SMART DATA SELECTION

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ABSTRACT

The fundamental precept presented in the *iNET Concept of Operations, v. 2007.1* is that new telemetry technologies must be created to enable a more flexible approach to testing that includes on-demand access to information acquired on the test article and the ability to reconfigure the telemetry stream definition. Significant advances have been made in this area but one approach that has not yet been addressed is a concept introduced early within the iNET CONOPS document, that

> *"The dominant inherent nature of TM in DoD testing is sampled time-history data from an ultimately analog world, (which) is not going to change drastically regardless of how data is transmitted to ground. A factor that could change that fact most is the degree to which* ***answers*** *instead of data are obtained on board the test vehicle."*

Ultimately, the most effective way of dealing with the exponentially growing gap between the quantities of data generated onboard the test article and the rate at which it is transmitted to ground is to generate answers on board the test article. The Test Resource Management Center (TRMC) Test and Evaluation (T&E) Science and Technology (S&T) Spectrum Efficient Test (SET) Program is sponsoring development of the Smart Data Selection (SDS) system which provides a capability to continually monitor measured data and then select which parameters, or which combination of parameters, to send to ground in a given time interval, based on what is actually happening with the system under test.

This paper will describe the SDS system architecture and the specialized algorithms developed to analyze and determine which data to transmit from the test article to the ground. This paper will also describe the training methods which allow the SDS system to "learn" which behaviors are "normal" and which are "abnormal". Finally, this paper will provide analysis results to substantiate the savings in bandwidth, simplified pre-test setup, and increased operator awareness.

The benefits of this work, in terms of efficient use of spectrum to support T&E are substantial, and they could be leveraged by any DoD ranges that execute aeronautical and precision-guided munitions testing.

INTRODUCTION

The fundamental precept presented in the *iNET Concept of Operations, v. 2007.1* is that new telemetry technologies must be created to enable a more flexible approach to testing that includes on-demand access to information acquired on the test article (TA) and the ability to reconfigure the telemetry stream definition. Significant advances have been made in this area by both the iNET and T&E S&T SET programs. One area that has not yet been addressed by these programs is a concept introduced early within the iNET CONOPS document, that

> *"The dominant inherent nature of TM in DoD testing is sampled time-history data from an ultimately analog world, (which) is not going to change drastically regardless of how data is transmitted to ground. A factor that could change that fact most is the degree to which* ***answers*** *instead of data are obtained on board the test vehicle."*

Ultimately, the most effective way of dealing with the exponentially growing gap between the quantities of data generated onboard the test article and the rate at which it is transmitted to ground – even with advancements brought forth by iNET – is to generate answers on board the test article. The Smart Data Selection (SDS) project is focused on developing a capability that will begin to do just that. The SDS capability continually monitors measured data and then selects which parameters, or which combination of parameters, to send to ground in a given time interval, based on what is actually happening with the system under test. This capability is not intended to replace the existing telemetry paradigm, as some parameters such as safety related data must always be sent to ground. Rather, SDS will augment current approaches to telemetry, and opens the door for an order of magnitude more spectrum efficiency in terms of sending actionable information/sec/Hz to ground.

Fundamentally, our approach uses onboard processing prior to transmission to reduce the volume of data that must be transmitted from the test article. Rather than sending all measured data points, the SDS system can send the results of various types of data analysis, resulting in a significant savings in spectrum. In addition, the SDS system plans to employ a combination of mathematical models and neural network techniques to predict which combination of parameters should be sent to ground based on the actual status of the system under test. SDS provides additional reductions in required bandwidth, simplified pre-test configuration, and provides greater operator awareness of system anomalies. Critical data, such as range safety data, will be sent to ground continually without interruption, and at the same time, transmission of lower priority items will be optimized.

This paper describes the SDS system architecture and the development of specialized algorithms to analyze and determine which data to transmit from the test article to the ground. This paper also describes the training methods which allow the SDS system to "learn" which behaviors are "normal" and which are "abnormal". Finally, this paper describes the test and demonstration approach which will identify the savings in bandwidth, simplified pre-test setup, and increased operator awareness. The SDS project is on-going and will be performing the described tests and demonstrations during the summer of 2013. The results of these tests and demonstrations will be presented at the International Telemetering Conference in October 2013.

TECHNICAL CHALLENGE

This effort presents a number of significant technical challenges, all of which are related to the problem of analyzing data onboard the test article, in real-time, to derive meaningful information about system trends, and more importantly, to learn and predict which behaviors are "normal" and which are "abnormal". The current State-of-the-Art in telemetry does not come close to having this capability. Nonetheless, the potential benefits of this high-risk, high-return activity, in terms of bandwidth savings (more than an order of magnitude), simplified pre-test setup of telemetry systems, and in increased operator awareness, are significant. However, employing mathematical modeling and neural network techniques to analyze onboard data to autonomously determine which data are transmitted to ground is undoubtedly a challenge. We must properly select data characteristics, develop algorithms for "learning" from data monitoring, and develop a system that can recognize patterns, both good and bad, while ensuring transmission of all critical data.

LEARNING BEHAVIORS

The purpose of the SDS effort is to attempt to eliminate the need for manual configuration of the telemetry stream and to instead train the system to determine which parameters are most important for transmission, based on real-time performance. To support this, new technologies that "learn" data behaviors and provide alerts to system users must be developed. The SDS project is considering several technologies to support the SDS capability. The following technology options are being evaluated for their ability to meet system requirements. It is important to note that it is assumed that the commutator system onboard the test article is "dynamic" and has an ability to change the telemetry stream definition based on information it receives from the SDS system.

- Data Representation
  Analysis of the behavior of data items over time will allow the SDS system to queue the commutator system onboard the test article with the results of the analysis rather than the entire set of individual data points. This will result in substantial bandwidth savings and will provide a more useful display of data values for test operators. As shown in Figure 1, the data analysis display graph describes the evolution of the data item over time by including its average and various envelopes. This example shows the full and the 95% envelope.

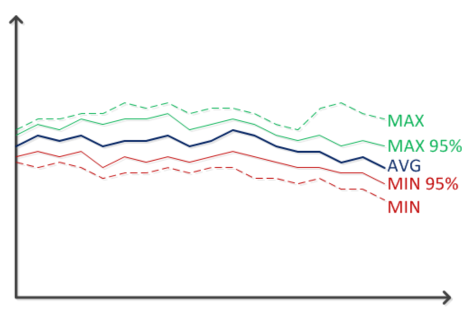

Figure 1. Display of Data Analysis

- Data Item Real-Time Monitoring
  The behavior of the various data items will be continuously monitored. The SDS module will calculate values that include average, variances, distributions, derivatives, etc. of the individual parameters over time. If significant or rapid changes are detected, this may signal a change in the status of the data item being measured, and in response, the SDS module will notify the commutator system onboard the test article to change the transmission rate of that parameter. The test operator will also be notified in the event of any significant changes in data values.
- Analysis of Previously Recorded Exercises
  Analysis of previously recorded exercises will allow the SDS module to understand the expected behavior of the various measured parameters over time. If the analysis identifies time intervals in which the behavior of data items is different from the other time intervals, the SDS system will ask the test operator to classify this behavior. Behavior classified as abnormal can be configured to ultimately trigger an increased transmission rate for the data item. The information collected during the analysis of previously recorded exercises provides input for the real-time monitoring capability described above.
- Neural Networks
  Neural networks have often been used to simulate learning by computer systems. The combined use of mathematical models and neural networks to evaluate the behavior of the various data items under test will provide the synergy required to obtain a truly useful tool to monitor the behavior of the test article during an exercise. The use of neural networks will be especially beneficial when analysis of the test article behavior requires correlation between multiple data items, for instance to distinguish between changes in the data items due to a normal maneuvers and changes due to a failure.

CONCEPT OF OPERATION

The following scenario highlights key features of the SDS system and illustrates how SDS is used in a test scenario to increase operator awareness with minimal user intervention and efficient use of bandwidth. During the exercise, SDS subscribes to all the TmNS Messages carrying measurements that are generated on the TA, extracts the individual measurements from the messages, and analyzes them with its pattern recognition algorithms.

In this example the SDS operates on the test article in conjunction with a dynamic commutator, i.e., in conjunction with a commutator that can dynamically adjust the subset of the measurements generated on the TA that are actually transmitted to the ground and that accepts external requests to modify the subset of transmitted measurements. Also, the TA has an Ethernet data bus and uses the iNET TmNS Message format. It is further assumed that the fuel pump subsystem is considered operational and therefore (in order to save bandwidth) summary measurement information is sent to the ground at the start of the test. Timestamps in the scenario are only for illustrative purposes.

15:02:05.153 pm	The SDS algorithms detect an abnormal pattern in the measurement representing the temperature of Fuel Pump 2 (the temperature has increased by an average of 1.4 F per second over the last minute).
15:02:05.200 pm	The SDS sends a request to the dynamic commutator on the TA to transmit to the ground the TmNS Package and/or TmNS Message including the Measurement of the temperature of Fuel Pump 2.
15:02:05.205 pm	The SDS generates a TmNS Message including an alert message stating that since 15:01:05.141 pm the temperature of Fuel Pump 2 showed an abnormal behavior: average raise of 1.4 F per second.
15:02:05.525 pm	The SDS Alerts Display on the ground shows the alert regarding the temperature of Fuel Pump 2.
15:02:06.015 pm	The dynamic commutator starts transmitting to the ground the TmNS Packages and/or TmNS Messages including the measurement of the temperature of Fuel Pump 2.
15:02:06.318 pm	The ground system starts receiving measurements about Fuel Pump 2, including its temperature.
15:02:11.125 pm	The ground operator assigned to monitor the SDS Alerts Display requests a display to show the available data from Fuel Pump 2. The ability to request the display of selected measurements is assumed to be supported by the ground system that works with the dynamic commutator/decommutator system and is not part of the SDS project.
15:02:41.318 pm	After monitoring the measurements from the Fuel Pump 2 the operator confirms that something is not functioning properly and decides to notify the exercise manager of the problem.

A potentially dangerous malfunction in a TA subsystem was quickly detected without consuming any bandwidth during normal operations and with minimal operator oversight.

TRAINING, TESTING, AND DEMONSTRATION

The Smart Data Selection module is a software library that can be integrated into any dynamic "commutation" mechanism onboard the test article. By this we mean any system capable of dynamically changing the telemetry stream definition during a test. The SDS module will continually monitor data on the TA network bus, perform analysis functions, and notify the dynamic commutator system of the need to change which parameters are sent to ground and at what rates. This is complementary to the decisions the commutator system is already making, and is independent of critical parameters, such as safety-related data, that are continually transmitted to ground. The following sections describe the training, testing, and demonstration approach for the SDS project.

TRAINING

One of the new key concepts provided by SDS is the ability to "learn" to recognize abnormal behavior of systems monitored by SDS. This learning process is composed of multiple elements.

Here are a few examples of mechanisms through which SDS can learn normal and abnormal behaviors of the system under test:

- Automatic Alert
  This category includes situations that would immediately trigger the attention of an test operator, such as:
  a. Sudden changes in the value of data: What triggered the change?
  b. Constant data: Is the sensor actually working?
  c. No data: Again, is the sensor working?

  These basic rules will be adjusted based on the analysis of previously recorded data; for instance, if the previous recordings are deemed "normal", the SDS will adjust the thresholds for these rules to avoid triggering any alert. Similarly, if the previous recordings include abnormal values the thresholds will be adjusted to ensure that a corresponding alert is triggered.
- Expected Behavior
  If specific information about the parameters to be measured is known and defined in a format that is readable by SDS, as is the case with the iNET Metadata Description Language (MDL), the SDS can predict certain types of behavior. For example, if an MDL file describing the measurements includes the type of units, SDS can automatically detect the type of the measurement and some of the typical behavioral characteristics. .
- Correlations
  Often, some actions by the operator (or control systems) may trigger sudden changes in the value of some data. During its training, the SDS system will attempt to detect correlations between events in the data. If correlations are detected, the SDS system will prompt the operator to indicate whether it is "normal", as in the circumstance in which one normal event triggered the other, or whether there is an "abnormal" situation involving multiple sensors.

The effectiveness of the SDS training clearly depends on the quality of the test data available to train the system. The most effective training data sets consist of a large number of recordings that include both nominal and abnormal measurements. Ideally, data sets include live recordings from previous exercises, or data generated by simulation. In addition, it is important that test data used for training are grouped by the type of the test during which they have been collected, and not only by the type of the Test Article from which they have been collected. This is important because many measurements will have different behavior depending on the test being performed. Correspondingly, in an operational situation, SDS must know the type of test being performed in order to apply the proper processing criteria.

TESTING

Once training of the SDS is completed, test engineers will run the SDS through a series of pre-flight tests to verify its ability to detect abnormal measurements. Ideally, the test data sets used to verify that the SDS can accurately detect abnormal events will be from the same Test Article as was used to train the SDS system, but different data sets should be used for training and testing of the SDS system. The ability of SDS to detect abnormal situations and the absence of "false abnormal" indicators will provide an assessment of the performance of SDS.

The SDS system under test will consist of two components:

- A TA component responsible for monitoring the measurements and generating appropriate priority change requests and alerts. The priority change requests will be sent to the TA commutator while the alerts will be sent to ground as messages.
- A ground component responsible for displaying the alerts recognized by the TA component.

Figure 2 illustrates the system configuration and includes both the TA and Ground SDS components. These components will be referred to specifically in the description below, though they could be substituted with other components of similar nature.

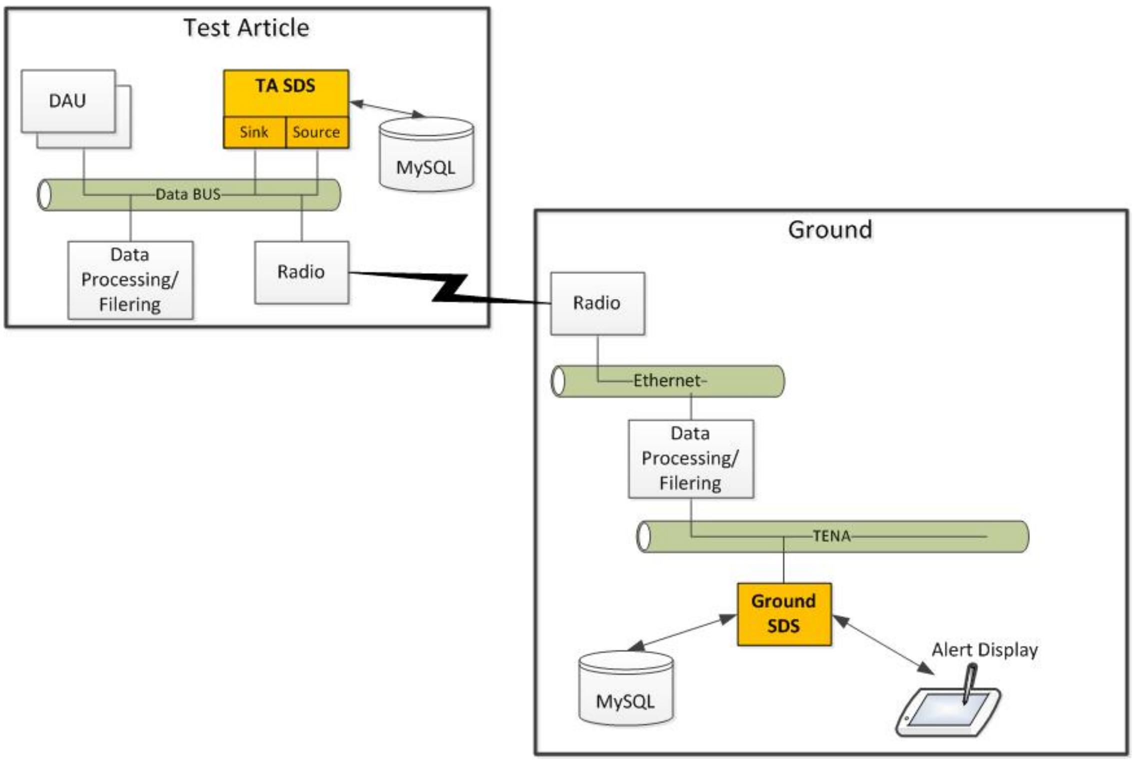

Figure 2. System Configuration with SDS Components

The TA component of the SDS subscribes to TmNS Messages carrying the measurements that SDS will analyze and monitor. In iNET parlance, the TA SDS will be a data sink as it receives TmNS Messages. A MySQL database stores all the information about the characteristics of the measurements it will analyze and monitor. This data characterization was collected during the SDS training phase. The individual measurements that need to be analyzed are extracted from the TmNS Messages and processed.

If an abnormal condition is detected by SDS, it will generate a corresponding TmNS alert message. The commutator will be configured to treat these messages with sufficiently high priority to ensure that they are transmitted to the ground. Depending on the situation, SDS will also send priority change requests to the commutator to increase the priority of the measurement.

Correspondingly, if a measurement that was behaving abnormally returns to its normal behavior, SDS will generate a corresponding end-of-alert TmNS Message, which the commutator sends to ground. If applicable, SDS will also send a corresponding priority change request to the commutator to assign a normal priority to the measurement.

The SDS ground component will alert the user to test conditions and enable the user to reject false alerts. The SDS ground component will also enable some local configuration of the alert display by the user. The SDS ground component is responsible for receiving the alert and end-of-alert messages generated by the SDS TA component and for displaying them to the user. The user will have the ability to mark a displayed alert as a “false alert”. This has the added benefit of keeping the list of alerts clean, while at the same collecting information that will be used to refine the SDS algorithms.

The ground SDS component will maintain all the information about alerts in a MySQL database and will support user queries of this database during the exercise. The same database can be used after the exercise to collect statistics, trends, etc. of the behavior of the various TAs during various exercises and to refine the SDS algorithms.

DEMONSTRATION

The SDS demonstration will be performed in a lab environment using standard PCs and two Gigabit LANs. For the purpose of the demonstration, the commutator and decommutator will communicate via a router rather than radios. The demonstration configuration is illustrated in Figure 3.

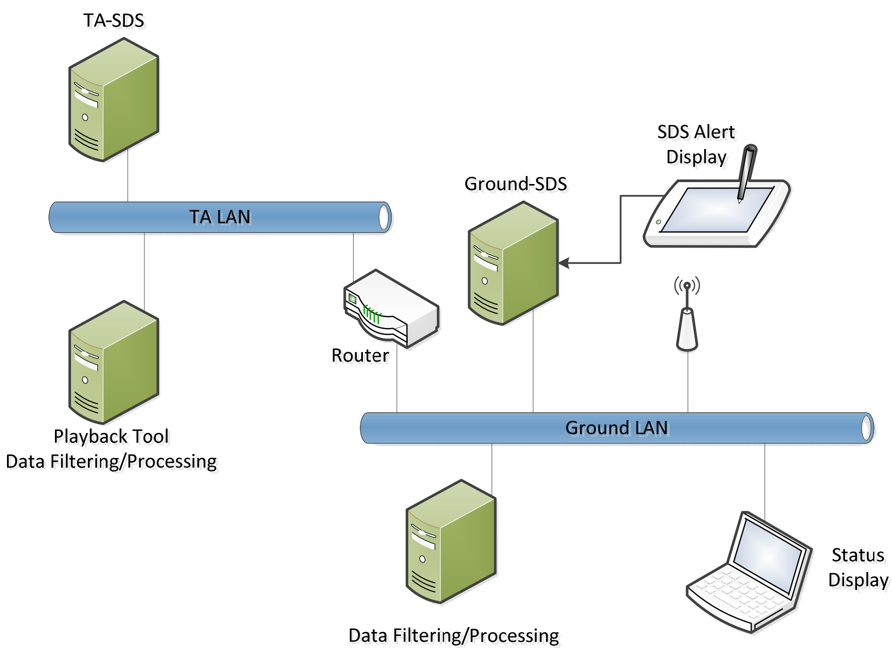

Figure 3. Phase 1 Demonstration Configuration

The TA, Ground, and GUI SDS components will be executing on separate computers just as they would in an operational configuration. The TA and Ground SDS components will be connected via the LAN but will not communicate directly with each other. The SDS GUI tablet will communicate with the Ground-SDS via a WI-FI connection.

A single computer will host the Playback tool (TmNS message source) and the commutator. These non-SDS applications would run on separate machines in an operational configuration, but the same functionality can be provided on a single computer to support the demonstration. The non-SDS components used in the demo include:

- Playback Tool
  This tool will playback TmNS Messages containing the recorded measurements that the SDS will analyze. The tool will read the measurements from a file and package them in appropriate TmNS Message(s). The final choice of the playback tool will be determined by the representation of the live recording that will be used for the demonstration.
- Data Filtering/Processing
  A dynamic commutator will receive TmNS Messages from both the Playback tool and from the TA SDS and send them to the ground according to their priorities. The commutator will also receive priority change requests from the TA SDS. A dynamic Decommutator will publish the content of the telemetry stream it receives from the Commutator to TENA.
- One laptop will be dedicated to run a Status Display system.

We will demonstrate the smart data select capability using the configuration described above by showing the response of the SDS system to changes in the system measurements on the TA. Based on the status of the data produced by the simulated data source, we will observe changes in the set of parameters that are sent to ground as well as alert messages. The following paragraphs present a possible demonstration scenario, depending on the actual characteristics of the recorded data used in the demonstration:

Demonstration Scenario	
1	All the systems other than the Playback tool are running. Status display shows baseline activity.
2	Start the Playback tool. TmNS Messages are processed. All initial measurements are normal so only a subset is transmitted to the ground. The values of these measurements are shown on the Status Display.
3	Some measurements start to show abnormal behavior. Corresponding alerts are generated by the TA SDS and appear on the SDS GUI tablet on the ground.
4	As abnormal behaviors onboard the TA are detected, the TA SDS sends corresponding priority change requests to the commutator. The Status Display reflects this change by altering the number of measurements displayed and/or the frequency by which they are updated.
5	Measurements return to normal behavior. The TA SDS sends corresponding end-of-alert message that is reflected in the SDS GUI. Similarly, priority change requests sent to the commutator will reset priorities to their original values, and the Status Display returns to the original display of measurements.
6	The operator uses the SDS GUI to review the log of the alerts.

CONCLUSIONS

The addition of a Smart Data Selection capability onboard the test article provides the following benefits to the T&E community:

- Bandwidth Savings/Increased Spectrum Efficiency
  When data values are determined to be within the “normal” range, the SDS module will transmit summary information to the ground rather than the entire data set. The summary information may include values such as the average, minimum, maximum, 95% minimum, 95% maximum, and variance. Transmission of selected data sets rather than the full data set represents a significant savings in bandwidth. The ultimate benefit of this is the ability to support more testing with available spectrum.
- Simplified Pre-Test Configuration of Test Article Commutator
  Analysis of previously recorded test events will allow the smart data selection capability to determine expected behaviors during test events. A dynamic commutator onboard the test article may use this information to automatically configure parameter transmission rates. Test operators will continue to have the ability to manually pre-configure data and mission critical data, such as flight safety, which will continue to be transmitted in full.
- Enhanced Operator Awareness of Test Conditions

With knowledge of the expected behaviors during test, the Smart Data Selection capability can be configured to automatically notify test operators when data values are outside of the normal range. This enhanced test awareness of test conditions allows test operators to focus on situations that require immediate attention rather than continuously monitoring all aspects of a system under test.

The benefits of this work, in terms of efficient use of spectrum to support T&E are substantial, and they could be leveraged by any DoD ranges that execute aeronautical and precision-guided munitions testing.

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