10th International Command and Control Research and Technology Symposium
The Future of C2

Paper 41

Tactical Digital Information Link-Technical Advice and Lexicon for Enabling Simulation (TADIL-TALES)

Topic: C4ISR/C2 Architecture

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Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE
JUN 2005

2. REPORT TYPE

3. DATES COVERED
00-00-2005 to 00-00-2005

4. TITLE AND SUBTITLE
Tactical Digital Information Link-Technical Advice and Lexicon for Enabling Simulation (TADIL-TALES)

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
ASRC Communications Ltd,Distributed Mission Operations Center,4500 Aberdeen Dr., SE BG 942,Kirtland AFB,NM,87117

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**		**21**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

ABSTRACT: Link 16 is a Communications, Navigation, and Identification (CNI) system, intended to exchange surveillance and Command and Control (C2) information among various C2 and weapons platforms, which enhance the missions of each service. Links 16 provides multiple access, high capacity, jam resistant, digital data, and secure voice CNI information to a variety of platforms. Link 16 is the primary NATO standard for the tactical datalink. NATO STANAG 5516/MIL-STD-6016 describes the TADIL J message formats and Link 16 network instructions.

There are immediate operational requirements for existing military simulations to exchange TADIL J/Link 16 data using a single interoperable standard. Several protocols have evolved to satisfy specific needs. The NATO STANAG 5602 "SIMPLE" Link 16 Standard is one such protocol. The standard is designed to be complementary to the SIMPLE Standard. As C2 distributed simulation expands in mission scale and complexity, tactical datalink implementations need to interoperate. Currently, there are five different Link 16 simulation protocols, and none interoperate. Recently, the Simulation Interoperability Standards Organization (SISO) has developed a Link 16 Simulation Standard. The objective of the simulation standard is to establish a single format to exchange TADIL J messages, and emulate a Link 16 radio frequency network that supports Distributed Missions Operations (DMO) training for the warfighter. The Air Force Distributed Mission Operations Center of Excellence (DMOC) located at Kirtland AFB, New Mexico, has sponsored these efforts to ensure interoperability between C2 systems in the DMO training environment.

In developing a standard for simulating Link 16 in Distributive Interactive Simulation (DIS) and High Level Architecture (HLA), it is recognized that there are widely varying requirements for achieving fidelity among different users. The standard attempts to establish procedures that may be used by the vast majority of users, by establishing discrete, scalable, interoperable levels of fidelity for different users. The standard also defines how each level of fidelity interoperates; consequently, allowing a low cost initial implementation with a path toward upgrading to higher Link 16 simulation as requirements evolve.

The IEEE 1278.1a-1998 Standard describes established DIS Transmitter and Signal Protocol Data Units (PDUs), but they are not specifically defined for Link 16 simulation. The SISO Link 16 Standard does not change the IEEE 1278.1a-1998 Standard fields for the Transmitter or Signal PDUs, but exploits the fact that both PDUs are variable length. For Transmitter PDUs, the standard defines how the variable length modulation parameter fields must be populated. For Signal PDUs, Link 16 specific information is relegated to the variable length data fields. In addition, Link 16 specific enumerations have been created to populate the standard fields.

The HLA instructions are formatted in compliance with the IEEE 1516 Standard for HLA. The instructions are presented in the form of a Base Object Model (BOM) that may be incorporated into a system FOM. RPR-FOM based simulations should be able to easily integrate the Link 16 BOM into their FOMs. Furthermore, there is a straightforward mapping between the DIS PDU implementations and the corresponding BOM components.

This paper presents the Link 16 DIS Transmitter and Signal PDU structures, HLA HLA BOM Object Model Templates (OMTs), general requirements, and implementation guidelines that provide interoperability among C2 systems.

1. Scope

This paper describes the protocol that establishes a standard for TADIL-J message exchange and JTIDS network simulation in the DIS and HLA interoperability frameworks. The intent is to describe the content of the standard fields of the Transmitter and Signal PDUs and establish procedures for their use. Compliance with these procedures will ensure interoperability amongst JTIDS simulation systems. Additional detail can be found in Reference 1.

2. References

1. SISO-STD-002-V2.9.6 DRAFT, version 2.9.6, 7 March 2005
2. IEEE 1278.1 – 1995 IEEE Standard for Distributed Interactive Simulation – Application Protocols
3. MIL-STD-6016B, Tactical Digital Information Link (TADIL) J Message Standard (DRAFT) 15 March 2002
4. NATO STANAG 5602, edition 1, Standard Interface for Multiple Platform Link Evaluation (SIMPLE) 20 Feb 2001
5. System Segment Specification for Joint Tactical Information Distribution System Class 2 Terminal, 15 April 1999
6. STANAG 5516, Edition 1, Tactical Data Exchange - LINK 16, Ratified 15 January 1997.
7. LINK-16 Enhanced Throughput Standard, August 11, 1998 Doc # VSD-618255-97-339-02
8. Joint Interoperability of Tactical Command and Control Systems Variable Message Format (VMF) Technical Interface Design Plan (Test Edition) Reissue 2, August 1996.

3. JTIDS Operating Characteristics

JTIDS uses the principle of frequency hopping Time Division Multiple Access (TDMA) to divide network time, and capacity, into divisions called time slots. Each time slot is 7.8125 milliseconds long with 128 time slots per second. Time slots are organized into three interleaved sets (A, B, and C). An epoch is 12.8 minutes long comprised of 32K time slots. There are 112.5 epochs in a 24-hour day. Therefore, the current epoch, set and time slot number can be calculated from the current time. Operationally, groups of time slots are assigned to a common function known as a Network Participation Group (NPG). Time slot assignments are published in a network data load (by a central net design agency), with participation groups identified by the time slot set, the "offset" of the time slot, and the time slot repetition rate. The repetition rate is expressed as an exponential power of 2, representing how often the time slot assigned to the NPG occurs within the set.

TDMA architecture requires that each JTIDS participant, known as a JTIDS Unit (JU), must know when its transmit time slots occur. JUs must be synchronized with a common network time to receive and transmit on the network. In JTIDS, one JU in a network is designated as the Network Time Reference (NTR).

4. General Requirements

This section describes general requirements for simulation of Link 16 independent of the simulation protocol used. The specific implementation under DIS is described in section 5. The specific requirements for implementation under HLA are described in section 6.

1. Simulators in compliance with this standard **shall at a minimum** have the capability to identify the NPG and net number of transmitted data to allow them to operate at TSA mode level 0 and 1.
2. All TADIL J messages **shall** be bit encoded in accordance with the MIL-STD-6016 TADIL J specification. In the specification, each time slot contains one 35-bit header, padded to 48 bits, and a varying number of 75 bit messages, padded to 80 bits, unless the message type indicator specifies otherwise.
3. Regardless of level of fidelity, all transmission modulation parameter fields **shall** be filled with meaningful data
4. When the header indicates Reed-Solomon encoding, the data area **shall** still be comprised of **non** Reed-Solomon encoded TADIL J messages.
5. Any simulator that is not emulating JTIDS network data load throughput **shall** have the ability to configure the maximum number of JTIDS words transmitted per second, but **shall not** exceed the JTIDS maximum of 1536 J-words

per second (twelve J-words per Pack-4 Single Pulse time slot multiplied by 128 time slots per second). This upper limit **shall not** apply to JTIDS LET (Enhanced Throughput) packets.

6. If the packing mode from the JTIDS header and the number of messages contained in the Signal message do not agree, (i.e. the header states that the packing mode is Pack-2 Double Pulse and there are 12 J-words contained with the message) extra messages **shall** be dropped by the receiving simulator—as would happen in a live JTIDS datalink. Simulators should be able to determine if the number of messages in the header matches the actual number of TADIL J messages. If there are fewer messages in the data area than prescribed by the packing mode, the receiver **shall** treat the missing messages as J31.7 "No statement" messages and parse the message stream accordingly.
7. Systems **shall** wait until the time slot occurs to transmit data in order to receive the latest update to data (i.e. time slots **shall** not be "pre-sent"). Receiving systems **shall** buffer messages after the time slot has occurred to account for network delays. The amount of time to buffer messages for a time slot **shall** be a runtime configuration item. The amount of time entered **shall** be the same for all participants in the same network and will cause the simulations to all "retire" a particular time slot at the same time. This effect is not important for lower levels of fidelity (Time Slot Allocation (TSA) modes 0, 1) but is critical for all fidelity levels that tie a message to a particular time slot along with a Network Data Load (NDL). If the effects of messages arriving later than the time slot are not important (multiple JUs transmitting in the same time slot, contention access, or data arriving while the receiving JU is transmitting), or the physical network infrastructure has low delays (less than 3 msec), the buffer time can be set to a low number or to zero.
8. All systems set at TSA level 2 or higher **shall** have their system times synchronized to a common time reference. Any error in the clock synchronization times (e.g. average NTP error) must be added to the network delays (the buffer time) before retiring a time slot. For real-time DIS or HLA simulation applications, NTP (or equivalent) is recommended. For non-real-time simulation applications, HLA time management is recommended.
9. All systems should have some representation of a terminal clock time. If medium fidelity synchronization is to be accomplished, the system **shall** model a terminal clock (and its associated drift).
10. At TSA level 2 or greater, if multiple messages are received with identical TSEC, net number and timeslot number, receivers **shall** not process messages except from the closest transmitting entity (in the simulation space).
11. There are three communication modes for a real JTIDS/MIDS network: modes 1, 2 and 4 (See Table 1). The selected communication mode determines whether or not the network can operate on multiple nets (by employing frequency hopping) and the transmitted data are encrypted. All JUs in a JTIDS/MIDS network must operate in the same communication mode.

Table 1. JTIDS Communication Modes

Communication Mode	**Frequency Hopping**	**Data Encrypted**
1	Yes	Yes
2	No	Yes
3	Not Used	Not Used
4	No	No

12. The normal JTIDS communication mode is mode 1. Frequency hopping and crypto variables are simulated appropriate to the specified level of fidelity.
13. When operating with JTIDS communication mode 2, there will be no frequency hopping, but encryption **shall** still be used, depending on the level of fidelity. The explicit frequency of 969 MHz **shall** be set in the transmission message frequency field and the bandwidth will be 3MHz. The net number in the signal message **shall** be zero for all transmissions (no multi-netting).
14. Mode 4 eliminates communications security in addition to the features of communications mode. The encryption fields **shall** be set to 0 when in communications mode 4 in addition to specifying the explicit transmit frequency as in communications mode 2.
15. Time slots **shall** be numbered sequentially, such that time slot 0 represents time slot A-1, time slot 98303 represents C-32767. When the epoch is 112, the last valid time slot is 45151 (end of the day).

16. Generated machine receipts **shall** use time slots as assigned in the network description. There is no special consideration given to machine receipts; they are treated as any other TADIL J fixed format message.
17. Relay is accomplished by transmitting relay information in assigned time slots. There is no special mechanism necessary to simulate relay transmissions.
18. Transmission messages **shall only** be sent with signal messages in conjunction with the following events: entering the Link 16 network, exiting the Link 16 network, during synchronization state changes, with PPLI messages, and with initial net entry messages.

4.1 Levels of Fidelity

This protocol allows simulations to achieve different levels of fidelity by assigning one of five Time Slot Allocation (TSA) levels. If the simulator allows for a settable level of fidelity, the level of fidelity **shall** be set at runtime. The TSA level **shall** be set in Modulation Parameter #1 of the transmission packet with an enumeration of 0-4 as described in Table 2.

Table 2: JTIDS Levels of Fidelity

TSA Level	Fidelity	Synchronization Fidelity	Issues	Recommended Usage
0	Low	Low	Does not emulate JTIDS network characteristics. Data rates are not constrained. Intended for legacy use.	Experiments and/or training concerned with message format and/or message content only.
1	Low	Low	Does not emulate JTIDS network characteristics.	Allows for bandwidth throttling to emulate JTIDS network throughputs without assigning messages to specific time slots. Net Data Loads can be loaded into terminal simulation equipment to simulate data rates in NPGs on the Link 16 network.
2	Medium	Low	Network delay must be sufficiently small if time slot sensitive conversations are required to duplicate live Link 16 networks (e.g. relay emulation, RELNAV, messages requiring responses).	Experiments and/or training concerned with throughput limits of the Link 16 network. Also suitable for experiments/training emulating message traffic and timing of JTIDS networks without emulating effects of RTTs, RELNAV, or stacked/multi-nets.
3	Medium	Low	Same as TSA Level 2.	Experiments and/or training concerned with emulating stacked-, multi-, and crypto- net emulation.
4	High	Medium	Extremely sensitive to network latency.	Experiments and/or training concerned with effects deriving from emulation of network entry and synchronization maintenance.

TSA level 0 is the lowest level of fidelity. The NPG and net fields are filled in the signal message, but all other data in the JTIDS transmission header is set to the default value. Multiple messages are permitted in a single Signal message. All messages within the signal message are assumed to be for the same NPG and Net with the same assumed packing. There is no TSA or metering with up to the maximum number of messages (as specified in the DIS standard) packed into the data area of a single signal message.

TSA Level 1 is similar to TSA Level 0 except that there is minimal metered data. When the TSA level is set to one, one time slot worth of information **shall** be in one Signal message. As in TSA level 0, the NPG and net fields are filled in, and the rest of the transmission information is set to default.

TSA Level 2 allows for metered data with no encryption. When the TSA level is set to 2, messages **shall** be assigned to individual time slots. The NPG, net, and time slot identification fields are filled in. The TSEC and MSEC are set to default. This level enables full TSA to include Encryption. When TSA mode is set to 3, stacked nets, multi-nets, and crypto-nets can be emulated. All transmission information fields are filled in. Low fidelity synchronization is achieved in accordance with paragraph 5.3.1.

TSA Level 4, everything from TSA 3 is emulated, with the addition of the medium fidelity synchronization procedures. All JTIDS header fields in the signal message **shall** be filled with non-default meaningful values. Medium fidelity synchronization is achieved in accordance with paragraph 5.3.2.

4.2 Communication between JUs with different fidelity levels

In the event that participants in a simulated JTIDS network cannot set their respective simulations to operate at a common level of fidelity (i.e. TSA Level) the following procedures apply:

If a low fidelity network participant is in a simulated JTIDS network with a higher fidelity NTR, the network participant **shall** follow the low fidelity synchronization procedures in paragraph 5.3.1 by skipping the RTT synchronization process and changing directly to the fine synchronization state once it receives a J0.0 Initial Entry message from the NTR or any IEJU.

If a higher fidelity network participant is in a simulated JTIDS network with a lower fidelity NTR, the higher fidelity participant **shall** either follow the low fidelity synchronization procedures in paragraph 5.3 or achieve fine sync with other high fidelity simulators. This can be accomplished by exchanging RTT B messages or by passively synchronizing with other available high fidelity simulators. If no other high fidelity simulators are available to synchronize with, the high fidelity participant **shall** skip the RTT exchange, and directly enter fine synchronization once the J0.0 is received.

If the NTR is a lower fidelity simulation and unable to simulate full NTR duties, the NTR **shall** still have the ability to transmit net entry messages. The signal message **shall** be filled in with a J0.0 with zeroed time slot information. RTT emulation will not be required of low fidelity NTRs.

A lower fidelity JU entering the net **shall** use the network synchronization ID received from the NTR/IEJU in its Transmitter messages. It will then issue PPLIs at the assigned rate. This is nominally once every 12 seconds (equivalent to the A-0-6 time slot block), though this can occur at times of up to 24 seconds. All simulators, regardless of fidelity, **shall** accept another terminal's statement of synchronization capability if the network synchronization ID matches its own network synchronization ID.

In a lower fidelity synchronization simulation, non-reception of a PPLI message pair for 60 seconds **shall** indicate that the unit has fallen out of the datalink. Synchronization procedures **shall** be re-accomplished—reception of a PPLI message stating fine synchronization must occur before data from the JU will be accepted.

4.3 Time Synchronization

For TSA Level 0-2, the Network Synchronization **shall** be set to zero. For TSA Level 3-4, the Network Synchronization IDs **shall** be a 32 bit unsigned integer uniquely generated by the NTR. The NTR **shall** use either a non-deterministic random number generator or a pseudo-random number generator using the timestamp of the time they begin to simulate a NTR as the random key seed. If using a seed based pseudo-random number generator, use the NTR selection time with precision equivalent to Network Time Protocol (NTP) as the seed. Seedless random number generators are encouraged; the goal is to make sure that all NTRs have unique synchronization IDs in the transmitter PDU.

If a system in the real world is capable of acting as NTR, any corresponding simulator **shall** also be capable, at a minimum, of acting as a low fidelity NTR.

If no simulators in a simulated JTIDS net are capable of acting as a NTR, participants **shall** be able to set the network synchronization ID to zero and transmit the synchronization state of fine synchronization. A zero in the network synchronization ID field **shall** be accepted as a wildcard matching any network synchronization ID.

If a network synchronization ID accompanying received data does not match a JU's own network synchronization ID, the data **shall** be considered as having not been received.

Simulated terminals **shall** accept net entry messages (J0.0) from any simulated transmitting terminal within reception range. When medium fidelity synchronization is applicable (TSA Mode level 4), and the net entry message has a network synchronization ID different than the local network synchronization ID, the JU **shall** revert back to coarse synchronization, use the new network synchronization ID, cease sending TADIL J data and attempt re-synchronization with the new network in accordance with the JTIDS terminal specification. If the network synchronization ID (i.e. during changeover of NTR or multiple IEJUs) is the same as the locally held key, the JU will not revert to coarse synchronization status and will not stop transmitting TADIL J data.

If an initial net entry message is received from a unit that does not have a Transmitting Terminal Primary Mode of IEJU or NTR, it **shall** still be accepted. Depending upon implementation, the simulation operator may be notified so that the sending simulator can correct this error condition.

All simulators **shall** have at least a low fidelity simulation of a terminal clock, potentially independent of the simulator's (or live equipment's) clock. Since whatever time an NTR has set is considered correct, an NTR may transmit a time that significantly varies from the actual simulated wall clock. In high fidelity simulation systems the terminal clock may model the clock drift of an actual JTIDS terminal. It is not expected that terminal clocks will be modeled at a high level of fidelity and the actual level of emulation is left to the implementer.

4.3.1 Low Fidelity Synchronization

Low fidelity synchronization is applicable to simulation systems interested primarily in providing tactical datalink information as part of an operational scenario. The low fidelity synchronization procedure allows such systems to exchange Link 16 messages without being encumbered by actual JTIDS transmission and message security requirements.

The NTR **shall** begin by issuing Net Entry message pairs at a rate in accordance with the JTIDS terminal specification (typically in time slot A-0-6 at a rate of every 12 seconds). A unique randomly generated key **shall** be filled into the network synchronization ID field. The primary JTIDS duty field **shall** contain a NTR enumeration.

Modulation Parameter 4 (Synchronization State) in the transmission message shall be set to "fine synchronization" after reception of the J0.0 Initial Net Entry message from the IEJU or NTR. The first data message that will be sent by a JU entering the network shall be the JU's PPLI.

4.3.2 Medium Fidelity Synchronization

Medium Fidelity Synchronization corresponds to only the high fidelity TSA level 4. It is applicable to those systems for which simulation of the fine synchronization methodology is paramount, potentially for high fidelity training, network testing and network experimentation. Because the latency of WANs (latencies up to hundreds of milliseconds) is orders of magnitude higher than in a real Link 16 network (latencies up to 3ms), this methodology will not meet the needs of sub-millisecond accuracy.

Communities with the need for sub-millisecond accuracy will need to use a centralized server on a real-time operating system to simulate the microsecond intricacies of the JTIDS network. The term "High Fidelity Synchronization" will be reserved for synchronization mechanisms that are able to model the sub-millisecond accuracy of the Link 16 network.

The accuracy of the synchronization mechanism shall have an error less than the simulated time of propagation. The accuracy of the synchronization mechanism must be taken into account when modeling fine synchronization.

The Medium Fidelity Synchronization procedure is as follows: First, the NTR **shall** begin by issuing Net Entry message pairs at a rate in accordance with the JTIDS terminal specification (typically in time slot A-0-6 at a rate of every 12 seconds). A unique randomly generated key **shall** be filled into the network synchronization ID field. The primary JTIDS duty field **shall** contain a NTR enumeration. At this point, the JU is considered to have achieved "coarse synchronization."

The JU **shall** then transmit the appropriate RTT message (A or B). The synchronization state **shall be** set to "coarse synchronization." The JU **shall** use its own terminal perceived time in the perceived transmit time field. The appropriate NTR/JU will answer (in accordance with the JTIDS terminal specification), using the JU perceived time and the entity distance to calculate the perceived receive time. The RTT is then transmitted. The transmitting JU **shall** fill its own terminal perceived time with the received transmit time field. The formula for filling in the receive time in the RTT reply is: $RTT_{reply} = RT_{terminal} - t_{delay} + t_{propagate}$

i. The t_{delay} is computed by: $t_{delay} = RT_{time} - TT_{time}$

b. Where

RT_{time} is the actual time held by the receiving/replying participant (Derived from NTP, GPS, etc)

$RT_{terminal}$ is the value of the simulated Link 16 terminal clock at the receiving/replying participant

TT_{time} is the actual time held of transmitting participant (Derived from NTP, GPS, etc)

t_{delay} is the difference between the receiver's real-time clock at the time of receipt and the sender's real-time clock at the time of transmission (i.e. it approximates the emulation network latency), and

$t_{propagate}$ is the propagation time of the radio frequency message in the simulated environment.

This formula computes the perceived time of receipt by the receiving simulator with respect to the simulated terminal clock of the sender.

The originating JU shall then update its own terminal time in accordance with the simulator model and the Link 16 fine synchronization procedures. After the appropriate number of RTT exchanges have occurred (depending whether the RTT A or RTT B method of synchronization was used and the internal terminal simulation model), the JU shall consider itself to be in fine synchronization and shall continually issue RTT message pairs to maintain synchronization at rates specified within the JTIDS terminal specification. Once the terminal emulator model has met the requirements for fine synchronization, normal message transmissions occur in accordance with Ref. 7 and Ref. 10.

5 JTIDS implementation under DIS

This section contains the requirements for simulation of JTIDS using the DIS Signal and Transmitter PDU. For the DIS Protocol Profiles, transmission and receipt of PDUs, and general service requirements, refer to Reference 1. In implementing the Signal PDU, perceived data should be able to be sent on a configurable port separate from all other DIS data. This allows datalinks to be selectively routed without additional hardware. This also allows for gateways to forward data between legacy DIS datalink formats and the new standardized format.

5.1 Transmitter PDU Description

Table 3 shows the format for the Transmitter PDU for JTIDS simulation.

Table 3: Transmitter PDU for TADIL J

Field Size (bits)	Transmitter PDU Fields			Description*
96	PDU Header	Protocol Version	8 bit enumeration	
		Exercise ID	8 bit unsigned integer	
		PDU Type	8 bit enumeration	
		Protocol Family	8 bit enumeration	
		Timestamp	32 bit unsigned integer	

Table 3: Transmitter PDU for TADIL J

Field Size (bits)	Transmitter PDU Fields			Description*
		Length	16 bit unsigned integer	
		Padding	16 bits unused	
48	Entity ID	Site	16 bit unsigned integer	
		Application	16 bit unsigned integer	
		Entity	16 bit unsigned integer	
16	Radio ID		16 bit unsigned integer	**Shall** contain the ID of the radio transmitting the signal.
64	Radio Entity Type	Entity Kind	8 bit enumeration	
		Domain	8 bit enumeration	
		Country	16 bit enumeration	
		Category	8 bit enumeration	21 - Link 16 terminal IAW Ref. 4 para 4.2.3.7
		Nomenclature Version	8 bit enumeration	
		Nomenclature	16 bit enumeration	
8	Transmit State		8 bit enumeration	
8	Input Source		8 bit enumeration	8 - Digital Data Device
16	Padding		16 bits unused	
192	Antenna Location	X component	64 bit floating point	
		Y component	64 bit floating point	
		Z component	64 bit floating point	
96	Relative Antenna Location	x component	32 bit floating point	
		y component	32 bit floating point	
		z component	32 bit floating point	
16	Antenna Pattern Type		16 bit enumeration	
16	Antenna Pattern Length		16 bit unsigned integer	
64	Frequency		64 bit unsigned integer	Mode 1 = 1131000000 (center frequency). For Mode 2 or 4, set to 969000000
32	Transmit Frequency Bandwidth		32 bit floating point	240000000 unless in Communications mode 2 or 4, then 3000000
32	Power		32 bit floating point	Power in dBm
64	Modulation Type	Spread Spectrum	16 bit Boolean array	Bit 1 set to 1: Frequency Hopping for JTIDS communications mode 1. All bits set to 0: For JTIDS communications modes 2 or 4

Table 3: Transmitter PDU for TADIL J

Field Size (bits)	Transmitter PDU Fields			Description*
		Major	16 bit enumeration	7 - Carrier Phase Shift Modulation (CPSM)
		Detail	16 bit enumeration	0 - Other
		System	16 bit enumeration	8 - JTIDS/MIDS
16	Crypto System		16 bit enumeration	0 - Other
16	Crypto Key ID		16 bit unsigned integer	
8	Length of Modulation Parameters		8 bit unsigned integer	8= 8 octets
24	Padding		24 bits unused	
8	Modulation Parameter #1	Time Slot Allocation Mode	8 bit enumeration	Integer enumeration 0-4
8	Modulation Parameter #2	Transmitting Terminal Primary Mode	8 bit enumeration	Integer Enumeration: 1 - NTR 2 - JTIDS Unit Participant
8	Modulation Parameter #3	Transmitting Terminal Secondary Mode	8 bit enumeration	Integer Enumeration: 0 - None 1 - Net Position Reference 2 - Primary Navigation Controller 3 - Secondary Navigation Controller
8	Modulation Parameter #4	Synchronization State	8 bit enumeration	Integer Enumeration: 2 - Coarse Synchronization 3 - Fine Synchronization
32	Modulation Parameter #5	Network Synchronization ID	32 bit unsigned integer	TSA Level 0-2, set to 0 TSA Level 3,4, set to 32 bit random number

Transmitter PDUs used in Link 16 simulation **shall** include all of the standard information, as well as the information described in the modulation fields. The Transmitter PDU **shall** contain the following fields:

1. The Radio Entity Type Category field **shall** be set to 21 for Link 16 terminal.
2. The Input Source field **shall** be set to 8 for Digital Data Device.
3. Frequency. This field **shall** specify the JTIDS center frequency of 1131000000 for communications mode 1. For communications mode 2 or 4, a frequency of 969000000 **shall** be used.
4. Transmit Frequency Bandwidth. This field **shall** contain the bandwidth of the JTIDS signal, simulating the use of the entire frequency band as an average over time. The field **shall** be represented by a 32-bit float value of 240000000, unless operating in communications mode 2 or 4, and then a value of 3000000 **shall** be used.
5. Modulation Type. The Modulation Type fields contain enumerations for the major and detail modulation fields:

    a. The Spread Spectrum field is a 16-bit Boolean array, and **shall** be set to 1 for frequency hopping only for JTIDS communications mode 1. For modes 2 or 4, the Spread Spectrum field shall be set to 0.

b. The Major modulation field is a 16-bit enumeration, and **shall** be set to 7 for Carrier Phase Shift Modulation.

c. The Detail modulation field is a 16-bit enumeration, and **shall** contain a 0.

d. The System field is a 16-bit enumeration, and **shall** be set to 8 for JTIDS/MIDS

6. Crypto System. For Link 16 simulation under this standard this field **shall** be set to zero.
7. Crypto Key ID. For Link 16 simulation under this standard this field **shall** be set to zero.
8. Length of Modulation Parameters. These fields **shall** specify the length in octets of the modulation parameters that follow this field. This length **shall** be set to 8, representing 8 octets for the DIS J Transmitter PDU.
9. Modulation Parameters. These fields **shall** specify the modulation type specific characteristics of the Transmitter PDU.

a. Modulation Parameter 1 shall contain the TSA mode with an enumeration of 0-4 for TSA level 0-4 as described in section 4.1.

b. Modulation Parameter 2 shall contain the transmitting terminal's primary mode. Setting the enumeration to 1 shall indicate that the entity is the NTR. Setting it to 2 shall indicate that the entity is a JU participant.

c. Modulation Parameter 3 shall contain the transmitting terminal's secondary mode, with the following enumerations: 0=None, 1=Net Position Reference, 2=Primary Navigation Controller, 3=Secondary Navigation Controller.

d. Modulation Parameter 4 shall contain the synchronization state. For TSA mode level 0-3 this shall be set to 3 for "fine" synchronization. For TSA level 4, it is initially set to 2 for "coarse" synchronization and the procedures in section 4.3.2 for medium-level synchronization are followed.

e. Modulation Parameter 5 shall contain the Network Synchronization ID. For TSA modes 0-2, it shall be set to default. For TSA modes 3-4, it shall be a 32-bit random integer. Only an NTR can generate a Network Synchronization ID; all other participants shall use the ID obtained from the NTR to which they are synchronized.

5.2 Signal PDU Description

The Signal PDU includes all standard fields as described in Reference 2. Examples of the Signal PDU for TSA Levels 0-3 are found in Reference 1, Annex B.

When used for Link 16 simulation the following specific information is required:

1. Entity and Radio ID. These fields shall contain the ID of the entity and radio transmitting the signal. Radios are numbered sequentially starting with 1.
2. Encoding scheme. Bits 0-13 shall contain the number of J-words not including the JTIDS header. Bits 14-15 shall contain the value 1 to indicate an encoding class raw binary data.
3. TDL Type. This field **shall** specify the TDL type as a 16-bit enumeration field, and **shall** be set to 100 for Link 16 JTIDS/MIDS/TADIL J.
4. Sample Rate. The sample rate **shall** be set to zero.
5. Data Length. This field **shall** contain the length of data in bits beginning after the samples field.
6. Samples. This field **shall** be set to zero.
7. Data Field. The JTIDS Network header portion of the Data Fields of the Signal PDU **shall** be set as follows:
8. Net Number. This field is an 8-bit unsigned integer, and is used to create virtual sub-circuits within NPG for stacked nets or between NPGs for multi-net.
9. Network/Needline Participation Group (NPG) Number. This field is a 16-bit unsigned integer (0-511) used to segregate information within a JTIDS/MIDS network. It creates virtual networks of participants.

10. TSEC CVLL. This field is an 8-bit unsigned integer, and is used for transmission security, and allows for simulated crypto netting. For TSA Mode 0-2 this record is not required and the field is set to “all F’s” indicating a no statement/wildcard.
11. MSEC CVLL. This field is an 8-bit unsigned integer, and is used for message security, is used in conjunction with the TSEC CVLL, and allows for simulated crypto netting. For TSA Mode 0-2 this record is not required and the field is set to “all F’s” indicating a no statement/wildcard.
12. Message Type Identifier. This field specifies the format for the type of Link 16 message in the PDU. This field **shall** be set with an enumeration in accordance with Table 4.

Table 4: Message Type Identifiers

Message Type	Enumeration
JTIDS Header/Messages	0
RTT A/B	1
RTT Reply	2
JTIDS Voice CVSD	3
JTIDS Voice LPC10	4
JTIDS Voice LPC12	5
JTIDS LET	6
VMF	7

13. Time Slot ID. For TSA level 0-1, this field is set to zero. This field is a 32-bit unsigned integer, and **shall** contain time slot information for time slot and epoch number in accordance with REF. 5. Time Slot number is bits 0 – 16. Time Slot 0 represents time slot A-1, time slot 98303 represents C-32767. When the epoch is 112, the last valid time slot is 45151. Bits 17 – 23 are padding and set to 1 for level 3. Bits 24 – 31 are the epoch number. An epoch is 12.8 minutes long, and there are 112.5 epochs in a 24-hour day.

Table 5 shows the format for the Signal PDU for JTIDS simulation.

Table 5: SIGNAL PDU for TADIL J

Field Size (bits)	Signal PDU Fields			Valid Range	Description
96	PDU Header	Protocol Version	8 bit enumeration		
		Exercise ID	8 bit unsigned integer		
		PDU Type	8 bit enumeration		
		Protocol Family	8 bit enumeration		
		Timestamp	32 bit unsigned integer		
		Length	16 bit unsigned integer		
		Padding	16 bits unused		
48	Entity ID	Site	16 bit unsigned integer		

Table 5: SIGNAL PDU for TADIL J

Field Size (bits)	Signal PDU Fields			Valid Range	Description
		Application	16 bit unsigned integer		
		Entity	16 bit unsigned integer		
16	Radio ID		16 bit unsigned integer		**Shall** contain the ID of the radio transmitting the signal.
16	Encoding Scheme		16 bit enumeration		Bits 0-13 **shall** contain the number of J-words not including the JTIDS header. Bits 14-15 **shall** contain the value 1 to indicate an encoding class raw binary data
16	TDL Type		16 bit enumeration		This field **shall** be set to 100 for Link 16 JTIDS/MIDS/TADIL J
32	Sample Rate		32 bit integer		This field **shall** be set to 0
16	Data Length		16 bit integer		This field **shall** contain the length of data in bits beginning after the samples field.
16	Samples		16 bit integer		This field **shall** be set to 0
160	JTIDS Network Header	NPG Number	16 bit unsigned integer	0-511	Network/Needline Participation Group (NPG) Number. Used to segregate information within a JTIDS/MIDS network. Creates virtual networks of participants.
		Net Number	8 bit unsigned integer	0-127	Network Number. Used to create virtual sub-circuits within NPG for stacked nets or between NPGs for multi-net.
		TSEC CVLL	8 bit unsigned integer	0-127, FF	Transmission Security, an integer identification of the crypto variable used for JTIDS transmission encryption. This variable allows for simulated crypto netting. All F's in this field **shall** indicate a no statement/wildcard.
		MSEC CVLL	8 bit unsigned integer	0-127, FF	Message Security, an integer identification of the crypto variable used to encode the JTIDS message. This variable allows for simulated crypto netting. All F's in this field **shall** indicate a no statement/wildcard.

Table 5: SIGNAL PDU for TADIL J

Field Size (bits)	Signal PDU Fields			Valid Range	Description
JTIDS Network Header (Con't)	Message Type Identifier		8 bit enumeration		Determines whether normal JTIDS header and message, RTT A/B, RTT Reply, JTIDS Voice, LET JTIDS, or VMF follows. **See table 5.2.2 for message type identifier enumerations**
	Padding		16 bits	0	Set to 0
	Time Slot ID	Time Slot Number	Bits 0-16	0-98303	Time Slot number; Time Slot 0 represents time slot A-1, time slot 98303 represents C-32767. When the epoch is 112, the last valid time slot is 45151 (end of the day)
		Padding	Bits 17-23	0	Set to 0
		Epoch Number	Bits 24-31	0-112	An epoch is 12.8 minutes long, 112.5 Epochs in a 24 hour day. Part of time slot identification
	Perceived Transmit Time		64 bit unsigned integer		NTP timestamp format-- NTP timestamps are represented as a 64-bit unsigned fixed-point number, in seconds relative to 0h on 1 January 1900. The integer part is in the first 32 bits and the fraction part in the last 32 bits. The precision of this representation is about 200 picoseconds, which should be adequate for even the most exotic requirements. See RFC1305 for detailed format. All F's in this field **shall** indicate a no statement/wildcard.
TADIL J Message Data					The message data, corresponding to the appropriate message type and described in Reference 1.

6 Implementation of Link 16 under the HLA

Link 16 TDL simulations are almost always part of a wider simulation - such simulations are used for many purposes including system development, test & evaluation and training. It is therefore almost certain that the HLA implementation of the Link 16 protocol will form part of a larger Federation Object Model (FOM). The HLA implementation of Link 16 is therefore defined as a Base Object Model (BOM), as described in BOM Study Group Final Report: (SISO-REF-005-2001). A BOM is defined as "a single aspect of simulation interplay that can be used as a building block" within a FOM.

The Link 16 BOM is described in the Object Model Template (OMT). The standard for HLA is IEEE 1516—2000 (Reference 2) in which the OMT is put forth in extensible Markup Language (XML). However, at the time of writing, many federations still use the older HLA 1.3 (Reference 3) pre-XML OMT format. In order to facilitate implementation, two versions of the BOM have been created. The file Link16-BOM.omd contains the HLA 1.3 OMT tables. These tables are reproduced in Annex A of this standard. A second file, link16bom.xml, complies with the OMT XML format found in Ref. 2. Both files, as well as the complete OMT tables may be found at the SISO web site (http://www.sisostds.org).

6.1 The Link 16 BOM

The Link 16 BOM is intended to describe how to implement a simulation of the Link 16 Tactical Data Link (TDL) and its associated message set, TADIL J, within a High Level Architecture (HLA) simulation. The Link 16 BOM is designed for integration within the Federation Object Model (FOM) of the HLA federation.

6.1.1 Assumptions

The Link 16 BOM assumes that:

1. The parent FOM contains all current DIS Transmitter PDU parameters as part of its object class hierarchy.
2. The parent FOM contains all current DIS Signal PDU parameters as part of its interaction class hierarchy.

6.1.2 Naming Convention

Conventions within the Link 16 BOM in OMT 1.3 format follow those adopted by the RPR FOM. These conventions are intended to address some of the OMT 1.3 format shortcomings, which have been addressed in the IEEE 1516.2 specification. These include:

1. All names have the initial letter of each word capitalized.
2. All enumeration names end in the text "Enum" followed by a number. The number indicates the number of bits in the enumerated value.
3. All complex data type names end in the text "Struct".

6.1.3 Levels of Fidelity

The HLA levels of fidelity are directly equivalent to the corresponding DIS levels of fidelity as defined in section 5.1.2.

6.1.4 Time Synchronization

The HLA time synchronization mechanism is directly equivalent to the corresponding mechanism for DIS as defined in section 5.1.

6.1.5 Protocol Implementation Details

This section defines how Link 16 BOM compliant federates are to implement the Link 16 protocol. The HLA protocol implementation details are directly equivalent to the corresponding details for DIS as defined in section 5.2.

6.1.6 Object Class Data

The Link 16 BOM defines no new object classes. Instead the BOM defines a single complex data type (`JTIDSTransmitterStruct`) that corresponds to the modulation parameters in the DIS Transmitter PDU defined in section 5.2.1. An attribute of this complex data type should be added to the object class in the parent FOM corresponding to the DIS Transmitter PDU. Modulation parameters of the Transmitter PDU shown in section 5.1, Table 3, map to the fields of the `JTIDSTransmitterStruct` complex data type attribute, shown in Annex A.5. Parent object class fields are also modified such that they refer to the corresponding Transmitter PDU fields.

NOTE: For a RPR FOM implementation, an attribute of the `JTIDSTransmitterStruct` complex data type should be added to the `RadioTransmitter` object class.

6.1.7 Interaction Class Data

The Link 16 BOM adds a family of interactions that will support future TDL implementation of other datalinks. The family of interactions is a hierarchy in which the BOM's base class for this interaction is a generic class - the `TDLBinaryRadioSignal` interaction. This class is an empty class, contains no parameters, and is neither publishable nor subscribable. The specific parameters are properties of the various subclasses of this generic base class, and it is these subclasses that are published and subscribed to.

The Link16RadioSignal interaction, shown in Annex A.3, which is a subclass of the `TDLBinaryRadioSignal` interaction, contains the JTIDS Network Header Parameters as shown in table 5. The `JTIDSMessageRadioSignal` interaction contains the Link 16 message data. Additional interactions shown in Annex A.3 define the other types of Link 16 messages. Parent object class fields are also modified such that they refer to the corresponding Signal PDU fields.

The Link 16 BOM design is such that the `TDLBinaryRadioSignal` interaction becomes a subclass of the parent FOM's equivalent of the DIS Signal PDU.Modulation parameters of the Signal PDU map to the fields of `the JTIDSTransmitterStruct` complex data type attribute (see section 5.4). Parent object class fields are also modified such that they refer to the corresponding Signal PDU fields.

NOTE: For a RPR FOM implementation, the `TDLBinaryRadioSignal` class becomes a subclass of the RPR FOM `RawBinaryRadioSignal` interaction class; this is done in order to allow access to the `HostRadioIndex` parameter in the `RawBinaryRadioSignal` interaction class. The `HostRadioIndex` parameter ties the Link 16 message to a specific Host and Radio Transmitter.

6.1.8 BOM Implementation

The BOM implementation, in OMT 1.3 format, is described in annex A. For RPR FOM 1.0 (Reference 5), `SpreadSpectrumStruct` complex data type and `TDLBinaryRadioSignal` should be added to the Radio Transmitter Object Class. For RPR FOM 2.0 (Reference 6), the `SpreadSpectrumStruct` complex data type already exits. Therefore, the field `TDLBinaryRadioSignal` **shall** be added to the `SpreadSpectrumStruct` complex data type, as shown in Annex A.5.

An attribute (`JTIDSTransmitterData`) of complex data type `JTIDSTransmitterStruct` is added to the RPR FOM Radio Transmitter object class. The `Link16RadioSignal` interaction class is added as a subclass of a new interaction class, the `TDLBinaryRadioSignal` interaction, which itself is a subclass of the RPR FOM's `RawBinaryRadioSignal` interaction class.

Table 6: Link 16 BOM Interactions in the RPR-FOM

RadioSignal	ApplicationSpecifcRadioSignal			
	DatabaseIndexRadioSignal			
	EncodedAudioRadioSignal			
	RawBinaryRadioSignal	TDLBinaryRadioSignal	Link16RadioSignal	JTIDSMessageRadioSignal
				RTTABRadioSignal
				RTTReplyRadioSignal
				JTIDSVoiceCVSDRadioSignal
				JTIDSVoiceLPC10RadioSignal
				JTIDSVoiceLPC12RadioSignal
				JTIDSLETRadioSignal
				VMFRadioSignal

NOTES:

1. The addition of the `TDLBinaryRadioSignal` interaction class and its associated subclasses was necessary because of the RPR FOM implementation limitations of the DIS Signal PDU. Section 5.2.2 defines the DIS Signal PDU used for all Link 16 messages in a Raw Binary Signal PDU. The RPR FOM equivalent of this PDU type (the `RawBinaryRadioSignal` interaction class) contains a parameter, called `SignalData,` containing one or more

octets containing the signal data. If the `SignalData` octet based storage scheme to store Link 16 messages was used the Link 16 message would be lost during byte swapping. The implementation is defined such that the Link 16 interaction becomes a subclass of the `RawBinaryRadioSignal` interaction to ensure the `SignalData` storage is not used. Data integrity is achieved by moving the Link 16 message storage into the lowest level classes (i.e the `JTIDSMessageRadioSignal`).

2. DIS to HLA gateways will require modification, but the modifications are well defined. DIS Raw Binary Signal PDUs need to be split into a `RawBinaryRadioSignal` interaction or the appropriate Link 16 interaction class, depending on the TDL type. Conversely, a HLA to DIS gateway must merge both interaction types into a single DIS Signal PDU.

ANNEX A: LINK 16 BASE OBJECT MODEL (BOM) OMT 1.3 TABLES

A.1 OBJECT MODEL IDENTIFICATION TABLE

Category	Information		
Name	Link 16 BOM		
Version	v1.0 Draft 2		
Date	9/9/2002		
Purpose	Link 16 Base Object Model (BOM)		
Application Domain	C4ISR & C2 platform simulations		
Sponsor	SISO		
POC (Title, First, Last)	Mr	Graham C	Shanks
POC Organization	AMS		
POC Telephone	+44 1383 828062		
POC Email	graham.shanks@amsjv.com		

A.2 OBJECT INTERACTION TABLE

Interaction1	Interaction2	Interaction3	Interaction4
Parent (N)	TDLBinaryRadioSignal (N)	Link16RadioSignal (R)	JTIDSMessageRadioSignal (IR)
			RTTABRadioSignal (IR)
			RTTReplyRadioSignal (IR)
			JTIDSVoiceCVSDRadioSignal (IR)
			JTIDSVoiceLPC10RadioSignal (IR)
			JTIDSVoiceLPC12RadioSignal (IR)
			JTIDSLETradioSignal (IR)
			VMFRadioSignal (IR)

A.3 PARAMETER TABLE

Interaction	Parameter	Datatype	Cardinality	Units	Resolution	Accuracy	Accuracy Condition	Routing Space
JTIDSLETradioSignal	LETHeader	LETHeaderStruct	1	N/A	N/A	N/A	N/A	N/A
	TADILJMessage	TADILJWordStruct	1+	N/A	N/A	N/A	N/A	
JTIDSMessageRadioSignal	JTIDSHeader	JTIDSHeaderStruct	1	N/A	N/A	N/A	N/A	N/A
	TADILJMessage	TADILJWordStruct	1+	N/A	N/A	N/A	N/A	
JTIDSVoiceCVSDRadioSignal	JTIDSHeader	JTIDSHeaderStruct	1	N/A	N/A	N/A	N/A	N/A
	Data	octet	29+	N/A	N/A	perfect	always	
JTIDSVoiceLPC10RadioSignal	JTIDSHeader	JTIDSHeaderStruct	1	N/A	N/A	N/A	N/A	N/A
	Data	octet	29+	N/A	N/A	perfect	always	
JTIDSVoiceLPC12RadioSignal	JTIDSHeader	JTIDSHeaderStruct	1	N/A	N/A	N/A	N/A	N/A
	Data	octet	29+	N/A	N/A	perfect	always	
Link16RadioSignal	NPGNumber	unsigned short	1	N/A	N/A	perfect	always	N/A
	NetNumber	octet	1	N/A	N/A	perfect	always	
	TSEC_CVLL	octet	1	N/A	N/A	perfect	always	
	MSEC_CVLL	octet	1	N/A	N/A	perfect	always	
	TimeSlotID [3]	unsigned long	1	N/A	N/A	perfect	always	
	PerceivedTransmitTime [2]	long long	1	N/A	N/A	perfect	always	
RTTABRadioSignal	RTTAB	RTTABStruct	1	N/A	N/A	N/A	N/A	N/A
RTTReplySignal	RTTReply	RTTReplyStruct	1	N/A	N/A	N/A	N/A	N/A
VMFRadioSignal	JTIDSHeader	JTIDSHeaderStruct	1	N/A	N/A	N/A	N/A	N/A
	TADILJMessage	TADILJWordStruct	1+	N/A	N/A	N/A	N/A	

A.4 ENUMERATED DATATYPES TABLE

Identifier	Enumerator	Representation
JTIDSPrimaryModeEnum8 [1]	NTR	1
	JTIDSUnitParticipant	2
JTIDSSecondaryModeEnum8 [1]	None	0
	NetPositionReference	1
	PrimaryNavigationController	2
	SecondaryNavigationController	3
JTIDSSynchronizationStateEnum8 [1]	CourseSynchronization	2
	FineSynchronization	3
TSALevelEnum8 [1]	LowFidelityLevel0	0
	LowFidelityLevel1	1
	MediumFidelityLevel2	2
	MediumFidelityLevel3	3
	HighFidelityLevel4	4

A.5 COMPLEX DATATYPES TABLE

Complex Datatype	Field Name	Datatype	Cardinality	Units	Resolution	Accuracy	Accuracy Condition
JTIDSHeaderStruct	Data	octet	6	N/A	N/A	perfect	always
JTIDSTransmitterStruct	TimeSlotAlocationMode	TSALevelEnum8	1	N/A	N/A	N/A	N/A
	TransmittingTerminalPrimaryMode	JTIDSPrimaryModeEnum8	1	N/A	N/A	N/A	N/A
	TransmittingTerminalSecondaryMode	JTIDSSecondaryModeEnum8	1	N/A	N/A	N/A	N/A
	SynchronizationState	JTIDSSynchronizationStateEnum8	1	N/A	N/A	N/A	N/A
	NetworkSynchronizationID	unsigned long	1	N/A	N/A	perfect	always
LETHeaderStruct [4]	Data	octet	6	N/A	N/A	perfect	always
RTTABStruct [5]	Data	octet	6	N/A	N/A	perfect	always
RTTReplyStruct [6]	Data	octet	6	N/A	N/A	perfect	always
TADILJWordStruct [7]	Data	octet	10	N/A	N/A	perfect	always
SpreadSpectrumStruct	TDLBinaryRadioSignalFlag	octet	1	N/A	N/A	perfect	always

A.6 NOTES TABLE

ID	Text
1	This is an 8-bit enumeration
2	NTP timestamp format-- NTP timestamps are represented as a 64-bit unsigned fixed-point number, in seconds relative to 0h on 1 January 1900. The integer part is in the first 32 bits and the fraction part in the last 32 bits. The precision of this representation is about 200 picoseconds, which should be adequate for even the most exotic requirements. See RFC1305 for detailed format. All F's in this field shall indicate a no statement/wildcard
3	See TimeSlot ID structure in Table 5.2.4
4	See LET Message Header structure in Table 5.2.11
5	See RTT A/B Message structure in Table 5.2.6
6	See RTT Reply Message structure in Table 5.2.7
7	See TADIL J Message Bit Orientation in Table 5.2.3