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**SECURE PERSISTENT LIVE, VIRTUAL, AND
CONSTRUCTIVE OPERATIONAL ALIGNMENT OF
RESEARCH, TECHNOLOGY AND DATA**

**Lance Call
L3Harris Technologies, Inc.**

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Interim Report**

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1.0 EXECUTIVE SUMMARY

Simulation Interoperability Standards Organization (SISO) Compressed Distributed Interactive Simulation (C-DIS) Version 1.0 improves the compression of DIS data compared to the initial Air Force Research Laboratory (AFRL) C-DIS Version 1.2 used in the Secure Live Virtual Constructive Advanced Training Environment (SLATE). This document highlights the changes that were made and summarizes the SISO C-DIS Version 1.0 performance on several different example data sets.

2.0 INTRODUCTION

The SLATE demonstration in 2018 used AFRL C-DIS V1.2 in a Full update mode. Changes and improvements have been made to the C-DIS standard by the SISO Product Development Group (PDG) to more aggressively compress fields and to support a larger range of values. This document summarizes the changes and the improvements in performance of the C-DIS standard.

3.0 C-DIS HISTORY

The AFRL version of C-DIS started in 2013 and was developed with an eye towards the September 2018 SLATE demonstration. After the SLATE demonstration it was decided to nominate C-DIS as a SISO standard in order to make it more widely and publicly available. A SISO PDG was formed at the SISO conference in February 2020. The PDG included representation from Cubic, Boeing, AFRL, Army, and some international partners. The PDG has reviewed two drafts of the standard and is hoping to complete the standard in the 2nd quarter of 2021.

4.0 DIFFERENCES BETWEEN AFRL C-DIS V1.2 AND SISO C-DIS V1.0

In addition to formatting, wording, and organizational changes to the document in order to be consistent with the SISO standard, there were several technical changes and additions made in order to improve performance. These changes were intended to address issues identified in the AFRL C-DIS V1.2 standard and make it applicable to a wider variety of data values and users.

4.1 Variable Integers (VARINT)

The largest change was to add the concept of VARINT that are used in Google's Protocol Buffers. VARINT uses an initial bit or bits as a flag to indicate how many data bits will follow. Using two flag bits allows four different sizes of data, which allows data to use only the required number of bits. In this manner small data values can use a small number of bits while larger values can still be supported. This concept was applied to both unsigned and signed values in C-DIS and was used extensively to reduce message sizes. This concept was used to replace the bit flag that indicated the size of the Site/App/Entity triplet used in AFRL C-DIS V1.2. It compresses a wider range of values than the AFRL C-DIS V1.2 scheme. Analysis was done based on historical DIS recordings to determine VARINT message sizes that provided the highest amount of compression. SISO C-DIS VARINT8s use a single flag bit, while all other

VARINTs use two flag bits. Unsigned VARINTs of UVARINT8/16/32 and Signed VARINTs of SVARINT12/13/14/16/24 bits are defined and used by SISO C-DIS V1.0.

4.2 Partial Updates

SLATE used the Full update mode of C-DIS which means that all required data fields are sent in every frame. Partial updates allow updates with only the data that has changed. Full updates are sent periodically to ensure that late joiners are able to get a full set of data in a reasonable amount of time.

Additional flags were added in the Field Present Flags to allow more fields to be left out of partial updates, making partial updates even more effective. The AFRL encoder was modified to be more aggressive about checking to ensure data values had changed more than the precision supported by C-DIS before providing new data to verify this approach. The AFRL encoder/decoder was used to gather the data in the performance section of this report.

SISO C-DIS more formally defined the C-DIS update rules for partial update mode, and changed the wording used to make it less confusing. Partial Updates are based on a C-DIS Update Multiplier * DIS Heartbeat rate. (Example: 2.4 Multiplier * 5 second heartbeat = 12 second C-DIS Full Update Rate). The C-DIS Update Multiplier default value is 2.4 but may be modified by federation agreement to support different use cases.

4.3 Variable Records

AFRL C-DIS V1.2 did not compress variable records. AFRL added definitions of compressed formats for known Variable Records such as articulated and attached parts in AFRL C-DIS V1.3 and V1.4 which were used in the SISO version. This allows compression of more data. SISO also applied the VARINT concept to these variable records.

4.4 Size Changes

A few C-DIS records were found to be too small to support some desired DIS data in SLATE. For example, some DDCP action request IDs were larger than supported by AFRL C-DIS V1.2. These fields were either increased in bit size or made into VARINTs in SISO C-DIS order to support larger values while still allowing compression for small values.

4.5 Text Strings

The Entity State marking string was changed to use five- or six-bit character representations and a string length to only send the amount of required characters rather than always sending 11 eight-byte characters. Only capital letters are supported.

4.6 Emission Protocol Data Unit (PDU)

The Emission PDU was completely reorganized to provide lists of fundamental data, beam angles and site/app pairs that are then indexed by each beam rather than sending duplicate data in each beam. This can reduce emitter information for complex emitters.

The DIS track/jam list was modified. Radars will not provide the information that is only applicable to jammers. The Emitter Beam/Beam Function enumeration is used to determine if a beam is a jammer or not.

These changes add complexity but can lower the size of Emission PDUs more than the direct approach used in AFRL C-DIS V1.2 particularly for large and complex emissions. Emissions

can make up a large part of the overall bandwidth requirement and therefore it was decided that the additional complexity was acceptable.

5.0 PERFORMANCE

5.1 Interservice/Industry Training, Simulation, and Education Conference (I/ITSEC) 2016 and Combined Scenario Analysis

The performance of the SISO C-DIS version 1.0 is significantly better than the original AFRL C-DIS V1.2. Graphs of the compression rates for two different scenarios (Combined and Thurs AM) used in testing are shown in Figure 1. The top two graphs show the percentage of the original size compared to the original standard DIS PDU and the bottom two graphs show the same information as a compression ratio = 1.0/percent size. The V1.2 ES and SISO ES items refer specifically to the performance of Entity State PDUs while the V1.2 All and SISO All refer to all Live, Virtual and Constructive (LVC) PDUs. LVC PDUs are Entity State, Fire, Detonate, Emission and Identification Friend or Foe (IFF). These are the PDUs that are expected to make up the bulk of the data for LVC, which was the original target for C-DIS compression.

Compression of Entity State PDUs is slightly better than the All LVC PDU case. There is a 6% reduction in PDU size on average for Full update mode and 23% reduction in size on average for the Partial Update mode for SISO C-DIS compared to AFRL C-DIS V1.2. The average SISO C-DIS compression is 40.3%=2.48:1 compression ratio in Full Update mode and 23.2%=4.3:1 compression ratio in Partial Update mode.

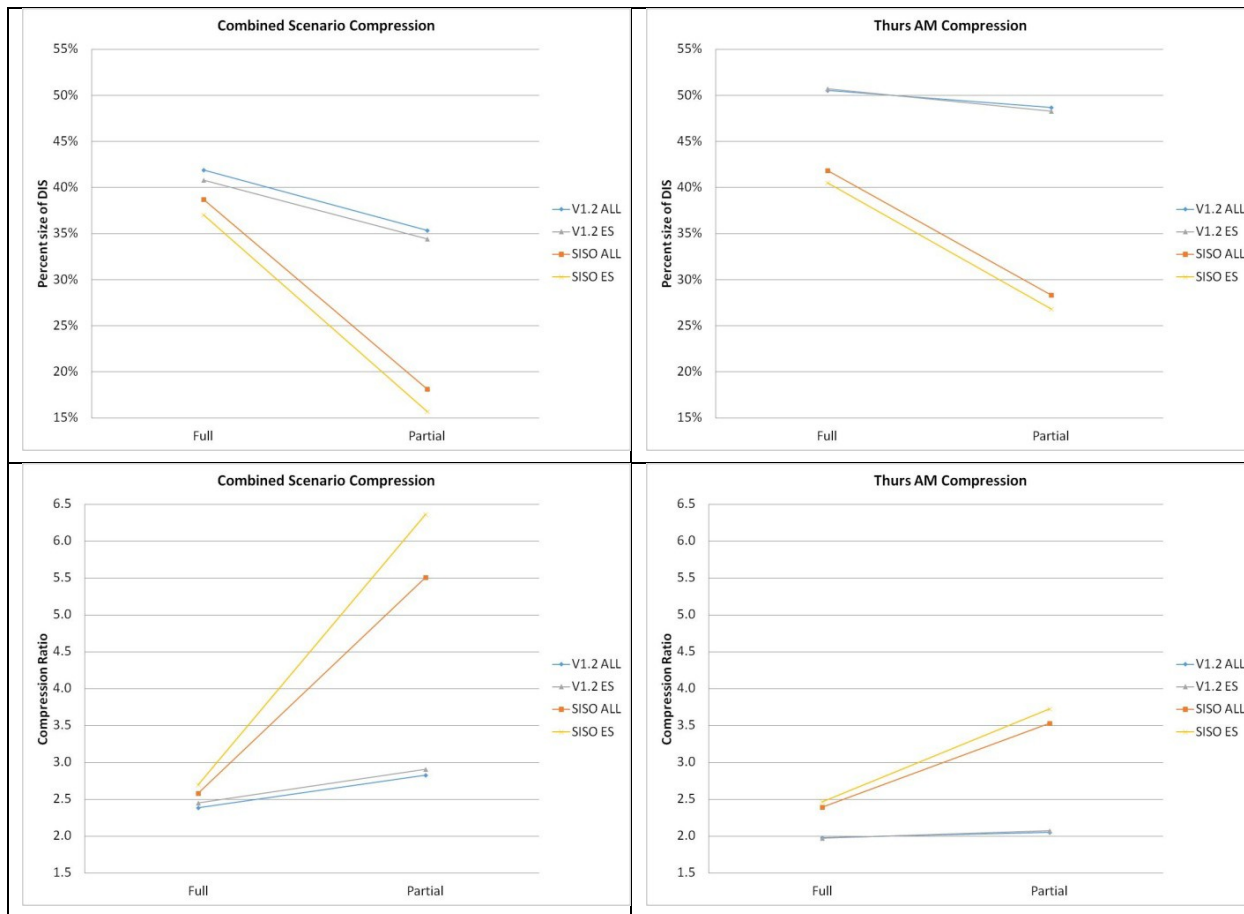


Figure 1 Summary of C-DIS Performance as a Percentage of DIS PDU Size and Compression Ratios.

The Combined Scenario contains 30 minutes of data collected from 5-minute samples of various scenarios to represent a wide variety of data types. One of the scenarios is a large scenario with many static entities, which allows for more compression, especially in the Partial Mode update case. The Thursday AM case is from the 2016 I/ITSEC and is an Air-to-Air scenario with no static entities. This is largely why C-DIS is able to reach compression ratios of nearly 6.5 for the Combined case, while only being able to reach 3.7 for the Thurs AM sample. Note how the partial cases can reduce traffic dramatically compared to the Full update mode. The slope of the lines show that SISO C-DIS is more aggressive and successful at reducing the sizes in partial update mode compared to AFRL C-DIS V1.2. The graphs also highlight how the makeup of the data, as indicated by the two different scenarios will affect the amount of compression that is possible.

Figure 2 and Figure 3 show the actual packet sizes compared to the percentage of all of the PDUs in the scenario. This shows that nearly 100% of the PDUs in both scenarios are less than 768 bits. 92% of PDUs in the Combined scenario and 72 % of the PDUs in the Thurs AM scenario are less than $768/2 = 384$, which would possibly allow packing two messages into a single 5G-Advanced Training Waveform (ATW) 768 bit message. Bit count breakpoints for two Messages (384 bits), three Messages (256 bits), and four Messages (192 bits) are shown on both graphs for

reference. If a message is less than 576 bits then 5G-ATW is able to use a higher encoding rate for the data, which allows receivers to more effectively receive the data. This higher encoding rate adds approximately 3dB to the link margin. Over 95% of all messages using SISO C-DIS are less than 576 bits.

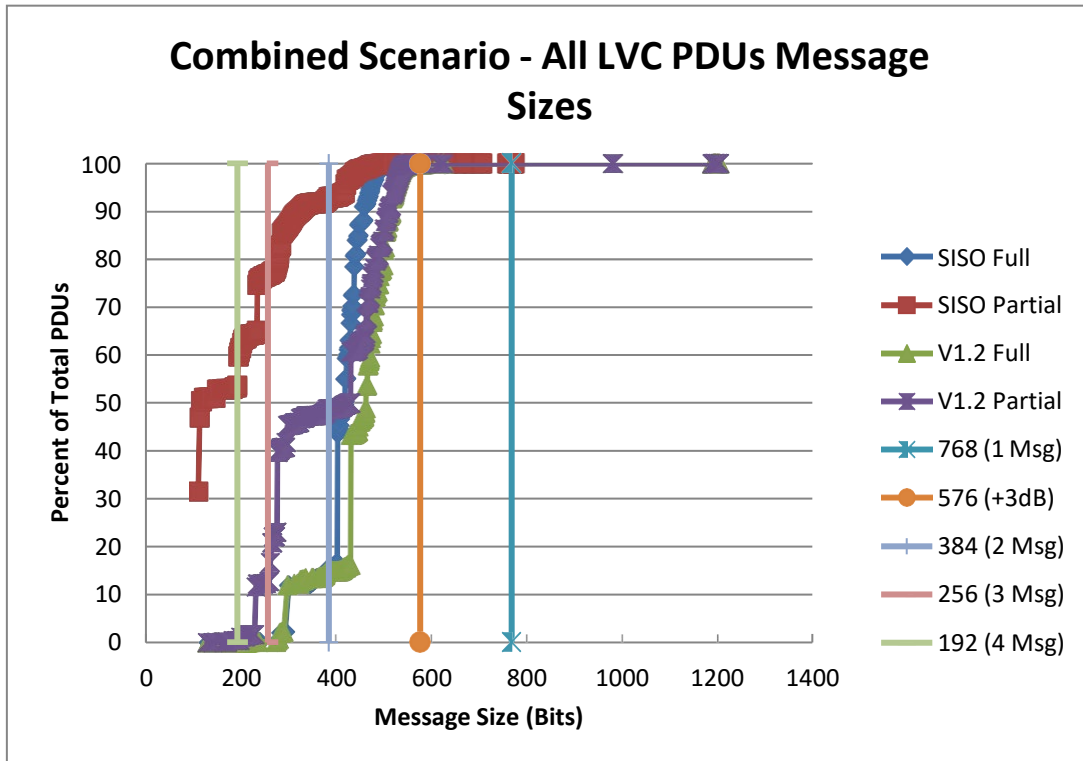


Figure 2. Packet Sizes for the Combined Scenario

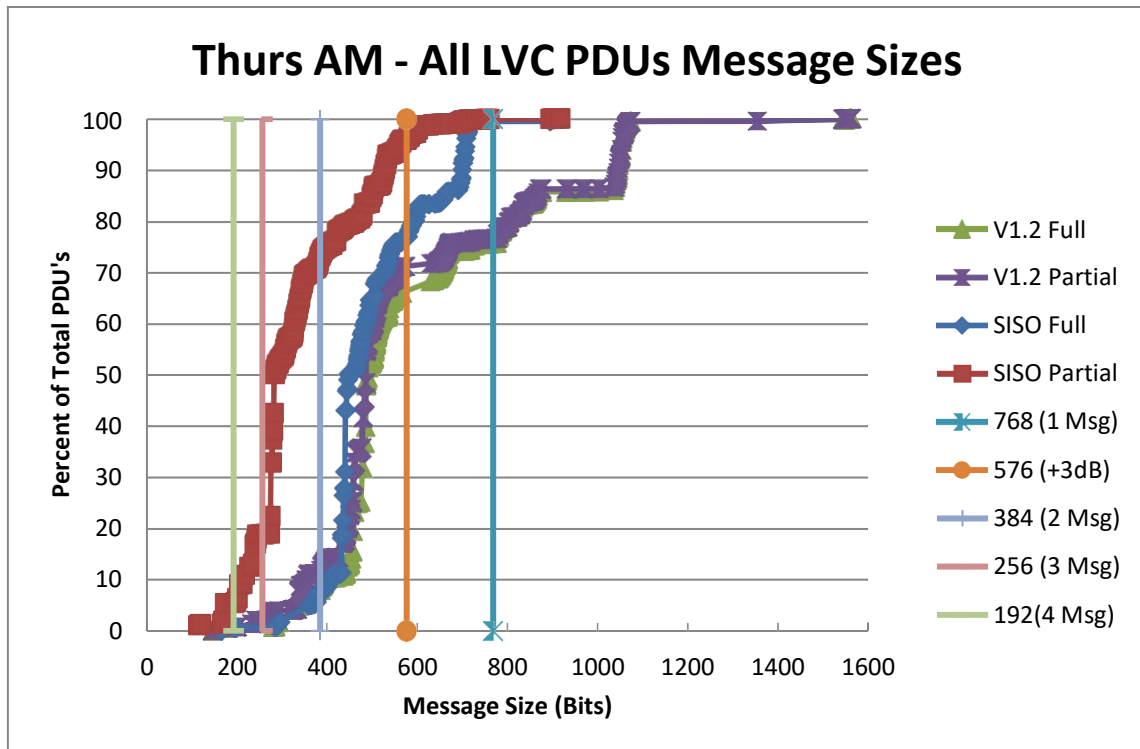


Figure 3. Packet Sizes for the Thurs AM Scenario.

These results suggest it would be very helpful if 5G-ATW systems could have the capability to pack multiple messages into a single packet. The question then remains, what scheme should be used to decide to pack multiple messages together? Option 1 would be to wait N milliseconds for a second message before sending the initial packet. This would preserve network bandwidth but add some latency, so this should be a small number, perhaps 5ms. Option 2 would be to only multipack if multiple messages are buffered and waiting to send which would avoid latency for messages when no data is buffered. This would not be quite as efficient on the network as Option 1. This function could be done in different points in the transmission process. Different solutions may need to be examined.

There are many different possible combinations of packet sizes, and they are not guaranteed to have four small messages together. The most likely possibility is to have two messages that fit into 768 bits. Analysis could be done to determine the most likely combinations of sizes within a given time frame to determine how many simultaneous messages are likely to occur. If messages are spread out in time then multi-packing will not be an effective strategy. The primary nodes where a link is highly loaded and where data may be close together are probably the ground uplink that is sending many entities and systems up to the jet, or on an aircraft (A/C) that is generating constructive entities from within the pod/Line-replaceable Unit (LRU).

Figure 4 shows a histogram of the number of messages as a percentage of all messages that occur within a 5ms window in the Thurs AM scenario. 57% of the time there is only one message, but about 23% of the time there are two messages, 10% of the time there are three, and 5% of the

time there are four messages. This analysis is based on trying to send all of the data in Thurs AM from a single transmitter as would occur if uplinking this scenario to live aircraft.

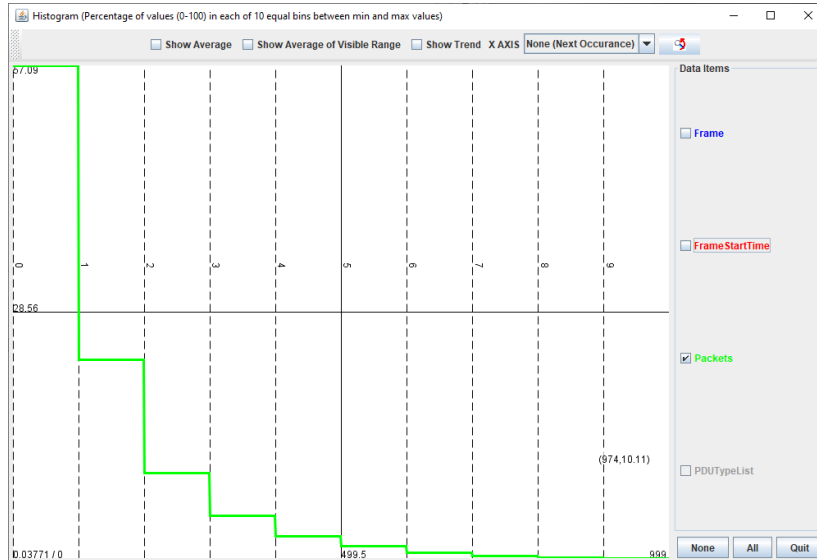


Figure 4. Thurs AM Histogram of Packet Count per 5ms Window.

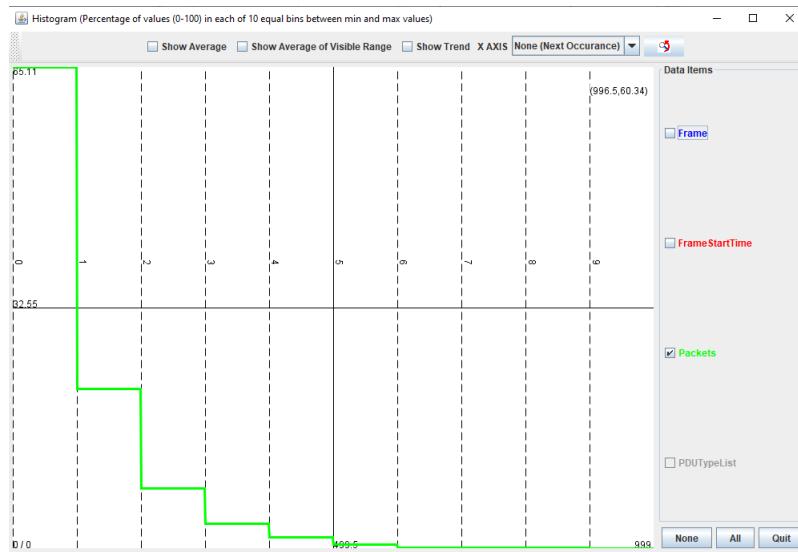


Figure 5. Thurs AM Histogram of Packet Count per 1ms Window.

A histogram with a 1ms window shows almost exactly the same distribution. Single PDUs only increase about 8%. This suggests that a 1ms wait time would be just as effective as 5ms and would only increase latency by 1ms.

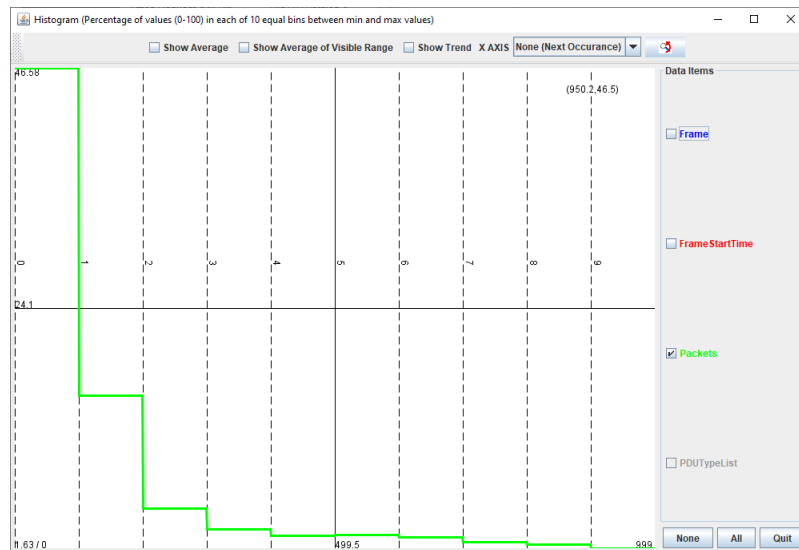


Figure 6. Combined Scenario Histogram of Packet Count per 5ms Window.

In the Combined Scenario 47% have one packet, 16% have two packets, 5% have three packets, and 3% have four packets that fall within a 5ms window.

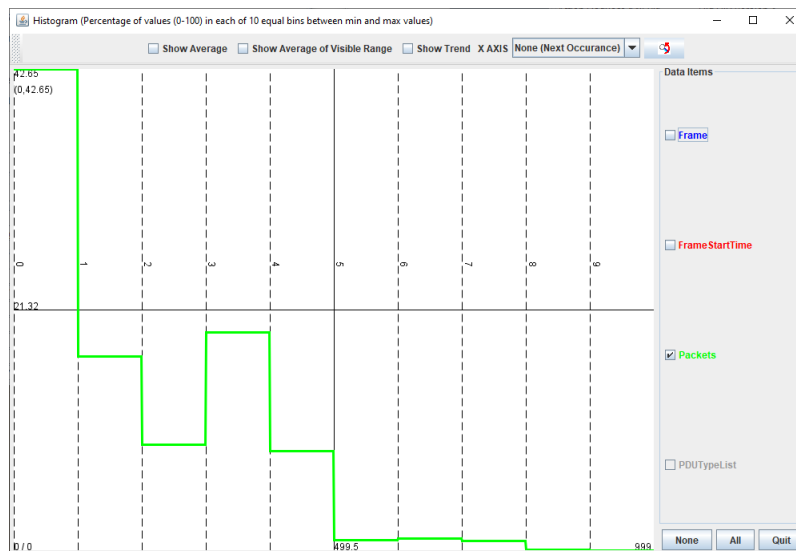


Figure 7. Combined Scenario Histogram of Packet Count per 1ms Window.

In the Combined Scenario 43% have one packet, 17% have two packets, 9% have three packets, and 19% have four packets that fall within a 1ms window. It is interesting that in this case there are more occurrences of four packets per 1ms window than two or three. This suggests that an application is sending four simultaneous packets.

This analysis is able to count packets, but it does not say what size each of those packets are. That would require additional software development to see if the packet sizes within a window are less than 768 bits.

5.1.1 Alternative to Multiple Message Packing

The MIT Lincoln Labs proposed an alternate approach to Multi-packing messages. A smaller frame equal to 1/2 of the current 768 bits could be defined in the waveform. This would allow the message to use half of the data messages while still maintaining the same coding rate used by existing messages. This would require four sync bits and eight data messages rather than four sync bits and sixteen data messages. This would allow a transmitter to send $(4 \text{ sync} + 16 \text{ data}) / (4 \text{ sync} + 8 \text{ data}) = 1.6$ times more messages per second because of the fewer number of data messages. The transmitter used by SLATE that sent 200 full size messages would be able to send $200 * 1.6 = 320$ small messages per second. Not all messages will be small, so the total number of messages would depend on the ratio of small and normal size messages that need to be sent.

Alternately the small messages could be distributed over the full 20ms 5G-ATW frame to reduce the density of data (12pulses/20ms vs 20pulses/20ms) and interference while maintaining the current number of messages per second.

Increasing the encoding rate of data packets does not affect the encoding rates of sync pulses. Performance of the whole system is not increased if data packets are encoded at higher rates while sync pulses remain at the same encoding rates. This means that the small message definition approach is better than the high encoding rate approach previously discussed.

The small message definition may be more feasible than the multi-packing approach previously described, and would incur no latency penalty.

Both the Multi-packing and small message definition approaches would require software updates to the existing 5G-ATW radio.

5.2 SLATE Data Analysis

The DIS logfiles from the SLATE demonstration on 12 September 2018 were analyzed to evaluate the C-DIS performance of the V1.2 Full update mode that was used during this LVC demonstration and compare that to the V1.2 Partial mode as well as the new draft SISO standard C-DIS V1.0 operating in both Full and Partial update modes. The purpose of this comparison is to evaluate the changes that have been made in the SISO standard, and to verify that they are effective with the best set of LVC data available to us.

The SLATE demonstration had 8 Live F-15 aircraft, 8 Live F-18 aircraft, 2 Virtual F-16s, 2 Virtual F-18s, 11 constructive aircraft, 7 Surface-to-Air Missiles (SAM), 4 AAA and 6 ground vehicles. Weapons and sensors were modeled for all but the 6 ground vehicles.

Analysis was done on four test cases.

1. All LVC PDUs (All)
2. LVC PDUs with all DATA PDUs filtered out since some of these DATA PDUs are not necessary for LVC. This most closely matches the set of PDUs used in the IITSEC 2016 and combined scenario analysis for comparison purposes. (No Data)
3. Only Entity State (ES) PDUs)
4. Only Emission PDUs (Emit)

The same data will be presented for each of these four test cases. Full indicates Full update mode that requires all data be sent every update but in smaller form and Partial indicates Partial update mode where only data that changes is sent.

Figures 8 and 9 summarize the results. Figure 8 shows the data as a percentage size versus standard DIS and Figure 9 shows the compression ratio = 1/percent. The scales are the same as the previous analysis graphs so that they can be directly compared. Each of the four cases was assigned a color to make association on the graphs easier. V1.2 cases have colored squares and SISO cases have colored circles.

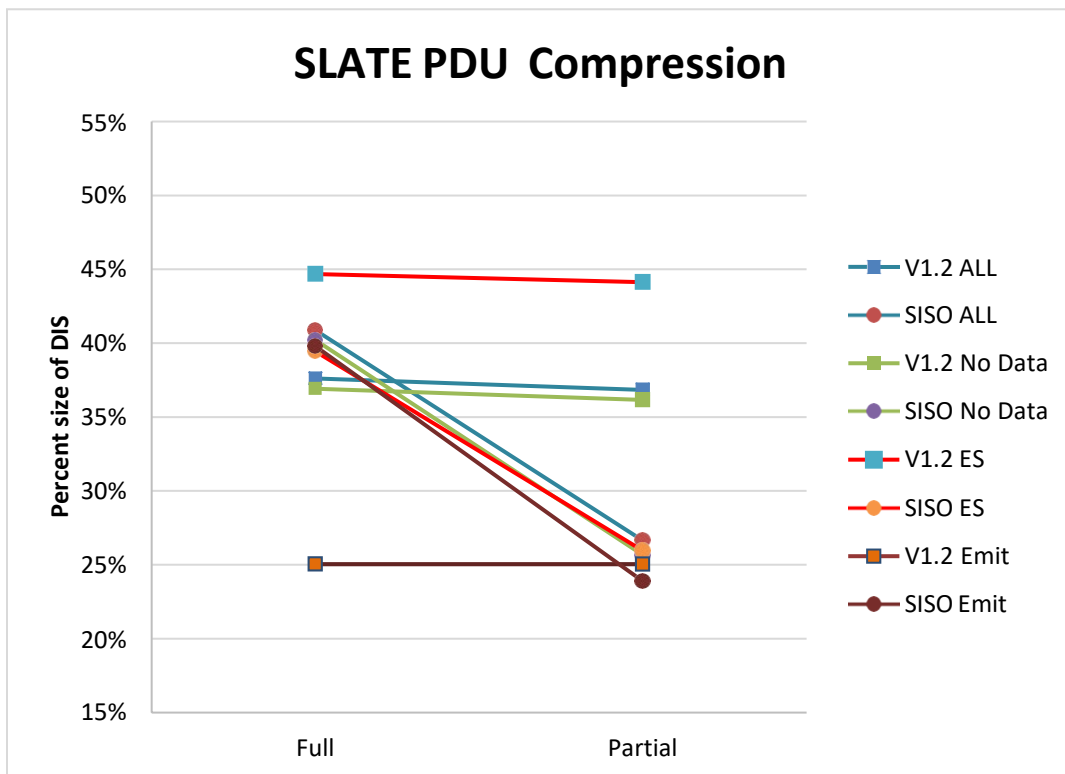


Figure 8. Compression Percentages for C-DIS vs. Standard DIS.

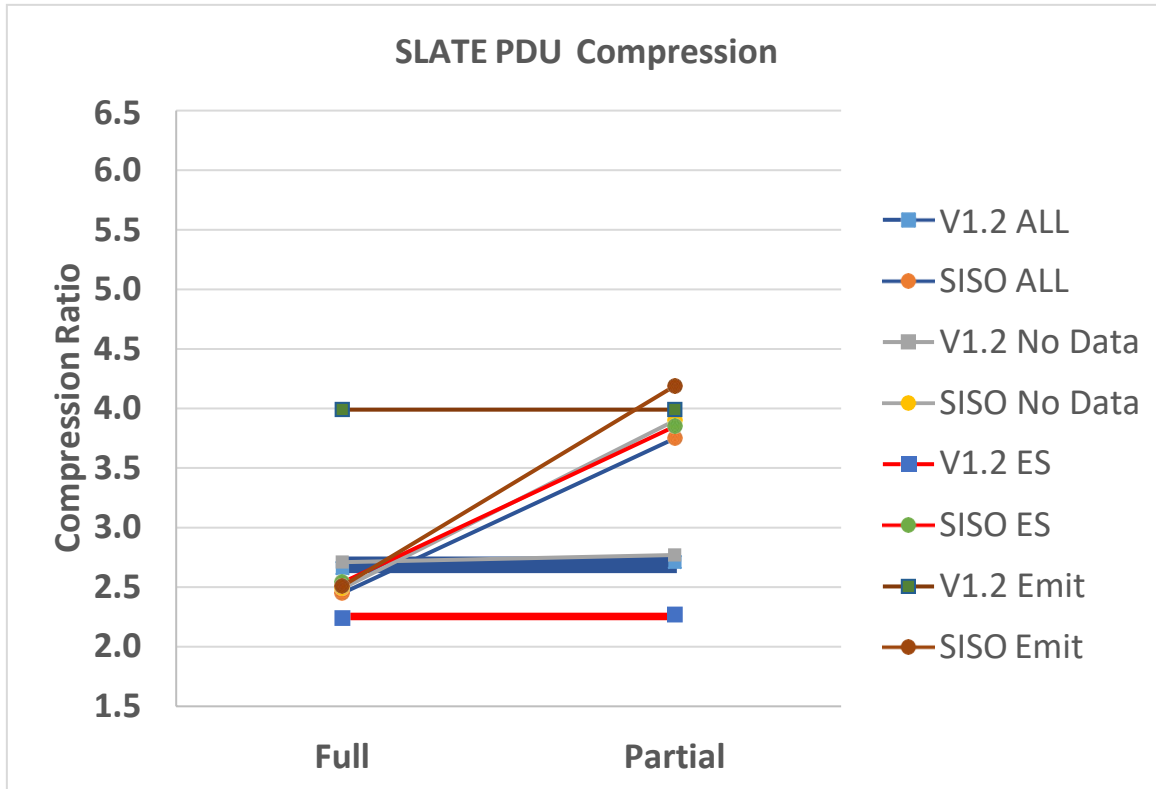


Figure 9. Compression Ratios of C-DIS vs. Standard DIS.

The main takeaway of these charts is that in C-DIS V1.2 the full and partial modes were very close to the same compression (as indicated by the horizontal lines), while in the new SISO C-DIS the partial updates show significantly more compression as indicated by the steeply sloping lines. This means that users can achieve much better compression using partial update modes. Another take away is that in SISO the compression ratio for all cases (All, No Data, ES, and Emit) are all clustered around 2.5:1 and then increase to around 4:1, while in C-DIS V1.2 the differences in each case are higher. This means there is now more consistent compression on more types of records. The one outlier is that C-DIS V1.2 emission in full mode compresses at a rate of 4:1 compared to only 2.5:1 for SISO. This means that the old way of compressing emissions is more efficient for simple emissions than the more complex SISO approach for emissions. The SISO approach however beats the V1.2 Partial update mode and will compress complex emissions better than the old approach. In general, SISO compresses a wider variety of data in a more consistent fashion.

5.2.1 All LVC PDU sizes (All)

Figures 10 and 11 show how using the new SISO C-DIS in partial update mode 98.6% of all messages are less than 768 bits, and 84.2% are less than 384 bits which is $\frac{1}{2}$ of a 5G-ATW frame. This suggests that it would now be sometimes feasible to pack two messages into a single 5G-ATW message. In reality this can only happen if multiple messages occur within an amount

of time that would be acceptable from a latency perspective, but in periods of high loading packing multiple messages into a single frame may be an option worth exploring. Many more messages will be able to use the higher rate encoding providing effectively a 3db signal gain.

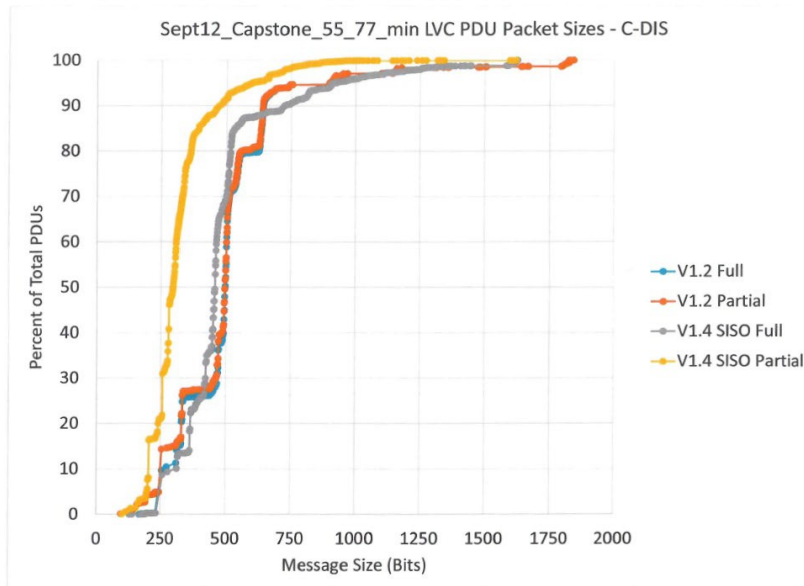


Figure 10. All LVC PDUs Message sizes with Normal Scales.

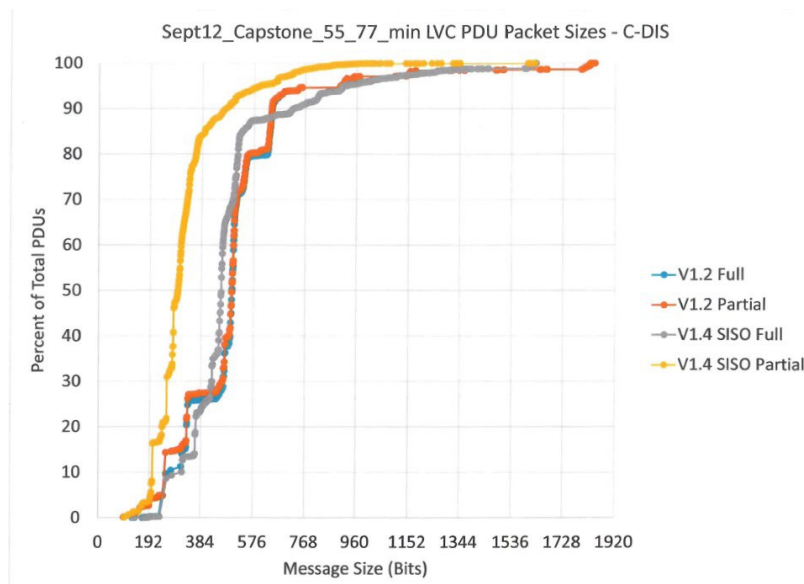


Figure 11. All LVC PDUs Message sizes with 5G-ATW frame Size Scales.

5.3 All LVC PDUS Except Data (No Data)

Figures 12 and 13 show All LVC PDUs except Data. Removing the Data PDU had little effect on packet sizes. While there were Radar Track Reports in these Data PDUs none of them had a full set of Radar Track Report data and therefore didn't affect the compression data in any major meaningful way. In the future when Radar Track Reports are fully filled out then they are expected to become a much larger percentage of the overall bandwidth and will affect the PDU sizes in a major way. C-DIS does specify compression for these SISO specific messages, but they are not publicly releasable like the rest of the SISO C-DIS Standard.

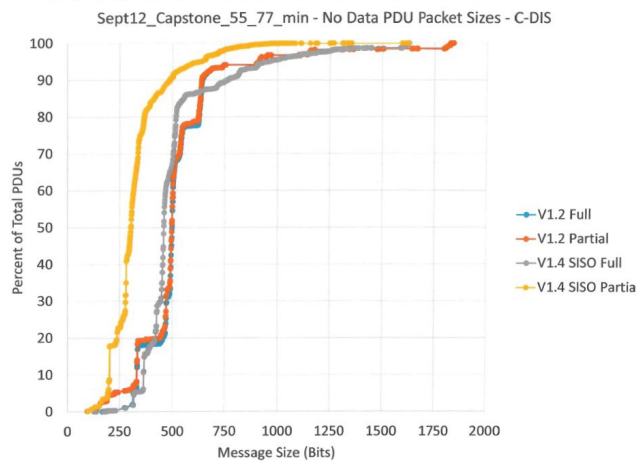
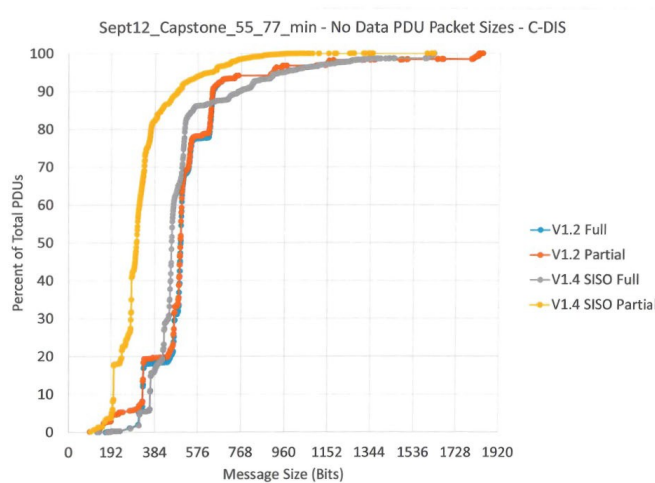


Figure 12. All LVC PDUs Except Data PDUs Sizes with Normal Scales.



All LVC PDUs Except Data PDUs Sizes with 5G-ATW Frame Size Scales.

5.3.1 ES PDU Sizes

The ES PDUs in Figures 14 and 15 show the most dramatic improvement from C-DIS V1.2 to SISO. There is an 18.7% decrease in size, and the number of Entity State messages that are smaller than 384 bits increases from around 5% all the way to around 97%. Since Entity State messages make up a large percentage of the message traffic it means that packing multiple messages into a single 5G-ATW frame may significantly decrease the required bandwidth.

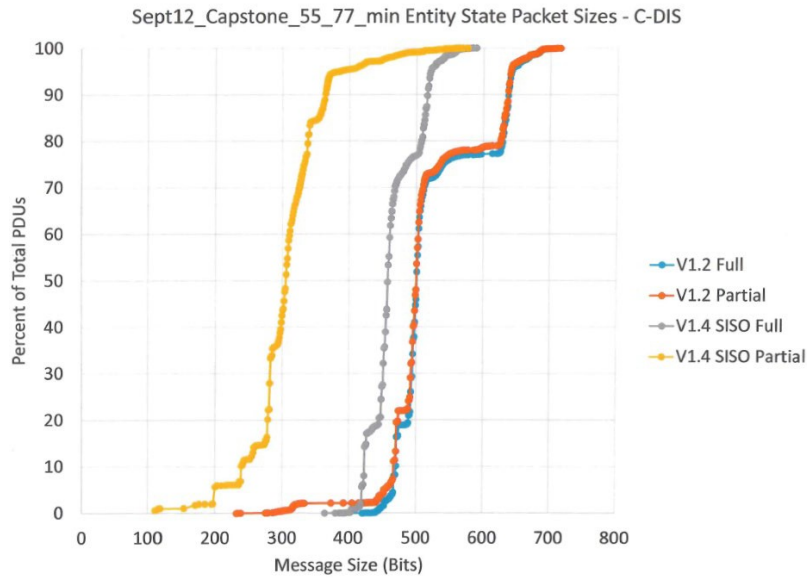


Figure 13. ES PDU Message Sizes with Normal Scales.

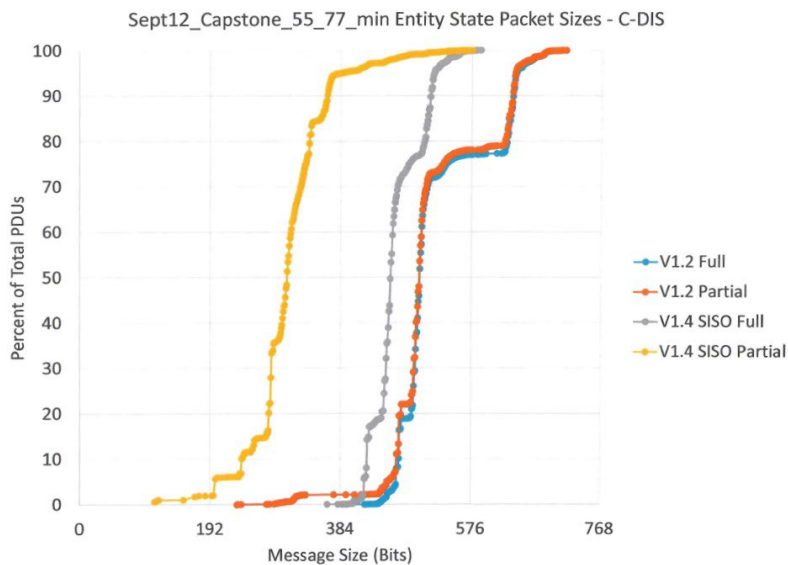


Figure 14. ES PDU Message Sizes with 5G-ATW Frame Size Scales.

5.3.2 Emission PDU Sizes (Emit)

Emission PDUs shown in Figures 16 and 17 were the only message where the SISO version increased the message sizes significantly compared to V1.2. This is because the simpler approach in V1.2 and Site, App, Entity (SAE) Values used in SLATE were a perfect match for V1.2, however the new SISO approach will compress a much broader range of SAE values and therefore be applicable to a larger range of use cases. In Partial mode SISO was still more effective. This illustrates the importance of using the Partial mode rather than the simpler Full update mode.

In all of the data analysis the number of different sizes of message increases in the SISO version going from around 150 different sizes in C-DIS V1.2 to over 850 different observed sizes in SISO, and partial updates also increases the number of different sizes observed. This means that the SISO version is making lots of small adaptations to each PDU resulting in a larger number of observed PDU sizes. This has no practical effect but does illustrate how the SISO version is making small and variable changes to each message type to achieve the most compression possible.

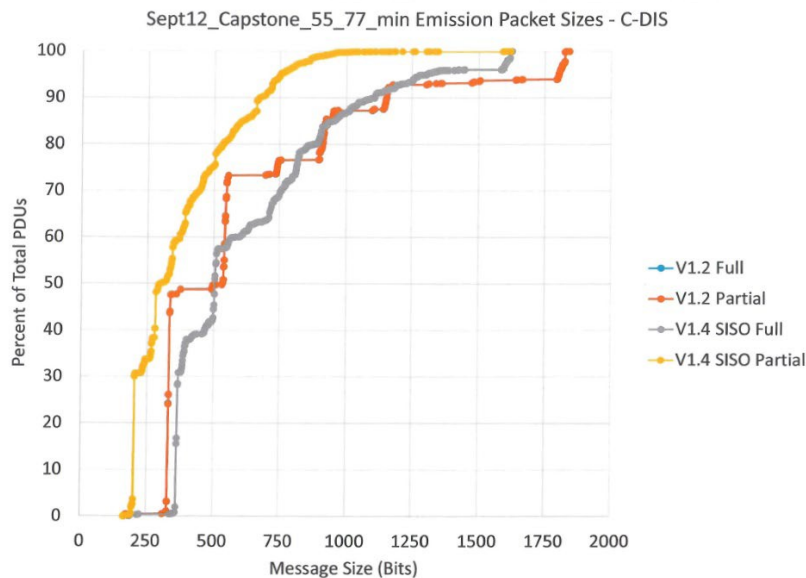


Figure 15. Emission PDU Message Sizes with Normal Scales.

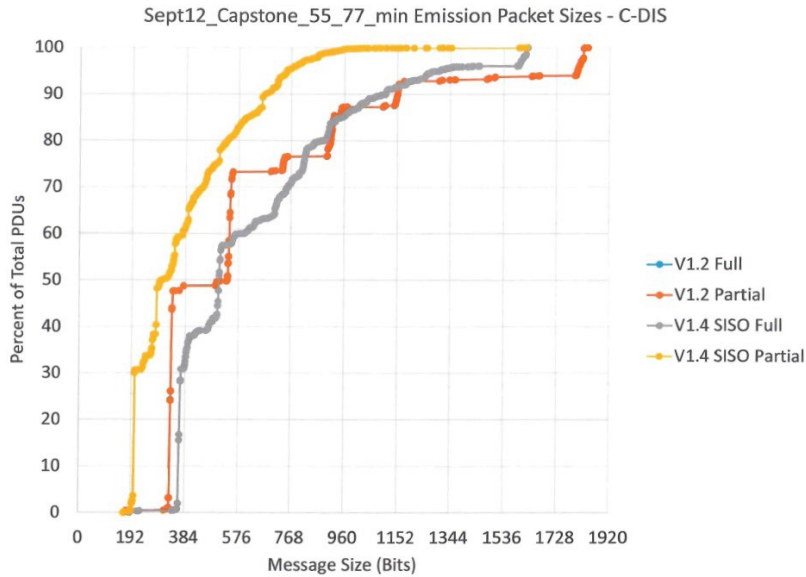


Figure 16. Emission PDU Message Sizes with 5G-ATW Frame Size Scales.

6.0 CONCLUSION

SISO C-DIS V1.0 provides significantly higher compression rates than AFRL C-DIS V1.2. Partial Update mode compression rates have particularly increased and would be the desired mode of operation. Use of VARINTs has allowed compression while still allowing support for a wider range of values that make C-DIS more useable in a wider variety of use cases. When using Partial update modes packet sizes are small enough to potentially combine multiple messages into a single 5G-ATW 768-bit frame.

LIST OF SYMBOLS, ABBREVIATIONS, AND ACRONYMS

A/C	Aircraft
AFRL	Air Force Research Laboratory
ATW	Advanced Training Waveform
C-DIS	Compressed DIS
DIS	Distributed Interactive Simulation
ES	Entity State
IFF	Friend or Foe
I/TTSEC	Interservice/Industry Training, Simulation, and Education Conference
LRU	Line-Replaceable Unit
LVC	Live, Virtual, and Constructive
MIT	Massachusetts Institute of Technology
PDG	Product Design Group
PDU	Protocol Data Unit
SAE	Site, App, Entity
SAM	Surface-to-Air Missile
SISO	Simulation Interoperability Standards Organization
SLATE	Secure Live Virtual Constructive Advanced Training Environment
VARINT	Variable Integer