Distributed Interactive Simulation Revisited: Capabilities of the Revised IEEE Standard

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Abstract. Distributed Interactive Simulation (DIS) is a widely-used networking protocol standard that provides a method of communicating entity information among simulators and simulations through Protocol Data Units (PDUs) to create a synthetic environment. Later this year (2009) a significant simulation milestone will be achieved when balloting of the revised Distributed Interactive Simulation (DIS) standard is completed, and it becomes officially designated as IEEE-1278.1-200X. This milestone represents six years of effort by a team of international simulation enthusiasts from military, industry, and government organisations including DSTO. The proposed new standard includes an extensive revision, clearing up ambiguities present in the existing 1998 version, and adding additional capabilities that reflect changes in military equipment and doctrine, and also advances in technology such as the Internet, mobile telephony, and the widespread use of the Global Positioning System for positional and time data. Five new Protocol Data Units have been added to include Information Operations capability, enhanced warfare support, and the ability to communicate information about individual attributes for a particular entity, object, or event. Where possible, backward compatibility has been maintained in the new version to maintain interoperability with existing systems. In this paper we review these new capabilities in detail, and explore what this will mean for the Australian simulation ecosystem.

1. INTRODUCTION

Distributed Interactive Simulation (DIS) is a networking protocol standard that provides a method of communicating entity information among simulators through Protocol Data Units (PDUs) to create a synthetic environment. These PDUs comprise data packets that are broadcast over the simulation network. DIS PDU Standards were developed under the guidance of the DIS Coordinating Committee, and utilised the IEEE Standards approval process [1].

There have been three formal IEEE DIS standards during the past 15 years reflecting the need to introduce new functionality as simulations and simulators become more sophisticated. The first 1993 version supported little more than land warfare; the second 1995 version added electromagnetic interactions and radio communications; while the latest 1998 standard further extended this to support a richer set of aerospace and maritime capabilities (including Identification Friend or Foe (IFF), underwater acoustic and environmental features).

IEEE standards are reviewed for currency every five years, and either revised or retired as formal standards. Since the most recent IEEE 1278.1 DIS standard was released in 1998, accordingly, in 2003, a decision had to be made about the future of the standard that had reached its fifth year. The Simulation Interoperability Standards Organisation (SISO) created a working group, the DIS Study Group, to examine the feasibility of extending the standard and this soon reached a critical mass of interest in a revised version of DIS.

The decision to proceed to a full revision of the standard was made in 2005 and a DIS Product Group was formed. The work of this group has now progressed the revised DIS standard through 14 drafts. The new standard will be known as IEEE 1278.1-200X.

In this paper, the changes to the standard are discussed with reference to the implications for the Australian Defence Organisation.

2. HISTORY OF DIS

The US Defense Advanced Research Projects Agency (DARPA) sponsored the SIMNET program in the early 1980s to network together manned tank trainers [2]. SIMNET was the first implementation of large scale, real time, human-in-the-loop simulator networking for team training and mission rehearsal and was very successful with over 300 simulators linked in a single exercise. The SIMNET architecture and protocols evolved into Distributed Interactive Simulation in the early 1990s.

DIS has since undergone the IEEE standardisation process three times:


These standards are referred to as protocol versions 2, 5, and 6 respectively. There have also been several draft versions that served as de facto standards while the community sought IEEE publication - DIS version 1.0 (May 92) DIS version 2.0 - third draft (May 93), and DIS PDU version 2.0 - fourth draft (revised) March 16, 1994.
DIS has evolved considerably over the past 15 years. The initial DIS 1.0 standard, IEEE 1278-1993 [3], had only 10 PDUs which supported the appearance and movement of entities, weapons firing, detonation of ordnance, collision detection, and logistical resupply.

The draft DIS 2.0 standards (2.0.3 and 2.0.4) and IEEE 1278.1-1995 [4] defined 27 PDUs to provide additional functionality supporting voice radio and tactical data links, simulation management, and electromagnetic emission representation for electronic warfare and laser interactions for smart munitions.

The latest standard, DIS 2.1.4, IEEE 1278.1a-1998 [5], has a total of 67 PDUs with additional support for emissions, entity information/interaction, mine warfare, entity management, field instrumentation, communications and environment.

Despite the considerable expansion in the number of PDUs in this latest version, few of these have been implemented in fielded systems. A timeline of the development of DIS is given in Figure 1.

![Figure 1: Development of DIS](image)

3. **SISO/IEEE STANDARDISATION PROCESS**

The Simulation Interoperability Standards Organisation (SISO) is an international organisation dedicated to the promotion of modelling and simulation interoperability and reuse for the benefit of a broad range of modelling & simulation communities. SISO's Conference Committee organizes Simulation Interoperability Workshops (SIWs) in the US and Europe. SISO's Standards Activity Committee develops and supports simulation interoperability standards, both independently and in conjunction with other organizations. SISO is recognized as a Standards Development Organization (SDO) by NATO and as a Standards Sponsor by IEEE.

Typically, the Standards Activity Committee (SAC) establishes a Study Group to consider specific issues. Each Study Group operates under specific Terms of Reference that identify the issues they are being asked to consider and the specific questions they are being asked to address.

After consensus has been reached within the group, a decision is made to apply for formal SISO approval to begin product work. This initiates the SISO Balloted Product process. The group proposing the product develops a SISO Product Nomination (PN) and presents it to the SAC.

After the PN is approved by the Executive Committee, the SAC creates a Product Development Group (PDG). If the proposed product is either a revision to an existing IEEE standard or intended as a new IEEE project, the SAC and PDG develop a Project Authorization Request (PAR) and submit it to IEEE. Upon IEEE approval, the PDG assumes the dual role of an IEEE Working Group.

Once the PDG has completed its work, it presents the status of the Product to the SAC for approval to begin balloting. If the Product is approved for balloting, the SAC issues a call to SISO community members to join the balloting pool.

PDGs developing IEEE standards follow SISO procedures up to the point of actual balloting. All SISO-sponsored IEEE standards are balloted and approved using established IEEE procedures. Upon completion of balloting and product approval under IEEE procedures, the PDG completes the PDG requirements to develop a Terms of Reference and establishes a Product Support Group.

In the present case, the DIS Product Development Group, approved by SISO in 2005, developed a standard means of submitting changes, namely via a Problem Change Request template (PCR). Over 200 of these were submitted during the five years development of the revised standard.

4. **PRINCIPAL CHANGES TO IEEE 1278.1**

The principal changes between IEEE 1278.1-1995 and IEEE 1278.1a-1998 and the proposed standard are described in the following subsections.

4.1 **Clarifications Added**

The existing standard has many ambiguities and thus extensive clarification of requirements has been added, throughout the standard. The DIS Exercise section has been expanded into a comprehensive section covering detailed requirements related to simulations, enumerations, objects, heartbeats, timeouts, thresholds, gateways and communication services.

All identifiers used in the standard were clarified and consistent and simplified terminology adopted. To provide flexibility and reduce the number of heartbeats issued in exercises, entity heartbeats are now defined by entity kind, domain, and whether the entity is moving or stationary.

Whenever possible, backward compatibility has been maintained by reusing existing fields. For example, all PDUs have a 96-bit header that defines protocol version, exercise identifier, PDU type, timestamp, length, with a 16-bit padding field. In the draft standard, this 16-bit field has been split into an 8-bit PDU Status record and an 8-bit padding field. The PDU Status record is used to indicate status information that either (1) affects the processing of this specific PDU, (2) provides information related to the interpretation of one or more data fields or their content, or (3) provides information that affects the processing of an entity, other object or environmental process associated with this PDU.
4.2 Information Operations

Information Operations (IO) refers to the integrated employment of electronic warfare (EW), computer network operations (CNO), psychological operations (PSYOP), military deception (MILDEC), and operations security (OPSEC), to influence, disrupt, corrupt, or otherwise affect enemy information and decision making while protecting friendly information operations.

To support Information Operations, a new IO family has been added that defines two new PDUs:

- **IO Action PDU** that communicates an IO attack or the effects of an IO attack on one or more target entities. This PDU contains information that can be used by a receiving simulation to model the effects of an IO attack.
- **IO Report PDU** that communicates the effects of an IO attack on one or more target entities. The information contained in this PDU is used by a receiving simulation to determine whether to continue an IO attack or change attack parameters. It can also be used for IO data analysis and identification of interoperability problems.

4.3 Emissions

Considerable changes have been made to the Electromagnetic Emissions (EE) PDU. Its use has been clarified to remove ambiguities such as notifying other systems of beam on/off status, and operation of the heartbeat/changed data update mechanisms.

The previous standard was ambiguous as to the requirement for all emitters from one system to be included in a single EE PDU. The new standard has introduced the Complete-Emitter and Partial-Emitter methods:

- **Complete-Emitter method**: a single EE PDU fully describes all active emitters associated with an entity.
- **Partial Emitter Method**: a single EE PDU describes a subset of active beams. Each beam is fully described. This method supports multi-beam emitters in cases where some beams update much more frequently than others and allows frequent updates of the track beam.

Further, a new jammer field has been added using an existing padding field to better support a wider range of multi-resolution simulations. The new standard will also be able to support more complex systems such as phased array radars.

4.4 Warfare Upgrade

Representation of weapons and their effects has been enhanced with the addition of two new PDUs.

A new Directed Energy Fire PDU has been added to support high-fidelity directed energy engagements, typically involving laser weapons and also microwave and acoustic weapons. This PDU is used in conjunction with the existing Fire and Detonation PDUs.

A new Entity Damage Status PDU has been added to communicate detailed damage information sustained by an entity from either a weapon, a collision with another object, or some other reason. This PDU enables damage to a specific location on an entity to be conveyed whether or not that location is associated with an articulated or attached part.

The new Annex I contains details concerning the use of these two new PDUs. The Warfare - General Requirements section has also been rewritten to incorporate the use of the Fire and Detonation PDUs for expendables and the use of the Detonation PDU for non-munition explosions.

The new standard also allows for a detailed representation of submunitions operations including visual appearance, from the time the initial submunition dispenser is launched until the time that all the individual bomblets either explode or become duds.

4.5 Radio Communications

The Transmitter PDU has been revised to include variable Transmitter Parameters records, in addition to the existing Modulation Parameters and Antenna pattern records.

While the 1998 version added specific Intercom PDUs, these have not been used widely and intercom has generally been modelled using the existing Transmitter and Signal PDUs. This process has now been formalised as Simple Intercom in the revised standard.

Propagation-less transmissions are used when line-of-sight, range and other propagation effects are either not required or for training, testing and troubleshooting where propagation models may interfere with these activities. The revised standard requires that the Antenna Location X, Y, and Z subfields be set to zero to indicate such transmissions.

4.6 Transfer Control

The Transfer Control Request PDU was added in DIS version 6 to enable simulations to transfer control of entities. The Transfer Control function has been renamed the Transfer Ownership function and the Transfer Control Request PDU has been retitled the Transfer Ownership (TO) PDU. The entire TO function has been revised to improve its functionality in the new standard. These changes include:

- Transfer Ownership can now be either: Push Transfer where one simulation desires to transfer ownership to another simulation or Pull Transfer where a simulation requests to take control of another simulation's entity
- The TO PDU requires Simulation Management and Simulation Management with Reliability PDUs
• Making use of the new PDU Status record to indicate entity transfer status

4.7 Attribute PDU
A new Attribute PDU has been introduced to communicate information about individual attributes for a particular entity, other object, or event. This PDU shall not be used to exchange data available in any other PDU except where explicitly mentioned in the PDU issuance instructions within this standard.

The Attribute PDU has two functions:
• PDU Extension – A means to extend any PDU by creating new Attribute Records that can be sent in an Attribute PDU. The Attribute PDU for a state PDU (eg Entity State) can be sent at any time. A transient PDU (eg Fire) can be extended by bundling the Attribute PDU with it.
• Partial Updates – A mechanism for new PDUs that allows these to send changed data fields only instead of having to send all the data fields for the PDU type where the PDU issuance rules allow.

4.8 IFF
Transponder and Interrogator requirements have been updated to support high fidelity Mode 5 IFF and Mode S systems.

Mode 5 is the new military mode that replaces Mode 4 IFF, although existing Mode 4 equipped aircraft will continue to carry that equipment. The new Mode 5 transponders will include additional operational information about an aircraft included in their replies in addition to transmitting existing Mode 1, 2, 3/A, C and even Mode 4 data if available.

Mode Select (S) is a new civilian radar beacon system added to the present civilian Mode A and Mode C systems that are used for air traffic control. Mode S provides enhanced aircraft data that is downlinked to Air Traffic Control facilities on interrogation.

Mode 5 and Mode S equipped military aircraft will be coming on line over the next 2-10 years. US and NATO countries are retrofitting existing C4ISR systems that have interrogators to add both a Mode 5 and Mode S interrogation capability.

4.9 Time Requirements
Time requirements have been extensively clarified and revised. This includes clarification on:
• terminology, with new terms added to the DIS glossary such as GPS Time, Clock Skew, and Wall Clock Time
• absolute and relative timestamps
• issuance and receipt rules
• dead reckoning
• use of Start/Resume and Stop/Freeze PDUs
• synchronisation

Some of these changes reflect advances in communications technology. For example, there is now the ability to synchronise PDUs to GPS time: a simulation obtains the present synchronized time using the GPS satellite constellation. This can generally provide UTC time, usually to within 100 s.

4.10 Dead Reckoning
Dead-reckoning requirements have been updated including the addition of a new quaternion equation. This provides the flexibility of using a geometric representation of orientation dead reckoning in situations where the standard Euler angle approach can lead to singularities. Ambiguities and errors in the existing dead reckoning algorithms have also been removed.

Annex B - Dead Reckoning has been completely revised to clarify requirements although retaining all the existing formulas.

4.11 Variable Parameter Records
The Articulation Parameter record found in the Entity State and other PDUs has been renamed the Variable Parameter (VP) record to denote that its original design supports more than just its use for articulated and attached parts records. This now provides a way for additional information to be associated with entities within the Entity State PDU, and detonation events within the Detonation PDU.

Use of the VP has been proposed for the Entity State, Entity State Update, Detonation, and Transmitter PDUs. VP records have been defined to date for Articulated Part, Attached Parts Separation, Entity Type, Entity Association and Antenna Location.

It is envisaged that other PDUs will also utilise this new capability to extend their functionality.

4.12 Entity Separation
Entity separation has been addressed by clarifying how it is to be done for various situations including multi-stage missiles and submunition portrayal. There are two types of entity separation:

a) Sequential separation. The separation of one entity from another in a fixed, sequential pattern such as a multi-stage missile where each stage separates in a fixed sequence.

b) Non-sequential separation. The separation of one entity from another in a non-sequential pattern such as munitions launched from a fighter aircraft.

These operations can now be represented accurately using Entity State, Fire, and Detonation PDUs with appropriate VP records. A multi-stage missile can be modelled as either a single entity for its entire flight with no separate entities created or with separate entities that represent the planned separation of components.
4.13 New and Revised Annexes
Seven new annexes have been added as follows:

- Annex D - Transfer Ownership (Normative) that contains detailed requirements for transfer ownership.
- Annex E - Transponder and Interrogator Systems (Normative) that contains detailed requirements applicable to specific transponder and interrogator systems.
- Annex F - Objects (Normative) that contains detailed requirements related to object types and primary and secondary identifiers.
- Annex G - Heartbeats, Timeouts, Thresholds (Informative) that provides guidance on how to maintain interoperability when some simulations have implemented the new entity timeout requirements and some have not.
- Annex H - Radio Systems (Normative) that contains detailed requirements applicable to specific radio systems.
- Annex I - Warfare (Normative) that provides additional requirements related to PDUs used to support the warfare functional area.
- Annex J - Time Calculations and Uses (Informative) that provides additional information on time and its uses in a distributed simulation environment.

The existing Annexes have also been extensively revised.

4.14 Changes to Enumerations
DIS is supported by SISO reference document SISO-REF-010 [6] that contains enumerations for entities, systems, and effects. These enumerations are of three kinds: (1) entity type enumerations that define entities (typically military platforms such as ships and aircraft); (2) value-pair enumerations that define specific values for equipments such as types of radar; and (3) bit-mask enumerations that set specific bits in a field to define system characteristics such as appearance of an entity.

These enumerations require considerable revision to support IEEE-1278.1-200X. Due to their enhanced functionality, the sections describing Transfer Control, Radio Communications, IFF, Simulation Management, and Warfare need to be further populated.

New enumerations have also been added such as those for the PDU Status Record, (see section 4.1). Enumerations have been proposed that define whether an entity has been transferred from another simulation application, whether the simulated entity is Live, Virtual, or Constructive, whether the PDU is coupled with an Attribute PDU, the type of object fired by a Fire PDU, and the type of object detonated by a Detonation PDU.

Of course, the new PDUs themselves need new PDU-type enumerations (an 8-bit record in the PDU Header field). The proposed enumeration values are:

- 69 Entity Damage Status PDU
- 70 Information Operations Action PDU
- 71 Information Operations Report PDU
- 72 Attribute PDU

These new PDUs also have additional associated enumerations. For example, the IO Action PDU has enumerations for IO Warfare, IO Simulation Source, IO Action Type, and IO Action Phase.

The IFF enumerations have been completely revised to allow for the new Mode S/Mode 5 capabilities as have the enumerations related to Radio Communications.

4.15 Summary of Changes
The principal changes to the standard are summarised in Table 1.

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<th>Area</th>
<th>Changes Summary</th>
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<tbody>
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<td>Clarifications</td>
<td>Removal of ambiguities</td>
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<tr>
<td>Information Operations</td>
<td>New capability; two new PDUs</td>
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<tr>
<td>Emissions</td>
<td>Removal of ambiguities; partial and complete emitter methods</td>
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<tr>
<td>Warfare Upgrade</td>
<td>Directed Energy and Entity Damage Status PDUs; support for submunitions</td>
</tr>
<tr>
<td>Radio Communications</td>
<td>PDUs revised; Simple Intercom practice and propagation-less communications formalised</td>
</tr>
<tr>
<td>Transfer Control</td>
<td>Revised to include Push/Pull</td>
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<tr>
<td>Attributes</td>
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<td>Interrogate Friend or Foe</td>
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<tr>
<td>Time requirements</td>
<td>Extensive clarification</td>
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<tr>
<td>Dead Reckoning</td>
<td>Addition of quaternion method for rotations; ambiguities/errors removed</td>
</tr>
<tr>
<td>Variable Parameter Records</td>
<td>New capability that extends some PDUs</td>
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<td>New Annexes</td>
<td>Seven new annexes added; existing annexes revised</td>
</tr>
<tr>
<td>Enumeration additions</td>
<td>New enumerations required to support new PDUs and other added functionality</td>
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</table>

4.16 Other Proposed Changes
Further changes were proposed that did not make it into the current draft standard.

- A Draw Shape PDU was proposed to communicate information about a region of interest or a geometric shape / object that is not defined by the standard entity enumerations. For example, this PDU could be used to draw threat rings or cones in simulations where the sensor itself is not being simulated.
- An extension schema was proposed for enumerating life forms to greater detail than is possible in the present standard. This could use VP records to provide additional detail such as weapons being carried.
Enhanced visualisation was also proposed using VP records to communicate details such as car lights flashing or opening a door. Such changes may be included in a later revision of the DIS standard as it continues to evolve.


Considering that the current version is described by both the 1995 and 1998 standards combined totalling roughly 350 pages, it can be seen that the revised draft of 681 pages represents a vast increase. The new standard will become version 7 of the DIS protocol.

5. IMPLICATIONS FOR AUSTRALIA
What are the implications for the Australian simulation community when this new version is passed by the IEEE balloting process? Should we adopt this new standard without reservation, or remain with the existing standard? What opportunities does the new standard offer to the Australian Defence Organisation (ADO)?

The current state of DIS-compatible ADO simulators shows that these are largely compliant with the 1998 (version 6) standard [7]. In general when developing the new standard, the approach was taken to retain backward compatibility wherever possible so that most ADO version 6 compatible simulators should be able to interoperate with a new version 7 compatible simulators. If a new version 7 PDU is received that cannot be processed by an existing system, the approach should be taken to reject such a PDU.

A recurring theme in the revised standard is the need to model new and enhanced military capabilities in a distributed simulation environment. Examples of this include the Mark XIIa IFF system, which is likely to be acquired by Australia in the next decade, and phased array radars, which are inadequately defined in the existing standard. Of the new provisions, many are not relevant to Australia, as the decision to acquire the corresponding assets and capabilities have not yet been made. Examples here include multi-stage missiles, and Directed Energy weapons. The authors are unaware of any requirement for the current generation of ADO simulators to provide distributed Information Operations modelling.

Perhaps most significantly, the refinements and clarifications made to the standard and also the greatly increased explanatory documentation will enable distributed simulation environments to be constructed in Australia with less integration effort and more certainty of outcome.

6. CONCLUSION
The IEEE DIS standard is being revised by SISO following a decision to extend the existing 1998 standard.

The new standard includes an extensive revision, clearing up many of the ambiguities in the existing version and adding additional capabilities for Directed Energy weapons, Damage Status, Information Operations, Transfer Ownership, Electronic Warfare, IFF, and the ability to extend the existing PDU set with an Attribute PDU.

The dead reckoning and heartbeat mechanisms, essential for maintaining entities during an exercise, have also been extended. There are five new PDUs and seven new annexes to describe various aspects of the emerging standard. There are also changes to the accompanying enumerations required for the new version.

The ADO simulation community should be made aware of the new standard although it should have minimal impact on existing systems.

7. REFERENCES
7. Ryan, P, Clark, P, Ross, P and M. Fairleigh, Interoperable Aerospace Training Simulators within the Australian Defence Force, SimTecT 2006, held Melbourne, May 29 – June 1, 2006