DYNAMIC FORMATTING OF THE TEST ARTICLE DATA STREAM

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INTRODUCTION

The telemetry community is faced with a number of challenges that are best addressed through the development and application of new technologies. One of the greatest hurdles is the need to support test activities in an environment of shrinking available spectrum. Since 1990, commercial interests have significantly eroded government allocation of telemetry spectrum. Also during this period, T&E telemetry use and data transmission rates have increased significantly. This increase is due in large part to increased use of telemetry to shorten test program schedules by maximizing data extraction from each test. In response to this need, the Test Resource Management Center (TRMC) has initiated a number of projects designed to overcome these obstacles through the development of technology. First is the iNET project, a Central Test and Evaluation Investment Program (CTEIP) project created to develop a modern, spectrally efficient telemetry architecture for the range community. Second is the Spectral Efficient Technologies S&T project, part of TRMC's T&E S&T program, which is developing spectral efficient technologies to reduce technical risk and enable implementation of the networked telemetry concept.

As identified in the iNET Needs Discernment Report dated 19 May 2004 and again in the iNET Test Capabilities Requirements Document (TCRD) dated June 2008, a critical need identified by the T&E community is to command and control onboard equipment, sensor parameters, legacy telemetry formats, and other functions from the Test / Training Command and Control Center (e.g., Ground Station). This need is supported by the iNET Scenario's 5 & 6 which describe a reconfiguration of transmitted telemetry information during a test (Aircraft & Missile).

Currently, with PCM the data stream is formatted prior to flight and can only be reconfigured if the instrumentation package is capable of storing multiple data loads. This is no minor endeavor, time consuming and sometimes sacrificing the entire telemetry package, forcing the test article to land and reload. Typically a format is loaded and checked out on the ground prior to take-off, without this verification step problems can inject themselves.

A key advantage for spectrum efficiency from network telemetry is the ability to dynamically change the data that is being telemetered, due to the 2-way data communication between the ground and system under test. In the current instrumentation systems, PCM formatters or dynamic network telemetry formatters do not exist. The benefit of reformatting can be realized in two primary methods, by modifying what data is in the format as well as the ability to reassign telemetry bandwidth where needed.

Successful research into these areas is essential for feeding the iNET development and future investment programs. Dynamic Commutator Decommutator System (DCDS) is the T&E S&T SET project, contracted through SAIC in May 09 for solving the issue of reconfiguration of the test articles telemetry format in real-time. This is a 2-year 2-phase effort that relies on a software based commutator/decommutator for modifying the telemetry stream. Transition for this technology has been targeted to support the CTEIP project iNET and has successfully finished the phase 1 effort with positive reviews from the iNET Program Director. DCDS is on track to meet several of the ongoing challenges for iNET and will culminate the effort with a field-tested prototype system with the completion of phase 2+.

The remainder of this paper discusses the DCDS architecture and concept of operations.

DCDS ARCHITECTURE

The approach employed by DCDS to enhance spectrum efficiency is inspired by the concept identified in the 2007 *iNET System Concept of Operations* that "by far the greatest overview level of spectrum inefficiency is not in modulation technique but rather in transmitting the same measurement for the entire flight. The ability to access less critical data on demand or as needed would prove significant savings in spectrum." Put another way, the greatest increases in efficiency lie in being able to select for transmission the data that is needed when, and only when, it is needed. With enough flexibility, a telemetry stream could contain only the measurands required at a particular point in time, resulting in a much more efficient transmission of information and utilization of RF spectrum. The DCDS does just that. It improves spectrum efficiency, not through improving RF techniques, but rather through changing and optimizing the contents of the data stream.

The DCDS defines and optimizes a test-specific telemetry stream layout and then generates all the data, files, and application code required to build a commutator/decommutator pair. The DCDS architecture consists of a user interface, data repository, code generation engine, and commutator/decommutator run-time environments. These components work together to create an optimized system that is flexible and dynamic. The DCDS enables real-time changes to the fidelity, sample rate, and number of parameters in the measurement list transmitted from the test article.

Figure 1 illustrates the DCDS architecture. The sections below describe major components of the system.

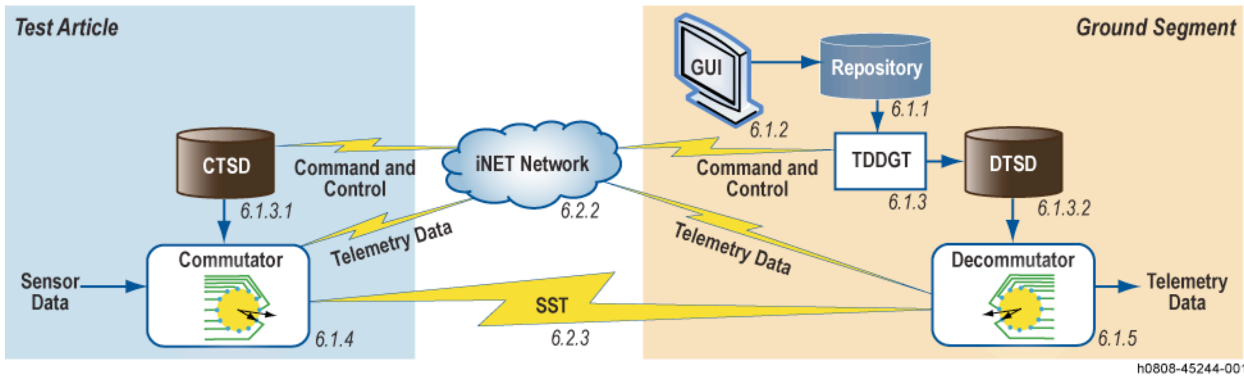

Figure 1. The DCDS Architecture Supports Enhanced Tools to Define and Optimize the Telemetry Stream

Data Repository

The DCDS uses a data repository to store all the relevant information about the sensor and system parameters available on the test article along with descriptions of how the telemetry stream format should incorporate these parameters. The DCDS user can update the data repository to effect changes in telemetry stream definition or processing.

The data repository maintains the configuration history of all elements within the repository.

Graphical User Interface (GUI)

The DCDS includes a graphical user interface that enables the range systems engineer to define the test Telemetry Stream characteristics. The GUI enables the user to inspect and modify any of the data that is stored in the data repository, and it will provide as much assistance and information as possible to the user. Examples of ways in which the GUI supports the tester include continuously monitoring the bandwidth requirements of the current Telemetry Stream and Telemetry Data Group definitions, offering predefined libraries of preprocessing algorithms applicable to the sensor data, and offering context-sensitive help.

In addition, the GUI will interface to the Telemetry Data Definition Generator Tool, which is described in the next section, enabling the user to prepare the data required by the commutator and decommutator.

Telemetry Data Definition Generator Tool (TDDGT)

The Telemetry Data Definition Generator Tool (TDDGT) automatically displays the bandwidth requirements of the current telemetry stream definition to the user, and continually highlights the costs and benefits of changes to the stream definition. The TDDGT also generates all software and telemetry stream definition files to be loaded onto the test article commutator and ground segment decommutator for execution of a test. Two programs are generated. The first program creates the particular packet from the parameter values within the commutator. The second program extracts the parameters values within the decommutator. The two programs are compiled and, together with some predefined libraries, are assembled to form the executables that will be loaded on the commutator and decommutator. The test article commutator and the ground segment decommutator each consist of fixed infrastructure and libraries that are exercise independent as well as custom programs and data specifically tailored to exercise needs. The exercise-specific programs and files execute within the respective run-time infrastructures of the commutator and decommutator. Together they process the dynamic telemetry stream for the test.

File preparation is fully automatic and removes the need for manual changes to commutator or decommutator software and firmware. Updates to the telemetry stream and associated commutator and decommutator systems require definition only by a range systems engineer, who executes the changes with a click of the "Generate Deployment Files" button on the TDDGT interface. If further telemetry format changes are required, the range systems engineer redefines the stream within the TDDGT and generates the new deployment files. The TDDGT will automatically generate, compile, and link the custom programs with the fixed infrastructure and libraries in response to the "Generate Deployment Files" request by the range systems engineer.

Commutator Telemetry Stream Definition (CTSD)

The CTSD comprises the generated code and files that are loaded into the commutator run-time infrastructure on the test article. The CTSD includes the logic and information required during the life of the test. While it is possible within the iNET architecture to upload information from the ground segment to test article through the iNET packet network, the DCDS is designed to limit traffic over that link to requests to modify the list of predefined measurands included in the active telemetry stream. The DCDS minimizes uploading of any critical information required to define the telemetry stream or how it is processed during the test.

Decommutator Telemetry Stream Definition (DTSD)

The DTSD comprises the generated code and files that are loaded into the decommutator run-time infrastructure within the ground segment. These files are loaded into the decommutator before the test. While the CTSD includes the programs to create telemetry packets from the sensor parameters, the DTSD includes the code to extract the parameters from the telemetry packets.

Once the raw parameter values have been extracted from the incoming telemetry stream, the decommutator needs to process these data by transforming them into appropriate engineering units and performing other data transformations, such as coordinate conversions, as required. Then the DCDS then publishes them to the ground segment.

CONCEPT OF OPERATIONS

This section describes an operational scenario in which test engineers use the DCDS. The scenario highlights how the DCDS will benefit DoD RDT&E ranges and DT, OT, and/or LFT&E users. The scenario includes some assumptions made for illustrative purposes that are not necessarily realistic. The overall objectives in the scenario are representative of those identified in the *iNET Needs Discernment Document*. Section 1 of this proposal identifies the iNET scenarios enabled by the DCDS.

"Mary" is a range systems engineer in charge of defining the telemetry formats for the fuel pumps subsystem of the new SuperWingX aircraft, the system under test at Mary's range. **Table 2** lists the resources allocated to Mary through negotiations with the other systems engineers and with the lead test engineer in charge of the SuperWingX flight test. Mary will decide which parameters (pressure, temperature, flow, RPM, voltage, etc.) she needs to monitor the behavior of the fuel pumps during the planned test. For instance, she may decide that she needs the exit pressure from pump P1 at a rate of 10 Hertz. **Each time she specifies the fidelity and sample rate of a new measurand, the DCDS will inform her of the current bandwidth consumption of the telemetry format.** The system will alert her if the required bandwidth exceeds the allocated 10,000 bits/sec allocated for nominal operation. She must either reduce her bandwidth consumption or negotiate a larger bandwidth.

Table 2. Resources Negotiated by the Range Systems Engineer

Resource Mode	Available Bandwidth	Description
Nominal mode	10,000 bits/sec	Bandwidth allocated to the fuel pump subsystem telemetry during normal test conditions.
Emergency mode	100,000 bits/sec	Bandwidth allocated to the fuel pump subsystem telemetry when the subsystem is not operating as expected, and test engineers require more data to fully understand the failure.
Degraded mode	1,000 bits/sec	Bandwidth allocated to the fuel pump subsystem telemetry when other subsystems require more bandwidth than normal.
Online storage	1 MB	Storage capacity of the SuperWingX commutation module. It stores performance data required by the test engineers when the subsystem is operating in emergency mode. When necessary, it can be incorporated into the telemetry stream.

In a similar way, Mary will define the set of parameters and the update rates required for the other modes of operation. **In the emergency mode, Mary will plan for additional data in the telemetry stream, and she will define the minimal set of measurands needed to execute the test in degraded mode. Finally, Mary decides how to use the online storage to store the detailed, historical data she would want to analyze in the event of system failure.** In this case, the 1 megabyte enables her to store more than 80 seconds of high fidelity data that the system will transmit to her in emergency mode.

An engineer monitoring the telemetry data during the exercise may request the switch from nominal to emergency data transmission, or the DCDS can automatically change modes based on thresholds of specific measured values. **Mary enters into the DCDS the thresholds that will trigger mode changes**. She knows that if the temperature of any pump rises above 200º F, something is definitely wrong. At that point, she configures the DCDS to switch to emergency mode. To determine what led to the temperature rise, she configures the system to transmit the historical data from the data buffer.

After Mary configures the DCDS to switch to emergency mode at 200º F, **the system calculates how much bandwidth is available in emergency mode for the transmission of the historical data, and how long it will take to transmit the entire buffer**. For instance, if the real-time measurement list in emergency mode requires 80,000 bits/second, and the allocated emergency mode is 100,000 bits/second, there are 20,000 bits/second available to transmit history data. If the online storage is full (1 megabyte), it will take approximately 400 seconds to transmit its content: Mary must decide whether this is acceptable. If this takes too long, she must either reduce the amount of live data in emergency mode, leaving more bandwidth for transmission of buffered data, or negotiate more bandwidth from the lead test engineer.

When Mary is satisfied with the fuel pump subsystem telemetry stream definition, and if this definition passes predefined validations such as allocated bandwidth, she signs it off, marking it as ready.

After Mary is done, "Chuck," the lead telemetry systems engineer, uses the DCDS to generate the commutator and decommutator source code and files required for test execution. **Chuck does not need to be a software developer to accomplish this task. The DCDS generates, compiles, and assembles the proper code images behind the scenes.** Chuck loads these files onto the test article commutator and ground segment decommutator and tests the system, making changes as necessary.

At the beginning of the flight test, SuperWingX telemetry operates in nominal mode. More extensive emergency mode data for the fuel pumps subsystem are recorded within the online storage. During the test, fuel pump P2 reaches a temperature of 201º F. **The commutator automatically switches the fuel pumps subsystem to emergency mode. At the same time, the commutator switches other subsystems to degraded mode to free up the bandwidth required to send additional real-time and historical data for the fuel pump subsystem.** After a few minutes, the temperature of the fuel pump drops, and the DCDS resumes transmission of the fuel pump telemetry at the nominal mode rate.

Scenarios that are more complete could involve the allocation of priorities to the various data sets. The user-defined transition criteria, such as the 200º F temperature threshold in the previous example, no longer directly trigger mode changes. Instead, they alter the respective priorities of various telemetry parameters within the measurement list. The commutator selects the data to transmit based on the current set of priorities of each set of data. The system can define these sets of data controlled by priorities in flexible ways and can include the historical data stored on the test article.

In the previous scenario, **the commutator automatically switches modes based on preconfigured criteria**. With uplink communication from ground segment to test article, as defined in the iNET architecture, **test engineers monitoring the test article could request mode changes in real time**. Test engineers also could be inserted as an approval mechanism for automatic changes. The **commutator could suggest changes to the telemetry stream definition based on thresholds, and the test engineers would have the power to approve or disapprove** of the changes.

Another assumption made in the previous scenario is that bandwidth available to the SuperWingX telemetry is fixed. Recovering additional bandwidth assigned to a subsystem in emergency mode requires putting other systems in degraded mode. In the iNET scenarios, additional bandwidth may become available to the test article in real time. Dynamic definition of telemetry formats will be even more important when available bandwidth can change over time, as the telemetry stream must adapt to these changes.

Figure 2 illustrates how the telemetry packets evolve in the preceding scenario. A simplified telemetry format consists of data from only three onboard sensors: fuel pumps (FP), gyroscopes (GY), and engines (EG). The DCDS user has defined nominal, emergency, and degraded modes of operation for the three sensors. The size of each box in **figure 1** is proportional to the bandwidth requirement for the sensor in its respective mode. The initial priorities assigned to each data group are shown as the **P:** values. A higher number corresponds to a higher priority.

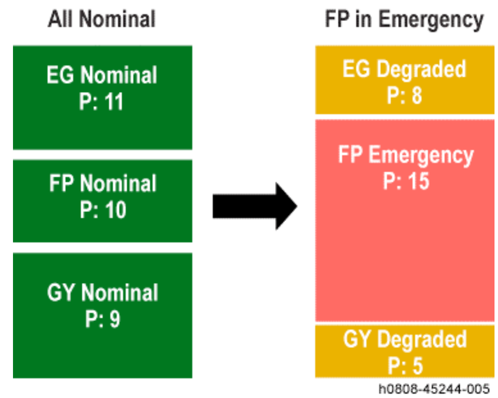

Figure 3. Mode Changes Produce Changes in Packet Size

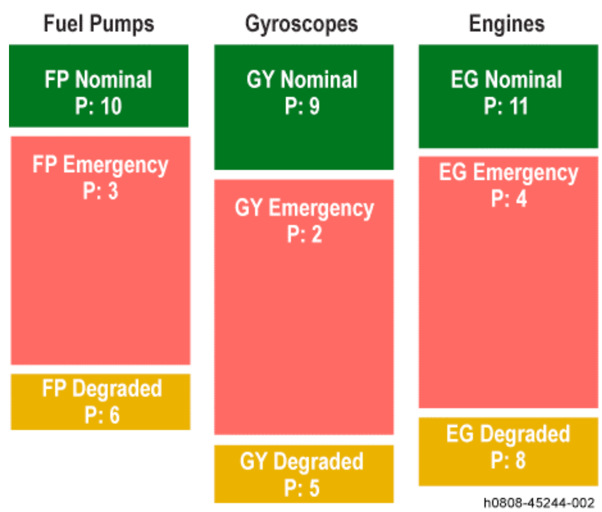

Figure 2. Test Vehicle Data Groups for Onboard Fuel Pumps, Gyroscope, and Engine Sensors

Figure 3 shows the changes in respective packet size when one system changes mode. When the FP is in emergency mode, it uses a larger portion of the available bandwidth, and the other subsystems switch to degraded mode with smaller packet sizes to compensate. The commutator selects the data to include in the transmission packet based on the priority level of each data group. When the priority of the FP Emergency mode data group is increased to 15, it is added to the transmission packet, and the FP Nominal mode data group is removed.

SUMMARY

A key advantage for spectrum efficiency from network telemetry is the ability to dynamically change the data that is being telemetered, due to the 2-way data communication between the ground and system under test. The benefit of reformatting can be realized in two primary methods, by modifying what data is in the format as well as the ability to reassign telemetry bandwidth where needed. DCDS is the T&E S&T SET project solving the issue of reconfiguration of the test articles telemetry format in real-time. Transition for this technology has been targeted to support the CTEIP project iNET and has successfully finished the phase 1 effort with positive reviews from the iNET Program Director. DCDS is on track to meet several of the ongoing challenges for iNET and will culminate the effort with a field-tested prototype system with the completion of phase 2+.