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TELEMETRY DATA ON DEMAND: THE KEY TO UNDERSTANDING THE TELEMETRY NETWORK REVOLUTION

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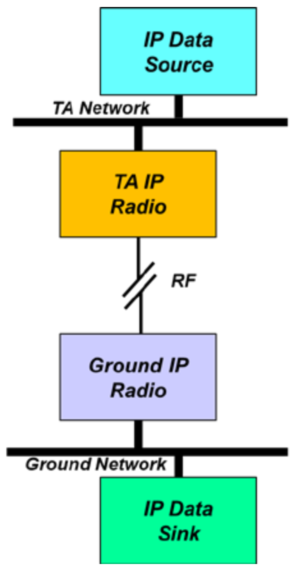
ABSTRACT

The telemetry network revolution takes aeronautical flight testing from a broadcast-only paradigm to a *TM-data-on-demand* paradigm. This paper explores this paradigm shift, focusing on fundamental architectural changes enabled by incorporating telemetry networking technologies into a flight test system. Two concepts are presented to help understand the *TM-data-on-demand* paradigm: retrieving and processing recorded data from a test article during a mission and onboard dynamic data analysis and compression. An example flight test system with both SST and TmNS components provides a foundation to further explore the paradigm-shifting capabilities a telemetry network brings to flight test. In addition to *TM-data-on-demand,* the current static spectrum allocation methodology must also be replaced with a more agile, *bandwidth-on-demand* paradigm. When both *TM-data-on-demand* and *bandwidth-on-demand* capabilities have been realized, a new era of efficient flight testing will emerge.

INTRODUCTION

For over 50 years, the IRIG 106 Standards have defined a simplex Serial Streaming Telemetry (SST) standard for telemetry communication links. Generations of flight test systems have been built around this unidirectional SST link architecture. The Central Test and Evaluation Investment Program (CTEIP) sponsored the Integrated Network Enhanced Telemetry (iNET) project which introduced a standards-based approach for a bidirectional, packet-based network communication link. The iNET project was designed to augment the existing SST link (thus the name "Enhanced Telemetry"), and a key product was the development of a set of networking standards that were incorporated into the IRIG 106 Standards, release 2017. The sheer breadth of these standards can make understanding the benefits of a telemetry network difficult to discern. A corollary would be to attempt to understand the benefits of High Definition Television (HDTV) by reading the HDTV standards. This paper explores network-based flight test systems by first presenting an abstracted telemetry network system followed by a representative system based on the IRIG 106-17 standards.

From an end user's perspective, all the complexities associated with a telemetry system can be abstracted away as show in Figure 1: a ground system sees the test article (TA) as a data source and the ground system operates as a data sink. Figure 1a shows a traditional SST implementation of an abstracted flight test system, whereas Figure 1b shows a telemetry network implementation. Given this simplified perspective, how does a telemetry network impact the traditional simplex paradigm? Exploring a broadcast TV analogy may prove helpful in answering this question.



(a) Traditional SST (b) Telemetry Network

Figure 1. Telemetry Data Distribution Overview.

BROADCAST TV VERSUS VIDEO-ON-DEMAND ANALOGY

Since the beginnings of broadcast television, TV stations have broadcast a series of preselected TV shows; only TV shows selected by the TV broadcasters were available. Prior to 1980, making sure one was home to watch a favorite TV show at the designated "same Bat-time, same Bat-channel" was just a normal part of watching TV. From the 80's and into the 90's, devices like video cassette recorders and digital video recorders were developed to enhance our TV viewing experience. While these devices placed us in control of *when* we watched TV shows, we did not have control over *what* was available to watch. The fundamental one-way broadcast paradigm remained unchanged: TV stations broadcast a series of preselected TV shows at predetermined times.

Enter the age of the Internet and the "content-on-demand" paradigm was born. Applications like YouTube® and Netflix® have revolutionized our viewing habits. No longer are we slaves to the TV broadcasters' preselected shows; we are now empowered to watch *what* we want and *when* we want to watch it. Having a bidirectional network that allows us to request specific videos from network-based video servers has fundamentally changed how we view videos. With this

paradigm change, video providers have changed and enhanced their offerings. The concept of "binge-watching" video series has become mainstream primarily due to video-on-demand.
A typical SST system follows a broadcast TV paradigm. Data Acquisition Units (DAUs) on a TA generate a predefined pulse code modulated (PCM) data stream that is recorded on the TA's recorder. Additionally, a second PCM data stream, which usually contains a subset of the generated DAU data, is typically transmitted to the ground via SST. On most systems, there is very little a Flight Test Engineer (FTE) can do to alter the data contained in the PCM data stream. Just like broadcast TV, PCM data streams are preprogrammed: an FTE only receives whatever the Instrumentation Engineer decided to transmit when the DAU was programmed.

As with the Internet, introducing network connectivity between a TA and a ground system fundamentally changes the "one-way" broadcast paradigm. No longer is an FTE restricted to preprogrammed data streams. Like video-on-demand, ground system applications can now make data requests to TA-based network data servers. The *TM-data-on-demand* paradigm shift is realized by incorporating support for dynamic data requests into a flight test system. Why is *TM-data-on-demand* so important? A TA can only telemeter only a fraction of the acquired data so the fundamental question facing all flight test teams is "Which acquired data should be telemetered to the ground?". The *TM-data-on-demand* paradigm shifts flight testing from a broadcast paradigm in which only a preprogrammed, static set of acquired data can be telemetered to an on-demand paradigm in which the acquired data being telemetered can be changed in response to either planned or unexpected events. *The key to the Telemetry Network Revolution is understanding the impacts of the TM-data-on-demand paradigm shift on a flight test system*. As video-on-demand fundamentally changed both video providers and our video viewing habits, implementing *TM-data-on-demand* requires a fundamental paradigm shift for developers and users of telemetry processing applications.

TM-DATA-ON-DEMAND SYSTEM CAPABILITIES

There are three fundamental capabilities required to implement vendor-interoperable *TM-data-on-demand:*

- A bidirectional IP network between the TA and the ground system
- A standardized request mechanism implemented by both data sources and data sinks
- A standards-based data message format in which payloads are described using a flexible, extensible data description language

A request-capable data source generates a stream of user-requested data messages across a data channel. A request-capable data sink receives and processes a stream of user-requested data messages. Figure 2 represents a typical configuration for a data processing app to request data from an airborne data server (e.g., an airborne recorder). This configuration parallels a typical web browser / web server architecture. Please note that the data server and data sink roles could be reversed whereby data messages flow from the request client to the request server. A web-based corollary would be uploading a photo to a web site versus downloading a photo (the client and server roles remain the same but the data transfer direction changes).

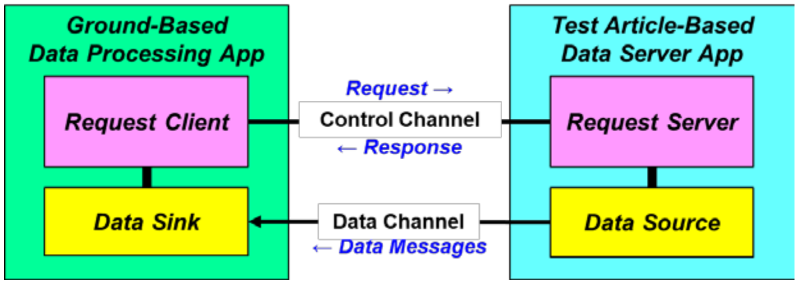


Figure 2. Request-Capable Data Source and Data Sink Example

A standards-based flexible, extensible data message format and corresponding description language is required for describing the encapsulation of telemetry data into data messages. Data sinks decompose data messages received from data sources by processing a data source's data description document which explicitly defines all data message structures. Integral to this data message format is the inclusion of a timestamp so that data messages may be accurately timestamped by the data source (i.e., on the TA). Vendor-interoperability is achieved when all data sources and data sinks use the same data description language for describing data structures being transported in a standard data message format.

Figure 3 presents a simplified Telemetry Network System. One or more DAUs generate data messages that go to the recorder app and a subset of those data messages are transmitted across the RF link to the data processing apps. This simplified system realizes the benefits of timestamping data at the data source along with using a flexible, describable data message format. However, despite being network-enabled, these system components still operate using the broadcast paradigm rather than the *TM-data-on-demand* paradigm.

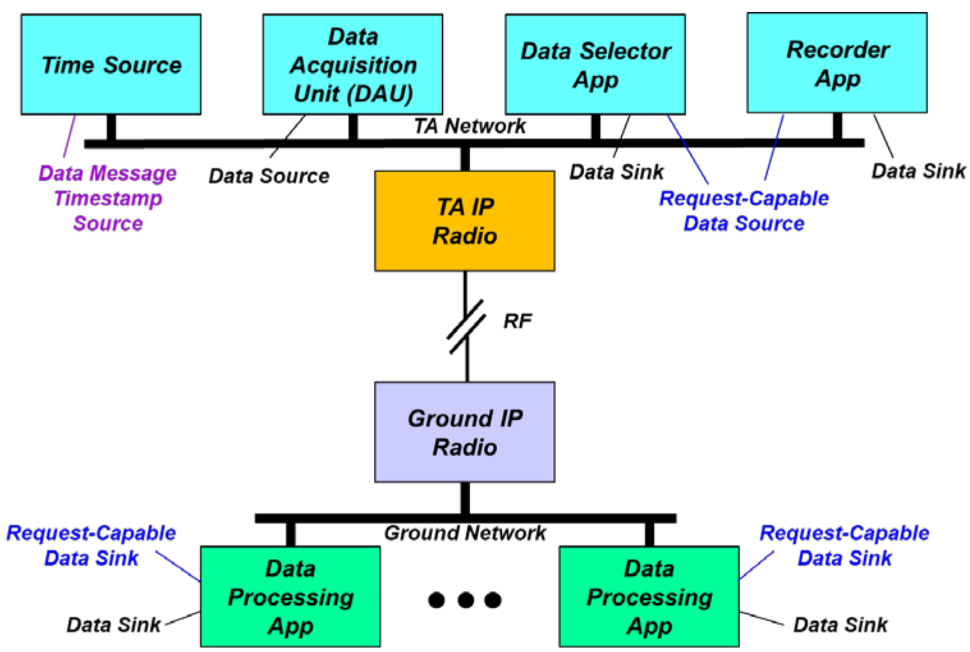


Figure 3. Simple Telemetry Network System

Enter the Request-Capable Data Sources and Data Sinks (the blue text items in Figure 3), the primary enablers of *TM-data-on-demand*. The introduction of these data processing apps now provides end users with the following capabilities:

1. Retrieval of recorded data from the TA Recorder App.

2. Data compression via down sampling of data by the DAU, Data Selector App, or Recorder App.

3. Data filtering via range threshold processing performed by the DAU, Data Selector App, or Recorder App.

Being able to retrieve a time range of recorded data from the TA Recorder App is a paradigm-shifting capability. This capability is similar to retrieving a video from a video server: “I want to watch Seinfeld season 2, episode 11”. If specific critical data was not received properly during a test maneuver (e.g., a TM dropout occurred), a data processing app could retrieve the missing data from the TA Recorder App in mere seconds. If a test point analysis app requires more data than originally telemetered, the app could retrieve the additional data (that was not originally telemetered) from the TA Recorder App. In both instances, adding support to ground data processing apps to receive and process data from a previous time is crucial to implementing *TM-data-on-demand*.

Data compression and data filtering techniques can be applied to both live and recorded data. The data compression technique is used to down sample the data. For example: an oil pressure sensor operates at 10 Hz resulting in the DAU sending an oil pressure measurement to the Recorder App ten times a second. The ground system could initially configure the DAU or Data Selector App to send oil pressure measurements to the ground once a second, resulting in a 90% reduction in RF traffic for this measurement. The data filtering technique applies a minimum and maximum threshold value to each measurement; the measurement data is only sent to the ground when a measurement value exceeds either the minimum or maximum threshold value. These two techniques may be combined as follows: under normal operating conditions, a 10 Hz measurement sample rate is transmitted to the ground at a reduced 1 Hz rate, but if the minimum or maximum threshold is exceeded, every sample is sent to the ground. A corollary might be a web photo browsing app in which previously viewed photos are displayed in a low-resolution format, but new photos are displayed in high resolution. Using these techniques empowers FTEs to receive exactly the data they need while efficiently using the RF bandwidth.

TmNS SYSTEM EXAMPLE

While Figure 3 represents an abstract telemetry system, Figure 4 represents a more realistic flight test system which can be used for exploring *TM-data-on-demand* capabilities. To assist with implementing a vendor interoperable telemetry network system, IRIG 106 Chapters 21 – 28 (formerly the iNET Standards) were developed to define a set of Telemetry Network Standards

(TmNS). Vendor components that comply with IRIG 106 Chapters 21 – 28 are referred to as TmNS components. In the context of TmNS components that implement *TM-data-on-demand*:

- Chapter 23, Metadata Configuration, defines the Metadata Description Language (MDL) used to describe not just measurement data but also app configuration.

- Chapter 24, Message Formats, defines the ubiquitous TmNSMessage Structure (used to transport measurement data).

- Chapter 26, TmNSDataMessage Transport Protocol, contains the Request-Defined Application Data Transfer section that defines request-capable data sources and data sinks.

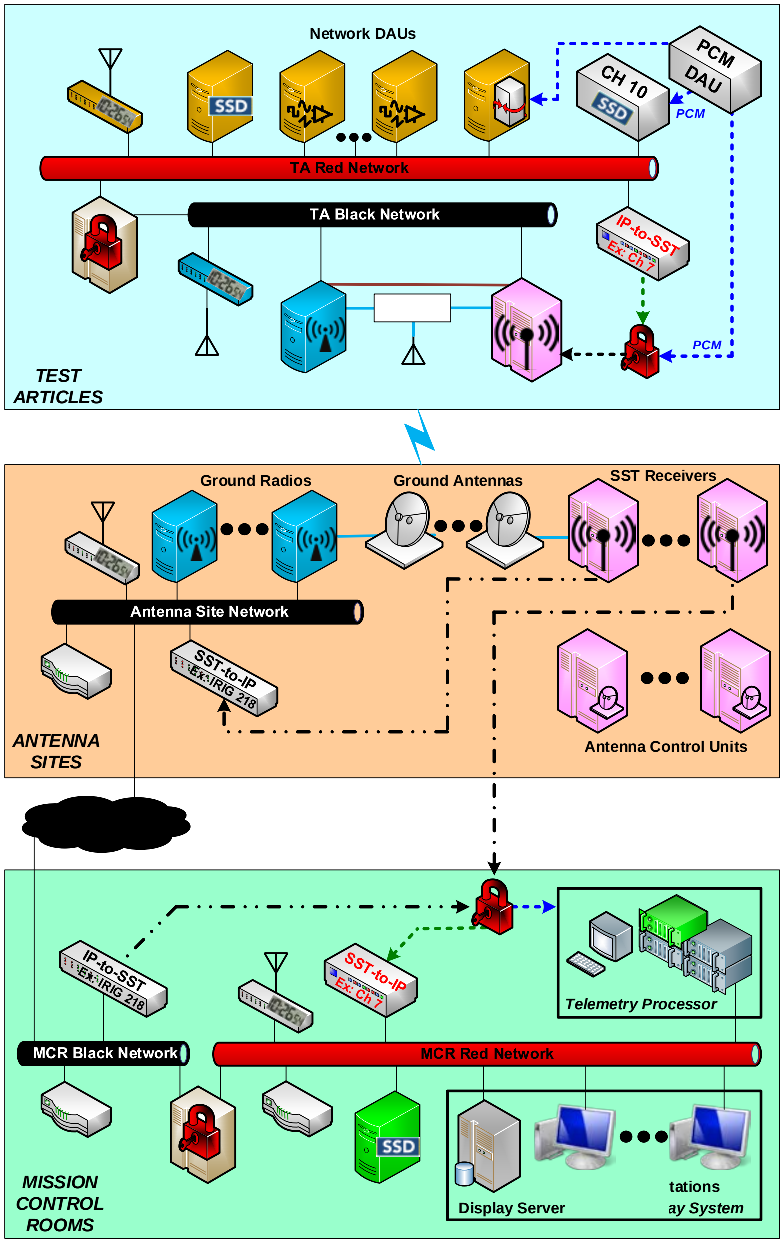


Figure 4. Flight Test System with both SST and TmNS Elements

Figure 4 shows a flight test system that includes both SST and TmNS elements. In the traditional SST implementation, PCM data from a PCM DAU is sent through a bulk encryptor to the SST transmitter. At the antenna site, an SST receiver regenerates the PCM data which is then transmitted either directly to the mission control room or converted to IP packets by a PCM-to-IP converter (e.g., TMoIP, IRIG 218). Traditional PCM data can also be encapsulated into IP packets onboard the TA by a PCM Gateway. Network DAUs generate IP traffic that can be sent to the ground either directly across the TmNS radio link or via an IP-to-SST link (e.g. IRIG 106 Chapter 7). On the ground, all telemetered data is transported via the range network to the Telemetry Processor in the mission control room and corresponding data processing apps in the Display System.

The *TM-data-on-demand* capabilities enabled by the Telemetry Network Standards are realized when data processing apps request TmNS Messages be sent to the ground. One approach to receive TA data on the ground is for a data processing app to subscribe to an existing IP data stream on the TA which is currently not being sent to the ground. This subscription mechanism is a standard IP networking function, refer to the Internet Group Message Protocol (IGMP). Once the subscription is established, the TA-based TmNS Message stream would be propagated to the ground. Enabling and disabling transmission of IP data streams between a TA and the ground is a simplified form of *TM-data-on-demand*.

The quintessential *TM-data-on-demand* capability is defined in the Telemetry Network Standards as Request-Defined Application Data Transfer. A data processing app sends a specific data request as shown in Figure 2. The data request includes a time range which may specify either previously recorded data or live data. Where are the data processing apps that generate data requests in Figure 4? The answer lies in the selected architecture. Data processing apps may be embedded in either the Telemetry Processor and/or the Display System. The Display System may directly communicate with the TA or may communicate with the Telemetry Processor which then generates the data requests. The TmNS Data Server App (TDS) was developed for the iNET program as the ground data gateway to the TAs. All ground data requests, whether Data Display or Telemetry Processor generated, go through the TDS. The TDS attempts to manage the data flow across the RF link by prioritizing the requests and limits the number of concurrent data requests being handled by the TA's TmNS Recorder. Ranges may choose to implement the TDS paradigm or a fully distributed environment in which any data processing app may submit data requests to the TA.

Two important components to implementing the *TM-data-on-demand* paradigm are enhancing the Display System's user interface to support data retrieval and dealing with asynchronous time. Ideally, the user interface should be as simple as pressing the rewind button on a DVR, but different data retrieval user interfaces for different types of data retrievals will need to be developed. Additionally, data processing apps in either the Display System or Telemetry Processor will need to deal with time slices of data rather than a continuous stream of live data.

A great example of *TM-data-on-demand* is the PCM Backfill App developed for the iNET program, see [1]. A PCM data stream is sent to an SST link as well as encapsulated in TmNS Messages by a PCM Gateway and recorded on the TA TmNS Recorder. The PCM Backfill app continuously monitors the PCM minor frame synchronization status and whenever a TM dropout is detected, the PCM Backfill app retrieves the missing data from the TA's TmNS Recorder and sends the missing data to the Display System. The result is lossless PCM data made available on the Display System within a couple of seconds after the RF link has been re-established.

While the Telemetry Network Standards provide a mechanism to selectively request individual parameters, the standards currently do not include a request mechanism to dynamically change data compression and/or data filtering as described previously. A representative TmNS Recorder, the Enhanced Query Data Recorder (EQDR), has been developed under the Test Resource Management Center's (TRMC) Test and Evaluation (T&E) Science and Technology (S&T) Spectrum Efficient Technologies (SET) program. Not only does the EQDR implement the Request-Defined Data Transfer protocol, the EQDR includes additional functionality like data compression and data filtering (thus the name "Enhanced Query"), see [2] and [3]. While the EQDR's enhanced query interface is currently outside the scope of the Telemetry Network Standards, future versions of these standards should include an enhanced query interface to facilitate the benefits associated with data compression and filtering.

The Smart Data Selection (SDS), also developed under a SET program, prototypes an intelligent Data Selector in which specialized algorithms were developed to analyze and determine which data to transmit from a TA to the ground, see [4]. The SDS takes onboard TA data processing to the next level. Rather than send all measured data samples to the ground, the SDS system applies bandwidth efficient algorithms to selected data. SDS also provides greater operator awareness of system anomalies while ensuring critical data, such as range safety data, is sent to the ground continually without interruption. As with the enhanced query interface, future versions of the Telemetry Network Standards should include an extensible data request interface to support SDS-like functionality. A proposed HTTP-based data request interface was presented in [5].

TM-DATA-ON-DEMAND CHALLENGES

Implementing *TM-data-on-demand* requires mission planning teams to view the telemetering of measurement data from a new perspective. The traditional broadcast-only paradigm views measurement data as a static data set to be prioritized for transmission prior to flight. Embracing *TM-data-on-demand* forces mission planning teams to embrace the true dynamic, multifaceted nature of telemetering mission data. These dynamic factors include:

- Time: maneuver test point being executed
- Discipline: importance of transmitting parameter based on specific maneuver
- Data Compression: can parameter be down sampled?
- Data Filtering: can parameter be monitored on the test article, and only down sampled and anomalous values be transmitted?

All these factors lead to the ultimate question: “What measurement data needs to be telemetered at any particular point in time?” The traditional broadcast-only paradigm response to this question is “Telemeter a static data set during the entire mission”. The *TM-data-on-demand* paradigm response is “It depends on a variety of factors…”. This new paradigm supports dynamically changing the telemetered mission data.

Even after all TA and ground applications have been enhanced to support *TM-data-on-demand* capabilities, there are still fundamental operational (non-technical) changes that need to be addressed. Mission planning teams should view all measurement data as “on-demand” data with an emphasis on prioritizing not just *which* parameters are to be telemetered but *when* parameters are required to be telemetered for ground system processing. Assigning most parameters as “top priority, required for the entire mission” negates the potential advantages offered by the *TM-data-on-demand* capabilities. How can safety of flight parameters be considered “on-demand” data? Simple: safety of flight parameters are the top priority parameters and must be telemetered for the entire mission. While *TM-data-on-demand* requires a fundamental change in how telemetered data is perceived, this new paradigm can still support the traditional broadcast-only paradigm *when needed*, as in the case for safety of flight data.

Ever since spectrum availability has become an issue in flight test, engineers have addressed the issue through increased modulation efficiency (i.e., more bits/Hz) and increased scheduling efficiency (more missions per day). The *TM-data-on-demand* paradigm exposes a third type of efficiency called *TM data efficiency* (i.e., data used vs data telemetered). In other words, what is the point of telemetering measurements to the ground if the data is not being immediately used? As stated previously, mission test teams need to justify not just *which* parameters are to be telemetered but *when* those parameters are required to be telemetered for ground system processing.

Spectrum scheduling entities are also affected by the *TM-data-on-demand* paradigm shift. Spectrum should no longer be viewed as a static asset to be allocated for the duration of a mission. A *bandwidth-on-demand* paradigm shift is required that treats spectrum as a dynamic asset to be continually reallocated during test missions. One approach to *bandwidth-on-demand* is to establish a spectrum pool in which each TA is allocated a guaranteed minimum bandwidth and the remaining bandwidth is shared amongst all the TAs. For example: TA1 is performing a test maneuver and is dynamically allocated a large portion of the shared bandwidth while TA2 waits to enter a test maneuver until more bandwidth is available. Once TA1’s maneuver has completed, the shared bandwidth is deallocated by TA1, TA2 is allocated a portion of the shared bandwidth and TA2’s test maneuver can begin. TmNS radios implement one form of *bandwidth-on-demand* via a time-division multiple access (TDMA) channel access method. TDMA allows multiple users to share the same frequency by dividing the signal into multiple time slots which are then allocated to different users [6]. To achieve better spectrum efficiency, the *TM-data-on-demand* paradigm shift requires *bandwidth-on-demand* for dynamic, real-time spectrum sharing.

CONCLUSION

The key to the Telemetry Network Revolution is to understand the impacts of the *TM-data-on-demand* paradigm on flight test systems. Retrieving previously recorded data from a TA recorder and data compression / filtering techniques empower flight test systems with new capabilities. Once these *TM-data-on-demand* capabilities have been deployed, the real benefits shall only be realized when mission test teams start to view telemetered measurement data as a dynamic data set rather than a static, preconfigured data set. Mission test teams need to prioritize telemetered measurement data based on a variety of factors to insure only required data is telemetered at the correct time. While the *TM-data-on-demand* paradigm shift holds the promise of more spectrum efficient flight testing, the current static spectrum allocation methodology must be replaced with a more agile, *bandwidth-on-demand* paradigm. When both *TM-data-on-demand* and *bandwidth-on-demand* capabilities have been fully realized, a new era of more effective and efficient flight testing will emerge.

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