to 1, indicates that the remaining fields in this Module provide values in mm. When set to 0, the remaining fields use µm.

Bits 0 through 6 of this field are reserved for future use and shall be transmitted as 0 and ignored by receiving Components.

16.2 Position Velocity/Acceleration Module

This data structure contains the positional velocity and acceleration of a Point.

Table 16-3: Position Velocity/Acceleration Module

Octet	Field Size	Field Name	Field Description	Field Value
Module Data				
0-3	4 Signed	Vx	The linear velocity in the X direction of the Point in µm/s	-2,147,483,648 – 2,147,483,647
4-7	4 Signed	Vy	The linear velocity in the Y direction of the Point in µm/s	-2,147,483,648 – 2,147,483,647
8-11	4 Signed	Vz	The linear velocity in the Z direction of the Point in µm/s	-2,147,483,648 – 2,147,483,647
12-15	4 Signed	Ax	The linear acceleration in the X direction of the Point in $\mu m/s^2$	-2,147,483,648 – 2,147,483,647
16-19	4 Signed	Ay	The linear acceleration in the Y direction of the Point in $\mu m/s^2$	-2,147,483,648 – 2,147,483,647
20-23	4 Signed	Az	The linear acceleration in the Z direction of the Point in $\mu m/s^2$	-2,147,483,648 – 2,147,483,647

16.3 Rotation Module

This data structure contains the current rotation of the Point using intrinsic Euler rotation calculated in the x-convention (the Tait-Bryan ZYX convention) (See Section 4.2). Further information on Euler rotation and alternative systems can be found in Appendix C.

Table 16-4: Rotation Module

Octet	Field Size	Field Name	Field Description	Field Value
Module Data				
0-3	4	Rx	The Euler X rotation of the Point in millionths of a decimal degree	0 – 359,999,999
4-7	4	Ry	The Euler Y rotation of the Point in millionths of a decimal degree	0 – 359,999,999
8-11	4	Rz	The Euler Z rotation of the Point in millionths of a decimal degree	0 – 359,999,999

16.4 Rotation Velocity/Acceleration Module

This data structure contains the rotational velocity and acceleration of the Point using intrinsic Euler rotation calculated in the x-convention (the Tait-Bryan ZYX convention) (See Section 4.2). Further information on Euler rotation and alternative systems can be found in Appendix C.

This module supports velocities as low as 0.001 degrees/s and as high as 1000 revolutions/s.

Note: For example, a value of 45,000 for Vrx would mean a rotation of 45 degrees/s, or 0.125 revolutions/s, or 7.5 rpm.

Table 16-5: Rotation Velocity/Acceleration Module

Octet	Field Size	Field Name	Field Description	Field Value
Module Data				
0-3	4 Signed	Vrx	The velocity of Euler X rotation of the Point in thousandths of a decimal degree/s	-360,000,000 – 360,000,000
4-7	4 Signed	Vry	The velocity of Euler Y rotation of the Point in thousandths of a decimal degree/s	-360,000,000 – 360,000,000
8-11	4 Signed	Vrz	The velocity of Euler Z rotation of the Point in thousandths of a decimal degree/s	-360,000,000 – 360,000,000
12-15	4 Signed	Arx	The acceleration of Euler X rotation of the Point in thousandths of a decimal degree/s^2	-360,000,000 – 360,000,000
16-19	4 Signed	Ary	The acceleration of Euler Y rotation of the Point in thousandths of a decimal degree/s^2	-360,000,000 – 360,000,000
20-23	4 Signed	Arz	The acceleration of Euler Z rotation of the Point in thousandths of a decimal degree/s^2	-360,000,000 – 360,000,000

16.5 Scale

This data structure describes the unitless, absolute scale of the Point in the X, Y, and Z directions. The Scale Module may be used for description of Points that have the ability to change size.

Table 16-6: Scale Module

Octet	Field Size	Field Name	Field Description	Field Value
Module Data				
0-3	4 Signed	X Scale	The scale of the Point in the X direction in unitless millionths. A value of 1 (encoded as 1,000,000) indicates that this point is at its reference size	-2,147,483,648 – 2,147,483,647
4-7	4 Signed	Y Scale	The scale of the Point in the Y direction in unitless millionths. A value of 1 (encoded as 1,000,000) indicates that this point is at its reference size	-2,147,483,648 – 2,147,483,647

8-11	4 Signed	Z Scale	The scale of the Point in the Z direction in unitless millionths. A value of 1 (encoded as 1,000,000) indicates that this point is at its reference size	-2,147,483,648 – 2,147,483,647

16.6 Reference Frame

This data structure contains the Address of the Reference Frame of the Point.

If a Reference Frame Module is included in a Point Layer, any other Modules included in this Point shall contain transform information relative to that of the Reference Frame.

Producers shall not transmit OTP Transform Messages containing circular references in Reference Frames. There is no limit on the number of levels of referencing, or on how many Points may refer to a single Reference Frame.

Producers shall not transmit transform information which results in calculated values which could not otherwise be encoded for a particular Point, e.g. including the maximum value for X in the Position Module for both a Point and its Reference Frame.

Table 16-7: Reference Frame Module

Octet	Field Size	Field Name	Field Description	Field Value
Module Data				
0	1	Reference System	The System Number of the Reference Frame of this Point	1-200
1-2	2	Reference Group	The Group Number of the Reference Frame of this Point	1-60,000
3-6	4	Reference Point	The Point Number of the Reference Frame of this Point	1-4,000,000,000

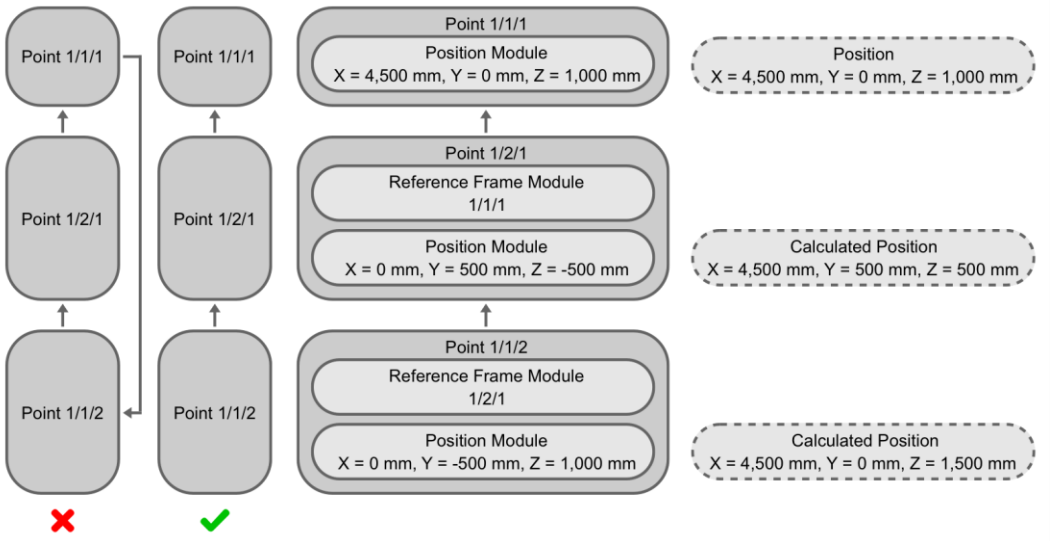

Figure 16-2: Reference Frame Example (Informative)

Appendix A: Defined Parameters

Table A-1: Vector Defines

Layer	Vector Define(s)	Value
OTP	VECTOR_OTP_TRANSFORM_MESSAGE VECTOR_OTP_ADVERTISEMENT_MESSAGE	0x0001 0x0002
OTP Transform	VECTOR_OTP_POINT	0x0001
OTP Point	VECTOR_OTP_MODULE	0x0001
OTP Advertisement	VECTOR_OTP_ADVERTISEMENT_MODULE VECTOR_OTP_ADVERTISEMENT_NAME VECTOR_OTP_ADVERTISEMENT_SYSTEM	0x0001 0x0002 0x0003
OTP Module Advertisement	VECTOR_OTP_ADVERTISEMENT_MODULE_LIST	0x0001
OTP Name Advertisement	VECTOR_OTP_ADVERTISEMENT_NAME_LIST	0x0001
OTP System Advertisement	VECTOR_OTP_ADVERTISEMENT_SYSTEM_LIST	0x0001

Table A-2: Timing Defines

Message	Timing Define	Timing
OTP Transform	OTP_TRANSFORM_TIMING_MIN OTP_TRANSFORM_TIMING_MAX OTP_TRANSFORM_FULL_POINT_SET_TIMING_MIN OTP_TRANSFORM_FULL_POINT_SET_TIMING_MAX OTP_TRANSFORM_DATA_LOSS_TIMEOUT	1 millisecond 50 milliseconds 2,800 milliseconds 3,000 milliseconds 7,500 milliseconds
OTP Module Advertisement	OTP_ADVERTISEMENT_TIMING OTP_ADVERTISEMENT_STARTUP_WAIT OTP_ADVERTISEMENT_TIMEOUT	10 seconds 12 seconds 30 seconds
OTP Name Advertisement	OTP_NAME_ADVERTISEMENT_MAX_BACKOFF	5 seconds
OTP System Advertisement	OTP_SYSTEM_ADVERTISEMENT_MAX_BACKOFF	5 seconds

Table A-3: Additional Defines

Reference	Value
OTP_PORT	5568
ESTA_MANUFACTURER_ID	0x0000

Appendix B: Example Messages (Informative)

B.1 Transform Message Example

A sample Producer ‘Automation-Server-Primary’ can provide transform information for 2 points within a particular System. It is able to provide the position of both Points, but rotation can only be provided for one of them.

A sample message may look like this:

Table B-1: Transform Message Example

Octet	Field Size	Field Name	Field Description	Field Contents
OTP Layer				
0-11	12	OTP Packet Identifier	Identifies this message as OTP	0x4f 0x54 0x50 0x2d 0x45 0x31 0x2e 0x35 0x39 0x00 0x00 0x00
12-13	2	Vector	Identifies OTP Layer data as OTP Transform PDU	VECTOR_OTP_TRANSFORM_MESSAGE
14-15	2	Length	Length of message	185 (example only)
16	1	Footer Options	Footer Options Flags	0x00
17	1	Footer Length	Length of footer	0x00
18-33	16	CID	Sender's CID	0x4d 0x6f 0x76 0x65 0x73 0x20 0x40 0x39 0xb0 0x20 0x6f 0x62 0x6a 0x65 0x63 0x74 (example only)
34-37	4	Folio Number	Identifies OTP Folios	326 (example only)
38-39	2	Page	Page number	1 (example only)
40-41	2	Last Page	Final page number	1 (example only)
42	1	Options	Options Flags	0x00
43-46	4	Reserved	Reserved	0x00000000
47-78	32	Component Name	Component Name	Automation-Server-Primary (example only)
OTP Transform Layer				
79-80	2	Vector	Identifies transform data as OTP Point PDU	VECTOR_OTP_POINT
81-82	2	Length	Length of PDU	118 (example only)
83	1	System Number	Unique within a network, identifies this System.	1 (example only)
84-91	8	Timestamp	Microseconds since the Time Origin	3,600,000,000 µs (example only)

92	1	Options	Options Flags	Bit 7 = 1 (example only)
93-96	4	Reserved	Reserved	0x00000000
OTP Point Layer				
97-98	2	Vector	Identifies Point data as OTP Module PDU	VECTOR_OTP_MODULE
99-100	2	Length	Length of PDU	39 (example only)
101	1	Priority	Data priority if multiple sources for this Address	100 (example only)
102-103	2	Group Number	Unique within a System, identifies this Group	1000 (example only)
104-107	4	Point Number	Unique within a Group, identifies this Point	1 (example only)
108-115	8	Timestamp	Microseconds since the Time Origin	3,599,000,000 µs (example only)
116	1	Options	Options Flags	0x00
117-120	4	Reserved	Reserved	0x00000000
OTP Module Layer				
121-122	2	Manufacturer ID	Identifies the Manufacturer ID of an encapsulated module	ESTA_MANUFACTURER_ID (example only)
123-124	2	Length	Length of PDU	15 (example only)
125-126	2	Module Number	Identifies the type of the module	0x0001 (example only)
127	1	Options	Options Flags	Bit 7 = 1 (example only)
128-131	4 Signed	X	The X location of the Point in µm or mm	10,000 mm (example only)
132-135	4 Signed	Y	The Y location of the Point in µm or mm	-1,500 mm (example only)
136-139	4 Signed	Z	The Z location of the Point in µm or mm	-2,000 mm (example only)
OTP Point Layer				
140-141	2	Vector	Identifies Point data as OTP Module PDU	VECTOR_OTP_MODULE
142-143	2	Length	Length of PDU	57 (example only)

144	1	Priority	Data priority if multiple sources for this Address	101 (example only)
145-146	2	Group Number	Unique within a System, identifies this Group	1000 (example only)
147-150	4	Point Number	Unique within a Group, identifies this Point	201 (example only)
151-158	8	Timestamp	Microseconds since the Time Origin	3,590,000,000 µs (example only)
159	1	Options	Options Flags	0x00
160-163	4	Reserved	Reserved	0x00000000
OTP Module Layer				
164-165	2	Manufacturer ID	Identifies the Manufacturer ID of an encapsulated module	ESTA_MANUFACTURER_ID (example only)
166-167	2	Length	Length of PDU	15 (example only)
168-169	2	Module Number	Identifies the type of the module	0x0001 (example only)
170	1	Options	Options Flags	Bit 7 = 0 (example only)
171-174	4 Signed	X	The X location of the Point in µm or mm	100,000 µm (example only)
175-178	4 Signed	Y	The Y location of the Point in µm or mm	1,000,500 µm (example only)
179-182	4 Signed	Z	The Z location of the Point in µm or mm	-10,000 µm (example only)
OTP Module Layer				
183-184	2	Manufacturer ID	Identifies the Manufacturer ID of an encapsulated module	ESTA_MANUFACTURER_ID (example only)
185-186	2	Length	Length of PDU	14 (example only)
187-188	2	Module Number	Identifies the type of the module	0x0003 (example only)
189-192	4	Rx	The Euler X rotation of the Point in millionths of a decimal degree	0 (example only)

193-196	4	Ry	The Euler X rotation of the Point in millionths of a decimal degree	0 (example only)
197-200	4	Rz	The Euler X rotation of the Point in millionths of a decimal degree	90,000,000 (example only)

B.2 System Advertisement Message Examples

A sample Consumer 'Lighting-Console-Primary' wants to learn the System Numbers of Producers on the network.

A sample message may look like this:

Table B-2: System Advertisement Message Consumer Example

Octet	Field Size	Field Name	Field Description	Field Contents
OTP Layer				
0-11	12	OTP Packet Identifier	Identifies this message as OTP	0x4f 0x54 0x50 0x2d 0x45 0x31 0x2e 0x35 0x39 0x00 0x00 0x00
12-13	2	Vector	Identifies OTP Layer data as OTP Advertisement PDU	VECTOR_OTP_ADVERTISEMENT_MESSAGE
14-15	2	Length	Length of message	80 (example only)
16	1	Footer Options	Footer Options Flags	0x00
17	1	Footer Length	Length of footer	0x00
18-33	16	CID	Sender's CID	0x54 0x69 0x6c 0x74 0x73 0x20 0x40 0x35 0xb0 0x20 0x6c 0x69 0x67 0x68 0x74 0x73 (example only)
34-37	4	Folio Number	Identifies OTP Folios	6292 (example only)
38-39	2	Page	Page number	1 (example only)
40-41	2	Last Page	Final page number	1 (example only)
42	1	Options	Options Flags	0x00
43-46	4	Reserved	Reserved	0x00000000
47-78	32	Component Name	Component Name	Lighting-Console-Primary (example only)
OTP Advertisement Layer				
79-80	2	Vector	Identifies Advertisement	VECTOR_OTP_ADVERTISEMENT_SYSTEM

			data as system advertisement	
81-82	2	Length	Length of PDU	13 (example only)
83-86	4	Reserved	Reserved	0x00000000
OTP System Advertisement Layer				
87-88	2	Vector	Identifies System Advertisement data as system number list	VECTOR_OTP_ADVERTISEMENT_SYSTEM_LIST
89-90	2	Length	Length of PDU	5 (example only)
91	1	Options	Options Flags	Bit 7 = 0 (example only)
92-95	4	Reserved	Reserved	0x00000000

A sample Producer ‘Automation-Server-Primary’ can provide transform information for two systems. When it receives the message in Table B-2, a sample response may look like this:

Table B-3: System Advertisement Message Producer Example

Octet	Field Size	Field Name	Field Description	Field Contents
OTP Layer				
0-11	12	OTP Packet Identifier	Identifies this message as OTP	0x4f 0x54 0x50 0x2d 0x45 0x31 0x2e 0x35 0x39 0x00 0x00 0x00
12-13	2	Vector	Identifies OTP Layer data as OTP Advertisement PDU	VECTOR_OTP_ADVERTISEMENT_MESSAGE
14-15	2	Length	Length of message	82 (example only)
16	1	Footer Options	Footer Options Flags	0x00
17	1	Footer Length	Length of footer	0x00
18-33	16	CID	Sender's CID	0x4d 0x6f 0x76 0x65 0x73 0x20 0x40 0x39 0xb0 0x20 0x6f 0x62 0x6a 0x65 0x63 0x74 (example only)
34-37	4	Folio Number	Identifies OTP Folios	100 (example only)
38-39	2	Page	Page number	1 (example only)
40-41	2	Last Page	Final page number	1 (example only)
42	1	Options	Options Flags	0x00
43-46	4	Reserved	Reserved	0x00000000
47-78	32	Component Name	Component Name	Automation-Server-Primary (example only)
OTP Advertisement Layer				
79-80	2	Vector	Identifies Advertisement	VECTOR_OTP_ADVERTISEMENT_SYSTEM

			data as system advertisement	
81-82	2	Length	Length of PDU	15 (example only)
83-86	4	Reserved	Reserved	0x00000000
OTP System Advertisement Layer				
87-88	2	Vector	Identifies System Advertisement data as system number list	VECTOR_OTP_ADVERTISEMENT_SYSTEM_LIST
89-90	2	Length	Length of PDU	7 (example only)
91	1	Options	Options Flags	Bit 7 = 1 (example only)
92-95	4	Reserved	Reserved	0x00000000
96-97	2 (example only)	List of System Numbers	Sorted list of up to 200 System Numbers	{1,5} (example only)

B.3 Name Advertisement Message Example

A sample Consumer ‘Lighting-Console-Primary’ wants to learn the names of Points for Producers on the network.

A sample message may look like this:

Table B-4: Name Advertisement Message Consumer Example

Octet	Field Size	Field Name	Field Description	Field Contents
OTP Layer				
0-11	12	OTP Packet Identifier	Identifies this message as OTP	0x4f 0x54 0x50 0x2d 0x45 0x31 0x2e 0x35 0x39 0x00 0x00 0x00
12-13	2	Vector	Identifies OTP Layer data as OTP Advertisement PDU	VECTOR_OTP_ADVERTISEMENT_MESSAGE
14-15	2	Length	Length of message	80 (example only)
16	1	Footer Options	Footer Options Flags	0x00
17	1	Footer Length	Length of footer	0x00
18-33	16	CID	Sender's CID	0x54 0x69 0x6c 0x74 0x73 0x20 0x40 0x35 0xb0 0x20 0x6c 0x69 0x67 0x68 0x74 0x73 (example only)
34-37	4	Folio Number	Identifies OTP Folios	400 (example only)
38-39	2	Page	Page number	1 (example only)

40-41	2	Last Page	Final page number	1 (example only)
42	1	Options	Options Flags	0x00
43-46	4	Reserved	Reserved	0x00000000
47-78	32	Component Name	Component Name	Lighting-Console-Primary (example only)
OTP Advertisement Layer				
79-80	2	Vector	Identifies Advertisement data as name advertisement	VECTOR_OTP_ADVERTISEMENT_NAME
81-82	2	Length	Length of PDU	13 (example only)
83-86	4	Reserved	Reserved	0x00000000
OTP Name Advertisement Layer				
87-88	2	Vector	Identifies Name Advertisement data as name list	VECTOR_OTP_ADVERTISEMENT_NAME_LIST
89-90	2	Length	Length of PDU	5 (example only)
91	1	Options	Options Flags	Bit 7 = 0 (example only)
92-95	4	Reserved	Reserved	0x00000000

A sample Producer ‘Automation-Server-Primary’ can provide transform information for several Points split across two Systems. When it receives the message in Table B-4, a sample response may look like this:

Table B-5: Name Advertisement Message Producer Example

Octet	**Field Size**	**Field Name**	**Field Description**	**Field Contents**
OTP Layer				
0-11	12	OTP Packet Identifier	Identifies this message as OTP	0x4f 0x54 0x50 0x2d 0x45 0x31 0x2e 0x35 0x39 0x00 0x00 0x00
12-13	2	Vector	Identifies OTP Layer data as OTP Advertisement PDU	VECTOR_OTP_ADVERTISEMENT_MESSAGE
14-15	2	Length	Length of message	236 (example only)
16	1	Footer Options	Footer Options Flags	0x00
17	1	Footer Length	Length of footer	0x00
18-33	16	CID	Sender's CID	0x4d 0x6f 0x76 0x65 0x73 0x20 0x40 0x39 0xb0 0x20 0x6f 0x62 0x6a 0x65 0x63 0x74 (example only)
34-37	4	Folio Number	Identifies OTP Folios	3000 (example only)
38-39	2	Page	Page number	1 (example only)

40-41	2	Last Page	Final page number	1 (example only)
42	1	Options	Options Flags	0x00
43-46	4	Reserved	Reserved	0x00000000
47-78	32	Component Name	Component Name	Automation-Server-Primary (example only)
OTP Advertisement Layer				
79-80	2	Vector	Identifies Advertisement data as name advertisement	VECTOR_OTP_ADVERTISEMENT_NAME
81-82	2	Length	Length of PDU	169 (example only)
83-86	4	Reserved	Reserved	0x00000000
OTP Name Advertisement Layer				
87-88	2	Vector	Identifies Name Advertisement data as name list	VECTOR_OTP_ADVERTISEMENT_NAME_LIST
89-90	2	Length	Length of PDU	161 (example only)
91	1	Options	Options Flags	Bit 7 = 1 (example only)
92-95	4	Reserved	Reserved	0x00000000
96-251	156 (example only)	List of Address Point Descriptions	Sorted list of up to 35 Address Point Descriptions	{(1, 1000, 1, Slider B), (1, 1000, 201, Revolve A), (5, 1, 1001, Audience Lift A), (5, 1, 1001, Audience Lift B)} (example only)

B.4 Module Advertisement Message Example

A sample Consumer ‘Lighting-Console-Primary’ may be able to support only position and rotation information. To inform Producers on the network of these capabilities a sample message may look like this:

Table B-6: Module Advertisement Message Example

Octet	Field Size	Field Name	Field Description	Field Contents
OTP Layer				
0-11	12	OTP Packet Identifier	Identifies this message as OTP	0x4f 0x54 0x50 0x2d 0x45 0x31 0x2e 0x35 0x39 0x00 0x00 0x00
12-13	2	Vector	Identifies OTP Layer data as OTP Advertisement PDU	VECTOR_OTP_ADVERTISEMENT_MESSAGE
14-15	2	Length	Length of message	87 (example only)
16	1	Footer Options	Footer Options Flags	0x00
17	1	Footer Length	Length of footer	0x00
18-33	16	CID	Sender's CID	0x54 0x69 0x6c 0x74 0x73 0x20 0x40 0x35 0xb0 0x20 0x6c 0x69 0x67 0x68 0x74 0x73 (example only)
34-37	4	Folio Number	Identifies OTP Folios	601 (example only)
38-39	2	Page	Page number	1 (example only)
40-41	2	Last Page	Final page number	1 (example only)
42	1	Options	Options Flags	0x00
43-46	4	Reserved	Reserved	0x00000000
47-78	32	Component Name	Component Name	Lighting-Console-Primary (example only)
OTP Advertisement Layer				
79-80	2	Vector	Identifies Advertisement data as module advertisement	VECTOR_OTP_ADVERTISEMENT_MODULE
81-82	2	Length	Length of PDU	20 (example only)
83-86	4	Reserved	Reserved	0x00000000
OTP Name Advertisement Layer				
87-88	2	Vector	Identifies Module Advertisement data as module list	VECTOR_OTP_ADVERTISEMENT_MODULE_LIST
89-90	2	Length	Length of PDU	12 (example only)
91-94	4	Reserved	Reserved	0x00000000

95-102	8 (example only)	List of Module Identifiers	Sorted list of up to 344 module identifiers	{(0x0000 0x0001), (0x0000 0x0003)} (example only)

Appendix C: Euler Angles, Quaternions, and Rotation Matrices (Informative)

The default modules in this standard include a way to express the rotation of a Point. The orientation of an object in space can be described using a number of techniques, the most common of which are Euler angles, rotation matrices, and quaternions.

This standard has chosen to support Euler angles, with full knowledge that not all orientations can be encoded in this manner. Manufacturers needing to support other forms of rotational notation will need to either perform a conversion to and from Euler angles, or implement a separate, manufacturer-specific module. Since no modules in OTP are mandatory, implementors should be aware that simply transporting a different encoding (or using a standard one, for that matter) does not guarantee that a receiving OTP Component will understand that module. A critical part of this standard is that Components must negotiate a common vocabulary of modules. For more information on Module Advertisement, see Section 7.4.

This appendix describes Euler angles and includes methods to convert to and from quaternions and direction cosine matrices.

C.1 Why Euler Angles?

The architecture of this standard intentionally allows for Producers that are very lightweight. These Components may not be able to sense the full orientation of a Point and, thus, may not have the knowledge or the math available to use quaternions. Euler angles are an intuitive alternative that will allow the widest variety of Components to communicate.

C.2 Limitations of Euler Angles

One of the main limitations of Euler angles is a concept called *gimbal lock*. Gimbal lock is a singularity that occurs when the second rotation in a set of Euler angles (in our case, the intrinsic Y axis, or "pitch") aligns the other two axes such that they are parallel. When this happens, any motion around the first axis (Z, or "yaw") is indistinguishable from motion around the third (X, "roll"). In these situations, where the angle of the second rotation approaches |90| degrees, the orientation of a Point in an OTP system cannot be uniquely described using Euler angles.

In many devices (most memorably, in the Apollo spacecrafts), this issue does not only occur at exactly -90 and 90 degrees, but also as the angle approaches those values. This standard does not provide a mechanism by which to accurately express the orientation of a Point that is in a state of gimbal lock.

C.3 Conversion of Euler Angles to Other Encodings

Euler angles can be converted to and from a variety of other encodings for rotational orientation. Some Euler angles may have more than one representation in the other formats.

C.3.1 Direction Cosine Matrices

Conversion of the set of Euler angles α, β, γ in Tait-Bryan ZYX convention to a direction cosine matrix is expressed as the following:

$$\begin{bmatrix} \cos\beta\cos\gamma & \sin\alpha\sin\beta\cos\gamma - \cos\alpha\sin\gamma & \sin\alpha\sin\gamma + \cos\alpha\sin\beta\cos\gamma \\ \cos\beta\sin\gamma & \cos\alpha\cos\gamma + \sin\alpha\sin\beta\sin\gamma & \cos\alpha\sin\beta\sin\gamma - \cos\gamma\sin\alpha \\ -\sin\beta & \sin\alpha\cos\beta & \cos\alpha\cos\beta \end{bmatrix}$$

Converting from a direction cosine matrix is done by solving for the individual angles shown in the matrix above.

If we consider the positions in the matrix to be

$$\begin{matrix} M_{11} & M_{12} & M_{13} \\ M_{21} & M_{22} & M_{23} \\ M_{31} & M_{32} & M_{33} \end{matrix}$$

then we can very easily solve for M_{31} to get β.

Since $\sin(180 - \beta) = \sin\beta$, there are actually two possible values for β,

$$\sin^{-1}(-M_{31})$$
and
$$180 - \sin^{-1}(-M_{31})$$

Once we have β, we can then solve for α and γ. Recall, however, that when β is equal to +90 or -90 degrees, we are in a state of gimbal lock. Though it is quite possible to compute the set of solutions for α and γ, it becomes a mathematical exercise, far beyond the scope of this standard (and its Appendices). Instead, let us assume that $|\beta|$ is not 90 degrees. Thus, we can safely solve for α and γ, without any fear of division by zero. Taking either solution for β above, we can use the following equations:

Note: If at all possible, using the four-quadrant inverse tangent `atan2` is preferable to the traditional [two-quadrant] tan^{-1}, as it is able to work over the range of -180 to 180 degrees instead of just -90 to 90.

$$\alpha = \operatorname{atan2}\left(\frac{\frac{M_{32}}{\cos\beta}}{\frac{M_{33}}{\cos\beta}}\right)$$

$$\gamma = \operatorname{atan2}\left(\frac{\frac{M_{21}}{\cos\beta}}{\frac{M_{11}}{\cos\beta}}\right)$$

This will result in two sets of angles (α, β, γ) that may be the desired Euler solution.

C.3.2 Quaternions

In order to convert Euler angles to quaternions, we can also go through a rotation matrix.

For a unit quaternion expressed as $q = [q_w \quad q_x \quad q_y \quad q_z]$, we can convert to a direction cosine matrix using the following calculation:

$$\begin{bmatrix} 1-2(q_y^2+q_z^2) & 2(q_xq_y-q_wq_z) & 2(q_wq_y+q_xq_z) \\ 2(q_xq_y+q_wq_z) & 1-2(q_x^2+q_z^2) & 2(q_yq_z-q_wq_x) \\ 2(q_xq_z-q_wq_y) & 2(q_wq_x+q_yq_z) & 1-2(q_x^2+q_y^2) \end{bmatrix}$$

To convert to Euler angles in the Tait-Bryan ZYX convention, as in C.4.1 above, using the matrix positions

$$\begin{matrix} M_{11} & M_{12} & M_{13} \\ M_{21} & M_{22} & M_{23} \\ M_{31} & M_{32} & M_{33} \end{matrix}$$

We can solve, again, for (α, β, γ):

$$\alpha = atan2\left(\frac{M_{32}}{M_{33}}\right) = atan2(\frac{2(q_wq_x+q_yq_z)}{1-2(q_x^2+q_y^2)})\ldots$$

$$\beta = \sin^{-1} -M_{31} = \sin^{-1}(-2(q_xq_z - q_wq_y)) = \sin^{-1}(2(q_wq_y - q_xq_z))$$

$$\gamma = atan2\left(\frac{M_{21}}{M_{11}}\right) = atan2(\frac{2(q_xq_y + q_wq_z)}{1-2(q_y^2+q_z^2)})$$

We could use that same rotation matrix to convert Euler angles back to quaternions, which yields.

$$q_w = \cos\frac{\alpha}{2}\cos\frac{\beta}{2}\cos\frac{\gamma}{2} + \sin\frac{\alpha}{2}\sin\frac{\beta}{2}\sin\frac{\gamma}{2}$$

$$q_x = \sin\frac{\alpha}{2}\cos\frac{\beta}{2}\cos\frac{\gamma}{2} - \cos\frac{\alpha}{2}\sin\frac{\beta}{2}\sin\frac{\gamma}{2}$$

$$q_y = \sin\frac{\alpha}{2}\cos\frac{\beta}{2}\sin\frac{\gamma}{2} + \cos\frac{\alpha}{2}\sin\frac{\beta}{2}\cos\frac{\gamma}{2}$$

$$q_z = \cos\frac{\alpha}{2}\cos\frac{\beta}{2}\sin\frac{\gamma}{2} - \sin\frac{\alpha}{2}\sin\frac{\beta}{2}\cos\frac{\gamma}{2}$$