Compressed DIS

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ABSTRACT

Radio Frequency (RF) networks have a limited bandwidth compared to landlines. Therefore, when operating over RF, it is desirable to use the available bandwidth with the greatest efficiency possible. The Compressed Distributed Interactive Simulation (C-DIS) standard developed by the Air Force Research Laboratory (AFRL) is a compressed-format version of the IEEE 1278.1-2012 Distributed Interactive Simulation (DIS) standard that significantly increases transmission efficiency. It is a government owned, non-proprietary standard. C-DIS is a bit-oriented data standard that reduces the size of DIS packets by 50-to-70 percent, effectively more than doubling the bandwidth of a network. The C-DIS standard will be used on the 5G-Advanced Training Waveform (5G-ATW) RF network as part of the Secure Live Virtual Constructive Advanced Training Environment (SLATE) Advanced Technology Demonstration (ATD).

C-DIS maintains all of the currently used DIS Protocol Data Unit (PDU) fields, concepts, approaches and enumerations, making translation from DIS to C-DIS and from C-DIS back to DIS efficient and accurate. It is intended to be used as a transport-level compression that allows DIS data to be readily compressed by transmitters and decompressed by receivers. C-DIS supports current standard SISO and CAF DMO enumerations and values and allows for future enumeration growth.

In addition to standard DIS messages, C-DIS also supports compression of the CAF DMO-defined messages used for Active Electronically Steered Antenna (AESA) Radars and Advanced Jammers. These messages include the Radar Track Report, Jammer Report Record, and Jammer False Targets Record. This enables the modeling of Electronic Attack and Jamming over the limited bandwidth RF network available for Live Virtual Constructive operations.

This paper discusses C-DIS compression techniques, message formats, usage rules, and performance results.

ABOUT THE AUTHORS

Lance Call is a Principal Software Engineer for L-3 Technologies at the Air Force Research Laboratory (AFRL). He graduated Magna Cum Laude with a Bachelor of Science degree in Electronics Engineering Technology from Brigham Young University in 1988. He has worked on real-time threat systems, and integration of live, virtual man-in-the-loop, and computer only simulations. He has been responsible for Cross Domain Security systems and rule set development, improving threat systems and integrating simulators with Live aircraft systems. He is an IEEE member.

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Mitchell Zamba is a Senior Multi-Desc Engineer with L-3 Technologies supporting the Air Force Research Laboratory, 711th Human Performance Wing, Human Systems Integration Directorate at Wright-Patterson AFB, OH. He has over 20 years of modeling and simulation experience with the Air Force and industry. He is currently working on SLATE, network, and encryption issues for international projects for interconnection to AFRL. Previously, he was with the Joint Advanced Distributed Simulation Joint Test Force (JADS JTF) in Albuquerque, NM, where he engineered and installed secure, wide-area networks used in the early research of distributed simulations.

J. David "Moses" Noah currently serves in AFRL's Warfighter Readiness Research Division as both the Tactical Fast Jet Team Lead and as the SLATE Program Manager. Dave recently retired as an F-16 pilot after more than 33 years in the United States Air Force. He is a Fighter Subject Matter Expert (SME) within this AFRL Division. He is a USAF Command Pilot with more than 3400 hours of fighter aircraft time, including 4 combat tours. He has Command-and-Control (C2) experience in both the Iraqi Theater Combined Air Operations Center (CAOC) as well as the CENTCOM Forward Headquarters Joint Operations Center (JOC). Dave received his degree from The Ohio State University (Genetics major, Mathematics minor) and has completed USAF Professional Military Education courses, including Air War College. He was awarded the Air Force's Kolligian Trophy by the USAF Chief of Staff in 1991.

Mr. Noah brings extensive Department of Defense (DoD) Industry experience to his current assignment. Dave started with Lockheed Martin in 2000 as a Program Manager of Tactical Aircraft Simulator Programs before being promoted to Senior Manager of Fighter Programs (F16, F-22, F-35 and A-10) for Lockheed Martin Headquarters. In 2007, he transferred to BAE, Inc. (SSA) as the Director of Air Force Programs before being recalled to USAF active duty where he spent 19 months as an Inspector General Division Chief at HQAFMC, Wright Patterson AFB.

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WHY BOTHER WITH DATA COMPRESSION?

Network bandwidths vary widely (as illustrated to scale in Figure 1). Fiber Optic networks can have bandwidths in excess of 10 Gigabits per second (Gbps), while wired networks can have speeds of 1 Gbps or 100 Megabits per second (Mbps). Radio Frequency (RF) networks typically have significantly lower bandwidths. The new 5G-ATW RF waveform supports 6.61 Mbps bandwidth. With a limited implementation radio, the actual 5G-ATW user bandwidth is approximately 1 Mbps. Bus bandwidths can also be limited and message size also differs. Wired Ethernet is typically 1500 bytes Maximum Transmission Unit (MTU) size. This means that messages that are larger than 1500 bytes will be fragmented into multiple messages, then reassembled at the receiver. This effectively doubles the number of messages that are required to be sent. In RF networks, there is additional overhead required for signaling, Forward Error Correction (FEC) coding, and syncing, in addition to the Encryption and IP overhead of the network. All of this overhead reduces the available user payload sizes and effective network bandwidth of RF networks relative to landlines. The 5G-ATW RF data link has a 690 bit user data payload size after all overhead. The exact number of Distributed Interactive Simulation (DIS) messages that exceed 690 bits depends on the distribution of Protocol Data Unit (PDU) types and application usage. In our historical data, approximately 85 percent of DIS messages exceed 690 bits. This means that 85 percent of standard DIS messages would need to be fragmented, doubling the required bandwidth for 85 percent of the messages and doubling the latency of those messages as well. This suggests that it would be desirable to compress the DIS messages to be less than 690 bits to avoid fragmentation, reducing bandwidth usage and latency. Message compression trades off additional computational requirements (encoder/decoder) and complexity for less bandwidth used on the network. When network bandwidth is very limited or the bandwidth is less than needed for a particular application, then it makes sense to use additional computational power to compress the data.

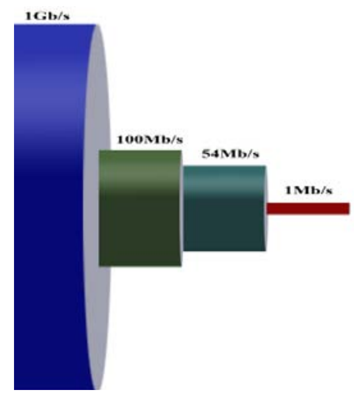

Figure 1. Common Network Rates

SECURE LIVE VIRTUAL CONSTRUCTIVE ADVANCED TRAINING ENVIRONMENT (SLATE)

SLATE exchanges DIS data between a Virtual and Constructive (VC) DIS network and Live (L) aircraft over three different data links in order to take advantage of existing systems and to limit the amount of simulation data that must be sent over the 5G-ATW link (see Figure 2). The first link uses real UHF/VHF radios and a gateway to exchange voice communications. The second link is Link16 via a Joint Range Extension (JRE), used to exchange TADIL J messages. The third link is the 5G-ATW data link, used to exchange all remaining DIS simulation data. The 5G-ATW has a user bandwidth of approximately 1 Mbps. The 5G-ATW doesn't need to pass Voice or Data Link messages due to this architecture that allows more entity and emissions messages to be passed, increasing the size and fidelity of the training exercise that can be supported. AFRL wanted to maximize the 5G-ATW portion of the link in order to maximize the training that would be

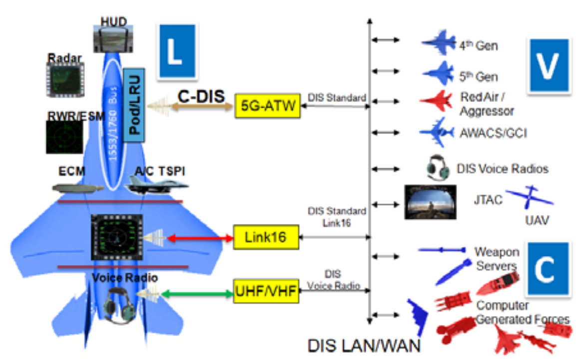

Figure 2. SLATE Network Architecture

possible over this link. Because of the relatively limited bandwidth (compared to landlines) the information sent over the 5G-ATW is a good candidate for compression.

ALTERNATIVE APROACHES

Live Entity (LE) Information/Interaction protocol

The first compression approach considered was the DIS LE Information/Interaction protocol. LE, however, does not support all PDUs (that is, Interrogate Friend/Foe (IFF), Emissions, and the Simulation Management (SIMAN) PDU family messages). In addition, there would be a significant amount of translation required to go between the DIS Entity State message and LE Time Space Position Information (TSPI) PDU. We would be required to extend the protocol to support Emissions, IFF, and SIMAN PDUs.

General Purpose Compression

The second compression approach considered was to use the Lempel-Ziv-Welch or some other, general-purpose compression algorithm. Literature research on the various algorithms seemed to suggest that the relatively small number of bits in the individual DIS messages would likely be insufficient to achieve sufficient amounts of compression to reach our 50 percent compression goal. A generic compression algorithm would have to be lossless. We feel that this approach may still have merit if an appropriate algorithm is found. A generic algorithm would have the significant advantage that it could be applied to all data in a message, including non-standard user data in Datums and Signal PDUs content as well. Additional research in this area may be warranted.

C-DIS

The third compression approach considered was to compress the DIS data based on a knowledge of the data fields and required precision. This C-DIS 1.0 approach, and minor increments to C-DIS 1.2, are described in the remainder of this paper.

C-DIS GOALS

The goals for C-DIS are: Support all IEEE 1278.1-2012 DIS PDUs; maintain existing PDU timing for simplicity and fidelity; focus on PDUs that make up the majority of DIS bandwidth (Entity State, Emission, Signal and IFF); one-for-one mapping of every DIS field in every DIS PDU (but in a compressed format); direct mapping from DIS to C-DIS and back without complex translations; support standard SISO and CAF DMO enumerations; support all DIS concepts and allow for expected growth; compress as much as possible (50 percent or better target); retain precision as much as possible; and, fit into 5G-ATW 690 bit message size.

The purpose of C-DIS is to allow two DIS networks running standard DIS protocols to communicate over a limited bandwidth network (as illustrated in Figure 3). This means that the C-DIS standard needs to be able to support all DIS PDUs in order to support standard DIS applications. Ideally, C-DIS shouldn't limit the DIS applications in any meaningful way. By limiting compression to a per packet basis, implementation of C-DIS is made relatively easy, and the fidelity of the original data is preserved. It is possible to define a compression scheme that limits PDU rates or performs filtering to reduce traffic, but the fidelity of the simulation may be significantly impacted. C-DIS is, therefore, designed to simply compress each individual message and to rely on federates to use existing DIS mechanisms (such as thresholds and timeouts) to modify the number of messages sent (if necessary). This approach insures that both DIS LANs observe and operate on data of equal fidelity and simplifies C-DIS implementation.

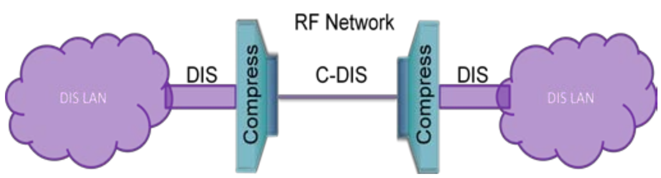

Figure 3. C-DIS compresses traffic between two DIS LANs

C-DIS attempts to compress each individual field in the DIS PDU to the extent possible. This maintains all DIS concepts and capabilities while using knowledge of the requirements for precision or enumeration of required size. This allows for the greatest degree of compression with the least amount of impact. This is a somewhat subjective exercise based on years of experience using the DIS protocol in aircraft simulations. This is something that a general purpose compression scheme could not accomplish. Other domains may use the DIS protocol differently, making it important to establish a compressed DIS standard that is usable by a larger community.

Mapping each individual field on a one-for-one basis makes encoding and decoding a straight forward process of simply compressing or expanding each field without needing translations of types or concepts. This means that there are no requirements to maintain separate lists of enumerations that are applicable only to C-DIS, or performing complicated algorithms to determine what the corresponding type should be in C-DIS or DIS.

One modification to the one-for-one mapping of fields is the Earth Centered Earth Fixed (ECEF) geocentric location used in DIS. After considering several different ways of encoding this field, it was decided to change the location coordinates from ECEF to Latitude/Longitude/Altitude (Lat/Lon/Alt). The root challenge for encoding ECEF is that the radius of the earth is very large compared to the typical desired altitudes, requiring many bits that would be wasted. Conversion for ECEF to and from Lat/Lon/Alt are readily available and in common use, making this approach very attractive. Rotations and velocities maintain their scaled ECEF values so that only location is converted, and rotations and velocities are simply scaled.

The 5G-ATW data link specification matured sufficiently in 2017 to determine the size of the user data message would be 690 bits after all IP, encryption, FEC, and other overhead. This provided a specific message size target in order to keep messages from being fragmented, which would double bandwidth usage and latency.

C-DIS COMPRESSION TECHNIQUES

C-DIS makes use of the following techniques in order to compress the data: eliminate byte boundary requirements; reduce enumeration and data field sizes as much as possible; remove padding and other unnecessary fields; replace floating point numbers with scaled integers; allow different units; use Lat/Lon/Alt instead of Geocentric ECEF; add bit flags to indicate the presence of optional or not applicable fields; and, allow the option of partial updates.

In order to achieve the maximum compression possible, the DIS data fields were changed to bit fields of length just sufficient enough to carry the information required by that field. This achieves the maximum amount of compression at the expense of making access to particular data more complex. Deciding on the number of bits to allocate for each field is the critical step in reducing size while maintaining fidelity and allowing for future growth. The size must allow for likely future growth without requiring changes to the C-DIS standard so that the C-DIS standard is reasonably stable. Because floating point numbers are scaled to integer values, there is less precision available in C-DIS than in standard DIS; C-DIS values have a smaller maximum value than the DIS equivalent field could support. Many values, however, have an intrinsic maximum value. For example, rotation angles have a maximum value of 360 degrees (2 x PI radians) so the integer value need not support values larger than 360. This allows an opportunity to identify reasonable minimum (precision) and maximum values and to allow them to be represented as a scaled integer value to achieve compression.

Some floating point frequency values have been encoded using a combination of scaled integer mantissa with an exponent value. This approach allows four or five decimal digits of accuracy while supporting very large numbers (up to mantissa x 10^{15}). This is used for transmitter and emitter frequencies that may cover a very large range of values but have a limited precision requirement. Sometimes values may cover a large range of values, making the number of bits for a scaled integer quite large. In these cases, C-DIS defines a units flag that can be used to indicate which units should be applied to the value. For example, the typical units of measure for altitude are centimeters (cm). C-DIS allows the units to be changed from cm to Dekameters (meters x 10) increasing the maximum altitude by a factor of 1000 while only allocating 1 additional bit to indicate the units. The tradeoff is less precise altitude values when using Dekameters.

C-DIS adds single-bit flags to indicate the presence or absence of individual or groups of fields that may not be necessary for a particular update. This mechanism is used in both full- and partial-update modes to indicate which fields are present.

C-DIS allows the encoder/decoder to operate in either full or partial update mode. In full update mode, all data in the message is encoded and sent on the network. In partial update mode, the encoder periodically sends full updates but, for all other updates it passes only partial data. This results in the most compression possible using C-DIS. In partial mode, decoders are required to save a copy of the current state of items (such as entities, and emitters), be able to look up the state of an item, then update the state with the new information provided in the partial update. This requires the decoder to have significantly more resources and processing power than full mode and makes the software more complex.

Many DIS Datums are used in custom ways and are not documented in the DIS standard. This makes it difficult to apply compression to these items using the C-DIS approach. Initially, C-DIS used the approach that none of these items would be modified and, therefore, all would be supported; however, they would not be compressed and could create messages of significant size. When Datums are used in messages that do not occur at a regular rate, there is little benefit in compressing the messages. However, if the data traffic contains many SIMAN PDUs with Datums or variable records that occur regularly, then compression becomes important.

C-DIS COMPRESSION EXAMPLES

C-DIS is based on the IEEE 1278.1-2012 specification. Table 1 explains the color codes used, Table 2 details the format of the DIS Header, and Table 3 details the Entity State PDU format used by C-DIS.

Table 1. Color Key for C-DIS Standard Tables

Meaning of Text colors
Red text indicates new items that have been added to the DIS Standard PDUs; or, indicates that field sizes have been altered.
Blue text Indicates items that are optional for most updates but are required as part of a "Full" update. "Full" updates are required for the first PDU update, at least once during the PDU Timeout period, and for the final PDU update.
Orange text indicates items that are completely optional and are not required as part of a "Full" PDU update. These items may simply not be applicable for a particular entity or system being modeled and may never be provided.
Green text indicates items that are new in the DIS 2012 Standard.
Purple indicates Field sizes that are variable depending on a bit flag.
Black text indicates items that are the same as the DIS 2012 standard.
Grayed out text indicates items that are not used in compressed DIS such as padding fields.

Table 2. C-DIS Header Format

Compressed DIS MESSAGE Format - DIS Header				
Field Name		DIS Size (Bits)	Smallest Possible Message	Notes
PDU Header	Protocol Version	8	2	3 simultaneous enumerated versions
	Exercise ID	8	3	8 simultaneous exercises
	PDU Type	8	8	
	Protocol Family	8	0	Derive from Local Lookup, if needed
	Time Stamp	32	26	107 usec LSB Time Flag, DIS=1.67 usec
	Length	16	14	Length in Bits 16383 max (2047 bytes)
	PDU Status	8	8	DIS 2012 New Field
	Padding	8	0	Not applicable

C-DIS compresses the DIS Header from 96 bits to 61 bits, resulting in a header that is 64 percent of the original size. It was decided not to pass the protocol family because it can be derived using a lookup table. The length was changed to bits. The 16383 (2047 bytes) maximum number of supported bits is larger than the common 1500 byte MTU.

Table 3 defines the size of each field in the C-DIS Entity State Message. C-DIS adds ten Field Present Flags to indicate which fields will be present in the Entity State Update. This allows the C-DIS encoder to send only those fields which are required for a particular update. For example, if a static entity is sent, then the C-DIS encoder could set the Entity Linear Velocity, DR-Params Other, DR-Params Entity Linear Acceleration, and DR-Params Entity Angular Velocity all to “0” to indicate that no velocities or accelerations will be provided in the PDU. These four bit flags save 246 bits of data from being sent, resulting in significant compression without any loss in fidelity. The Units flag indicates which units should be applied to the altitude that is passed. This allows the altitude to be encoded down to a precision of 1 cm or as large as 8.3 x 10^7 meters, but with reduced ten-meter precision. C-DIS defines two different sizes of the Site Application Entity (SAE) ID used throughout the DIS specification. If SAE numbers are sufficiently small (255:255:4095), the SAE Size flag is set to “1” to indicate that the SAE will use the smaller version SAE, saving 20 out of 48 bits. This provides some compression in the DIS Entity State PDU but is more critical in the Emissions PDU or other locations where a list of SAE IDs are used and, therefore, any improvement in size is multiplied by the number of SAE IDs on the list. A marking length was added so that if the Entity Marking uses fewer than eleven characters, then fewer bits may be used to encode the string. For example, if the Marking uses the full eleven characters, then four bits are added to the total required bits. However, if the Marking is ten characters or fewer, then bits are saved. At this time only world-based DR algorithms are supported, and this is sufficient for SLATE. Body-based DR algorithms could be defined in the future, if needed for other programs. The notes in the last column in Table 3 indicate the minimum and maximum values for each item and indicate how many values the CAF DMO MP 15 specification or the SISO REF 10 2016 enumerations document defines. This provides some insight into how much room for additional growth is left in the C-DIS fields for additional enumerations to be defined. The entity type enumeration was shortened from 64 bits to 45 bits while still supporting all defined SISO REF 10 2014 definitions. SISO REF 10 2015 added Human Personal Data to the Extra field that is not yet supported.

Table 3. C-DIS Entity State PDU Format

Compressed DIS MESSAGE Format - Entity State PDU					
Field Name		DIS Size (Bits)	Smallest Possible Message	Optional Bits	Notes
PDU Header	See Compressed DIS PDU Header Definition				
Field Present Flags	Variable Parameters		1		Variable Parameter Records 0=None 1=All Present
	Entity Type		1		0=None 1=Present
	Alternate Entity Type		1		0=None 1=Present
	Entity Appearance		1		0=None 1 = Present
	Entity Linear Velocity		1		0=None 1=Present
	DR Params-Other		1		0=None 1=Present
	DR Params- Linear Accel		1		0=None 1=Present
	DR Params- Angular Velocity		1		0=None 1=Present
	Entity Marking		1		0=None Present 1=Entity Marking Present
	Capabilities		1		Capabilities 0=None 1=Present
Units	Entity Location Altitude		1		0=Centimeters (cm) 1=Dekameters (dam)
Entity ID	SAE Size		1		0=Standard DIS SAE 1=Small SAE
	Site	16	8		
	Application	16	8		
	Entity	16	12		
Force ID		8	2		0=Other, 1=Friendly, 2=Opposing, 3=Neutral
Num Variable Recs		8		8	Present if Variable Parameters present flag is true
Entity Type	Kind	8		4	CAF DMO max 9, SISO Max 9 - Allow 15 Max
	Domain	8		4	CAF DMO max 11,SISO Max 12-Allow 15 Max
	Country	16		9	CAF DMO max 225, SISO Max 266 - Allow 511
	Cat	8		8	CAF DMO max 89, SISO max 101
	Subcat	8		8	CAF DMO max 246
	Specific	8		8	CAF DMO max 102
	Extra	8		4	CAF DMO max 7, SISO Max 190-Allow 15 Max
Alt Entity Type	Kind	8		4	
	Domain	8		4	
	Country	16		9	
	Cat	8		8	
	Subcat	8		8	
	Specific	8		8	
	Extra	8		4	
Entity Linear Velocity	X	32		16	+-32767 decimeter/sec (6369.59 Knots max)
	Y	32		16	+-32767 decimeter/sec (6369.59 Knots max)
	Z	32		16	+-32767 decimeter/sec (6369.59 Knots max)
Entity Location	X (Lat)	64	31		+-90 degrees Lat (approx 0.93 cm accuracy)
	Y (Lon)	64	32		+-180 degrees Lon (approx 0.93 cm accuracy)
	Z (Alt MSL)	64	24		+-8388607 cm or Dekameter Units Flag
Entity Orientation	Psi	32	13		0.0439 degree resolution
	Theta	32	13		0.0439 degree resolution
	Phi	32	13		0.0439 degree resolution
Entity Appearance		32		32	
Dead Reckoning Parameters	Algorithm	8	3		Only support World Based DR Algorithms (0 to 5)
	Other	120		120	

	Linear Acceleration X	32		14	+-8191 decimeters/sec/sec (Aprox 83.5 g)
	Linear Acceleration Y	32		14	+-8191 decimeters/sec/sec (Aprox 83.5 g)
	Linear Acceleration Z	32		14	+-8191 decimeters/sec/sec (Aprox 83.5 g)
	Angular Velocity Psi	32		12	+-720 deg per second max 0.35 deg resolution
	Angular Velocity Theta	32		12	+-720 deg per second max 0.35 deg resolution
	Angular Velocity Phi	32		12	+-720 deg per second max 0.35 deg resolution
Entity Marking	Marking Length			4	Number of characters Example "Viper1"=6
	Char Set	8		8	
	Marking	88		0-88	Marking Length*8
Capabilities		32		32	
Variable Parameter Records					
Variable Parameter Rec #N	Record Type	8		8	No Compression Applied to Variable Parameter Records
	Rec-Specific Fields	120		120	

The Emissions PDU is complex and will not be fully detailed in this paper, but one of the main sections of the Emissions PDU is the Fundamental Params structure shown in Table 4. This structure is compressed with a floating point number that uses a 17-bit Mantissa and 4-bit exponent. This approach allows a very large set of possible values while preserving sufficient resolution for Electronic Warfare (EW) simulation. ERP is limited to single DB increments. This supports a robust RF simulation. Simulators that need very refined data can use the beam parameter index and Common Emission Parameter Database (CEPD) data to recreate values with the necessary precision and additional detail.

Table 4. Emission Fundamental Parameters table

Fundamental Params	Frequency	Mantissa	32		17	Frequency x 10^{X}
		Exponent			4	Exponent
	Frequency Range	Mantissa	32		17	Frequency Range x 10^{X}
		Exponent			4	Exponent
	ERP		32		8	0 to 255 dBm
	PRF		32		10	Freq x 100 (Max 102.3 KHZ)
	Pulse Width		32		10	tenths of usec (102.3 usec max)

PARTIAL UPDATES

C-DIS allows encoders to send full or partial updates. All encoders and decoders must be in the same mode and do not change modes dynamically. Decoders that support partial updates are much more complex to code because they must store the state of objects and then update those objects when partial updates are received. They must also remove those objects if the object is removed from the scenario, or after timing out.

The first update of any object must always contain a full set of data in the update. This allows decoders to know what kind of an object is being received and allocate an appropriate state with detailed data. It also allows the decoder to send an immediate update out with a full set of data for simulators to use. The C-DIS encoder must send out a full update at least once during every DIS timeout interval. The C-DIS encoder must track when the last full update was sent and ensure that full updates are sent at appropriate intervals. C-DIS defines the default values for fields that have not yet been received, or are not contained in a full update. This is typically zero. For example, the alternate entity-type field should be set to "0," unless an explicit update is received in an update PDU to change the value. This is necessary to avoid undefined behavior and because the alternate entity type may never be provided.
C-DIS specifies the fields that must be present in a full update message. In the Entity State, the full update must contain the Field Present Flags, Units, Entity ID, Force ID, Entity Type, Entity Appearance, and Entity Marking fields in addition to appropriate location, velocity, and acceleration fields depending on the Dead Reckoning Algorithm (DRA) type. Fields like Alternate Entity Type, Capabilities, and Variable Parameters may never be sent. C-DIS decoders should initialize these items as described in the C-DIS standard. C-DIS decoders only create objects from full updates. C-DIS decoders update those objects with received full or partial updates. C-DIS decoders must remove objects if requested by Entity State Appearance Bit 23 or after DIS Timeout is reached so that the object list does not continue to grow over time. Emissions and IFF that are associated with removed entities may be immediately deleted or allowed to timeout.

Simulators that start or restart after an exercise has begun must wait for a full update before having full information for an entity. This means longer times to get the full picture of the DIS entities. If the heartbeat time is five seconds for an aircraft entity, then the C-DIS decoder may wait for up to twelve seconds (heartbeat time * 2.4 s) before receiving a full update required to create an entity object. Allowing partial updates causes simulators to gradually acquire information on entities that existed prior to joining. Entities that are created once the C-DIS decoder is up will start immediately because the C-DIS encoder is required to send a full update for the first update.

The C-DIS encoder and decoder are both more complex if they support partial updates. The C-DIS encoder must track times of last updates for Entity State, Emissions, Designator, Transmitter, and IFF and decide when a full update is required versus a partial update. In addition, the encoder will have different data items to marshal to send for full or partial updates, making the code more complex. The C-DIS decoder must check to see if it has an existing object state whenever a message is received and either create or update an object as necessary. The decoder must be able to remove or timeout objects that have not been updated after the DIS timeout period. This uses more memory and CPU to implement than the full update approach. This may not be an issue for desktop systems, but it was of concern for SLATE when implementing the C-DIS encoder/decoder in an embedded processor on the SLATE pod.

C-DIS LIMITATIONS

C-DIS is a lossy compression scheme, meaning that exact values are not always sent but values that are sufficiently close to the original, so as to have no discernible effect on the DIS simulator, are sent in order to compress the data to the maximum extent possible. A lossless algorithm would allow the exact original bits in the message to be recreated, but would likely not achieve the same degree of compression. C-DIS provides no tools to change the number of PDUs per second. C-DIS expects that participants will use DIS thresholds and timeouts at the source of the DIS data to manage the number of PDUs per second if the message count exceeds the capability of the network. C-DIS does not currently compress the Variable Record messages. However, a proposal for how variable records may be compressed from 40-to-60 percent has been made and may be implemented and tested in the future. Similarly, C-DIS doesn't compress most Datums, but C-DIS techniques have been applied to the well-defined CAF DMO Datums Radar Track Report, Jammer Report, and Jammer False Target reports, and are contained in a C-DIS extension.

C-DIS does not address the contents of the Signal PDU, only the Signal Header. This means that, if the contents of the Signal PDU is large, very little compression will be achieved. It has been observed that voice communications PDUs will be compressed by as little as 5 percent. Standard DIS techniques can be used to mitigate voice, to some extent, by choosing a compressed voice codec and lowering sample frequencies to reduce voice bandwidth. For the SLATE project, this is not a concern because DIS voice is not passed over the 5G-ATW network. It is instead sent directly to a live radio Bridge to be transmitted by real UHF/VHF radios. Link16 messages are sent via a JRE to a real Link16 transmitter, so these Signal PDU messages are also not required to pass over the 5G-ATW network.

Table 5. C-DIS Precision and Maximum Value Summary

Item	Precision	Maximum Value
Position	1 cm/ Dekameters	8388607
Velocity	0.1 m/sec	6369 Knots
Acceleration	0.1m/sec/sec	83.5G's
Angle	0.0439 degrees	180,360
Angular Velocity	0.35 deg/sec	720 deg/sec
Frequency/ Frequency Range	4 or 5 decimal places	131071/ 16777215 $x10^{15}$
PRF	100Hz	102.3 KHz
Pusle Width	0.1 usec	102.3 usec
Power	1 dBm	255 dBm

C-DIS is lossy primarily due to the loss in precision when converting floating point numbers into scaled integer numbers. Table 5 summarizes the precision and maximum values for most of the floating point numbers used in C-DIS. This precision is adequate for the SLATE project and is believed to be sufficient to support most CAF DMO-like simulations without significant effects. Simulations may use beam parameter index and CEPD to preserve and increase fidelity of emitters and jammers, if necessary.

C-DIS PERFORMANCE

Direct Analysis

There are many possible variations in PDU lengths, so it is difficult to estimate compression rates directly. In order to determine compression rates on actual data, the test setup described in Figure 4 was used to measure sample data from various scenarios. Because the compression rate varies widely between the different kinds of PDUs, the compression ratio depends heavily on the mix of PDU types and PDU occurrence rates.

C-DIS Test Setup

The C-DIS test setup consisted of three pieces. First, a Packet Logger application capable of both logging and replaying packets was used to replay DIS log file data onto the network in standard DIS format. Log files from several different demonstrations and training events were analyzed. AFRL's DIS Filter Gateway was modified to implement the C-DIS specification to act as both C-DIS encoder and C-DIS decoder capable of either full or partial update mode. The DIS Filter Gateway was used to convert the DIS traffic into C-DIS traffic. A second Packet Logger was then used to create a log of the new C-DIS packets. Because there is a one-to-one mapping of DIS to C-DIS packets, both logs contain the same number of packets. The sizes of the packets can be compared to determine the actual compression ratio. The DIS Filter Gateway can filter specific PDUs, allowing the analysis of individual types of PDUs or combinations of types of PDUs. AFRL used its Packet Analyzer software to generate reports of message sizes and second-by-second data rates.

Figure 4. C-DIS Test Setup

ALL DIS PDU Types Measurement Results

The analysis of the results of all DIS message sizes from AFRL's 2016 I/ITSEC demonstrations is shown in Figure 5. By plotting PDU size against the running total percentage of PDUs, it is easy to see how many PDUs will be less than a particular size—which is of primary importance for the 5G-ATW 690 bit limit. It is easy to see that only 13 percent of DIS messages would be less than 690 bits, while 45–50 percent of C-DIS messages would be less than 690 bits. This is a significant size reduction, but still leaves many messages that are larger than desired. Full updates averaged 65 percent of the size of DIS packets, while the C-DIS with partial updates averaged 61 percent. Signal PDUs that contain voice compressed to 96 percent of original size and large Data PDUs compressed to 96 percent of their original size. This illustrates the fact that C-DIS does not reduce the size of voice and data PDUs with most Datums and that the mix of PDU types will impact the amount of compression achievable.

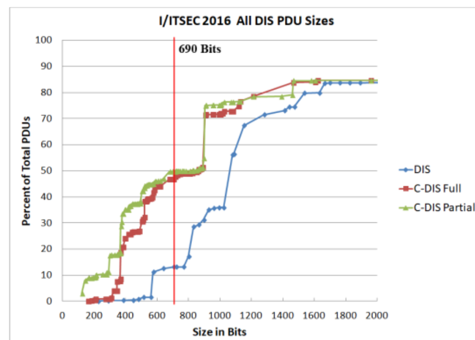

Figure 5. I/ITSEC 2016 PDU DIS/C-DIS Size

LVC PDU Measurement results

Due to the SLATE architecture, no voice or data-link PDUs are used. There are also no significant number of Data PDUs in the traffic. The remaining PDU types are defined as the "LVC PDUs" and are typically dominated by the Entity State, Emission, and IFF PDUs. Additional analysis was performed to see how well LVC PDUs were compressed. 65 percent of the PDUs are less than 690 bits if C-DIS full messages are sent, and 77 percent of the PDUs are less than 690 bits if partial updates are allowed. This shows that, in this case, about a 12 percent improvement can be achieved by using partial updates. If the 5G-ATW message size were slightly larger, there would be almost no advantage to using partial updates because their sizes are almost identical above 700 bits. This highlights that the effectiveness of using compression depends on the actual physical characteristics of the data links being used to transport the data. We also compared the second to second Kbits/sec data rate in each mode. Results

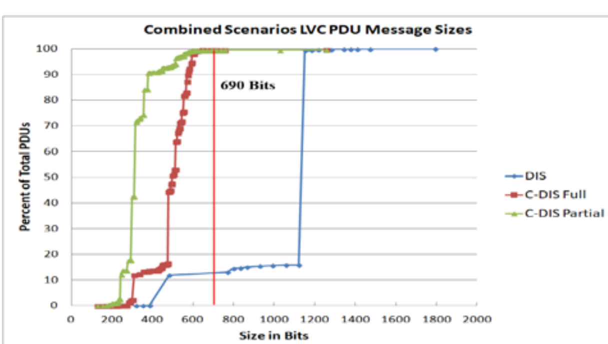

Figure 6. Combined Scenario LVC PDU Sizes

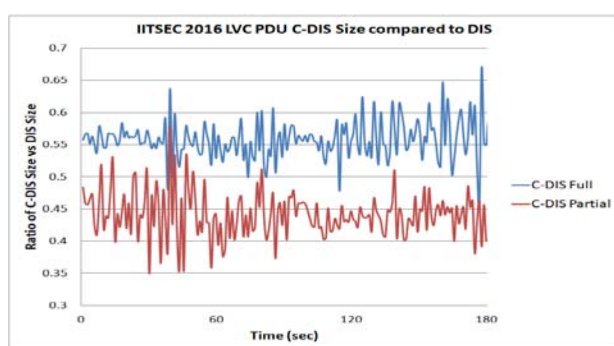

Figure 7. Second by Second Compression Ratio

shown if Figure 7 show that the compression rates vary from second to second, depending on the mix of messages sent and that the partial update approach messages are smaller by about 10–15 percent as compared to the full update approach. Another set of test data was created by taking five-minute samples from five different log files (representing small and large scenarios) with different mixes and types of entities and combining them into a single testing log file that could be analyzed. This combined log file testing provided a large cross section of different PDU combinations to provide an idea for how effective C-DIS might be in general conditions. Only LVC PDUs were analyzed. The results are shown in Figure 6.

Nearly all of the messages are less than the 690 bits for both full and partial options, while only 11 percent of the normal DIS PDUs fit. In this case, there would be no benefit as far as frame size between full and partial updates for the 5G-ATW, but there would be a significant benefit using C-DIS over using standard DIS. Table 6 summarizes the average size of C-DIS messages compared to DIS messages for several different test cases.

Table 6. Average C-DIS Sizes vs DIS for Full or Partial Updates

Scenario	Avg Full %	Avg Partial %
IITSEC 2016 Thurs AM ALL PDU	66	62
IITSEC 2016 Thurs AM LVC PDU	56	44
5 Combined Scenarios ALL PDU	64	55
5 Combined Scenarios LVC PDU	51	35
Sweden CAS 4 Virtual + 28 CGF Entities LVC PDUs	N/A	29

Analysis of the I/ITSEC 2016 data revealed that nearly 70 percent of the entities were using between 1–8 articulated parts in the Entity State PDU, which caused the C-DIS Entity State messages to often exceed 690 bits. This led to the creation of specifications for compression of Variable Record formats for Articulated Parts, Attached Parts, Separation, Entity Type, and Entity Association Records to increase the number of Variable Records that may be added to a message without breaking the 690 bit 5G-ATW limitation. These variable records are able to be compressed to 40–60 percent of their original size, allowing Entity States to contain two articulated parts for C-DIS in full mode or five articulated parts in partial update mode. Two 5G-ATW messages support fifteen articulated parts in full mode and eighteen articulated parts in partial update mode.

DATUMS

Datums are used to communicate system-specific data that is not of use to all participants or to provide functionality that is not defined within the DIS standard. These are often sent only occasionally and do not contribute significantly to overall DIS traffic. In this case, it is not necessary to compress them. CAF DMO uses the Radar Track Report Datum to provide details about the operation of Active Electronically Steered Antenna (AESA) radars. This Datum is used at rates similar to the DIS Emissions PDU and therefore can be a significant portion of the overall simulation traffic. Because the CAF DMO standard is limited in distribution, C-DIS has a separate extension to the standard that allows the definition of compressed CAF DMO Datums. It currently supports compression of Radar Track Report, Jammer Report, and Jammer False Target Report Datums. It would be possible to create compressed versions of other commonly used Datums that contribute significantly to bandwidth and add them to the C-DIS Datum compression standard.

CAF DMO Radar Track Report Compression Results

Three different approaches to compressing the Radar Track Report were created, each one slightly more aggressive and complex to implement. The results of V1 and V2 are shown in Figure 8. Not shown is V3 which was a slight modification to V2 and estimated to improve compression by approximately 5 percent. The Radar Track Report is relatively large compared to other DIS PDUs. It would take up to seven 5G-ATW messages for standard DIS, while the compressed versions would take a maximum of four. Because large messages like Radar Track Report require multiple messages, their contribution to the total bandwidth is multiplied by the number of message fragments required to pass the data.

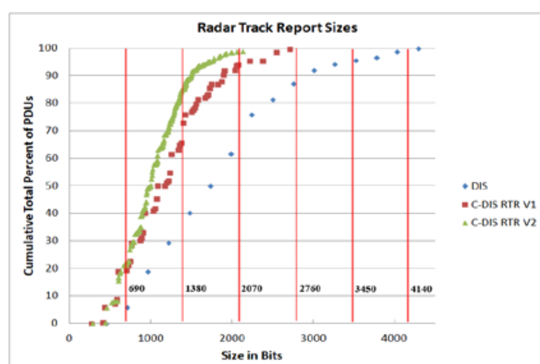

Figure 8. Radar Track Report Message Sizes

Compressions Diminishing Returns

Exact benefits of compression are data-link specific. If the data link is known, then compression might be tailored to reach specific targets (such as 690 bits for 5G-ATW). Sometimes, reaching a particular size is not feasible but, if the link message size is close to the compressed message size, it may be possible. Changes to compression that yield slight improvements in compression ratio are not always helpful unless they reduce a message below a particular bit size that is data-link specific. For 5G-ATW, the goal is to reach sufficient compression to stop packet fragmentation while maximizing the precision of the information passed. Each physical data link will have different critical factors and sizes.

C-DIS STATUS

The C-DIS specification was first created in 2013 for SLATE. The current C-DIS v1.2 specification is an AFRL Government Non-Proprietary standard that currently supports Entity State, Fire, Detonation, Collision, all SIMAN PDUs, Emission, Designator, Transmitter, Signal, Receiver, and IFF Layers 1, 2, 3, 4 & 5. C-DIS v1.2 is an approximately 100-page document (similar to IEEE’s 1278-1.2012 Section 7) that details the DIS PDU contents and contains word descriptions of each field, followed by a table of fields and sizes (as shown in the Entity State example in Table 3). Improvements to v1.0 have increased the fidelity of frequency values and made some slight changes to data items to make the standard more consistent and easier to implement. AFRL intends to propose C-DIS as a SISO draft standard in the future.

AFRL has implemented a C-DIS encoder and decoder that allows either full or partial updates in AFRL's Java-based DIS Filter Gateway for testing and verification purposes. Cubic implemented C-DIS on an embedded processor in the SLATE pod running Yucto Linux and on a standard Windows PC-based ground station. This demonstrates that the standard can be implemented with limited resources for embedded applications, if necessary. An initial, partial implementation was demonstrated by Cubic at I/ITSEC in 2016. Cubic is scheduled to test a full C-DIS 1.2 implementation in the F-15 Boeing Systems Integration Lab with the BigTac™ threat generation system in St. Louis, MO in the fall of 2017. C-DIS will be used for live flight tests with sixteen live aircraft in September 2018.

C-DIS CONCLUSIONS

C-DIS requires additional computations to be performed by the sender to encode data and by the receiver to decode data. This is an appropriate tradeoff when bandwidth is limited. C-DIS relies on standard DIS thresholds and timeouts to reduce message counts. C-DIS helps to support the ability to model AESA radars and advanced Jamming techniques in an LVC environment. It does not address voice or data-link message contents or all Datums, but it does address several CAF DMO Datums that contribute significantly to the DIS traffic load. C-DIS compresses LVC messages by 50–65 percent, allowing more entities, sensors, and more complex interactions to be modeled, leading to improved training. C-DIS allows most messages to fit into the 5G-ATW 690 bit messages, effectively doubling bandwidth compared to standard DIS messages for the SLATE demonstration. C-DIS could be used over any data link or bus where bandwidth is limited, or where message transport size is smaller than standard DIS messages.

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