CGMS-51-NOAA-WP-04
4 April 2023

Prepared by: NOAA
Agenda Item 8.9
Discussed at WG-1

Subject	**Small Satellite DCS Use as an Operational Concept**
In response to CGMS action/recommendation	
HLPP reference	2.1.2
Executive Summary	The Satellite DCS Use Concept Validation project was originally scoped to determine if satellites can successfully interface with the Data Collection System (DCS) receivers (DCPR) and thus provide a low-rate data (100, 300, or greater bps) service to satellite users. Satellite use of the DCS fosters a new means for collecting and distributing meteorological and climatology data. This can be done using DCS equipped smallsats in polar orbits. With a commanding capability be implemented in GOES, this DCS equipped smallsat could also relay these commands from other DCS systems. The initial concept has been successfully validated with TES-10. The concept is valid and DCS can be utilized to some degree by satellites. The launch and operation of TES-11 will provide a more significant validation of the operational challenges of this concept. Regulatory controls for access and protections will need to be considered by CGMS and the DCS hosting agencies once this second test is concluded. An agreement will need to be reached regarding the permitted use of DCS by satellite systems and under what conditions. It is expected that the task group on Data Collection Services under WG-I will prepare for an initial agreement discussion at CGMS-52.
Action/Recommendation proposed	For information at WG-1 and consideration by TGDCS

1 INTRODUCTION & BACKGROUND

DCS Transmitters (met aides) transmit in the 401-402 MHz band to uplink data to the DCPR on GOES, MeteoSat, Himawari, and possibly other satellites. Other satellites are also allocated to use this band (space-to-Earth) for space operations purposes. Nominally, there would be little, if any RF interference, with this arrangement. However, these other satellites typically transmit with omni antennas and so inadvertently also radiate in direction of the DCS receiver on GOES and other DCPR equipped satellites.

Spacecraft equipped with omni antennas are increasing in numbers, resulting in a heightened need to protect DCS from RFI, which can be difficult and costly to resolve.

Beginning in July 2020, the DCS transmitter onboard the TechEdSat (TES)-10 CubeSat had successfully passed multiple data transmissions through the GOES-E and GOES-W receivers that were subsequently decoded at the GOES ground stations. As a result, TES-10 has shown the proof-of-concept for Low Earth Orbit (LEO) DCS. It is now up to the follow-on TES-11 and perhaps TES-12 which is anticipated to launch after TES-11, to verify DCS as a practical communication medium for LEO satellites.

The TES-11 LEO DCS transmitter experiment is expected to begin in August 2023, following the launch of TES-11 on a Firefly alpha rocket into a Sun synchronous 98° inclined orbit. The TES-11 will build on the success of TES-10 by utilizing Data Collection Platform Relays (DCPRs) on four geosynchronous orbiting satellites operated by NOAA and EUMETSAT. The JMA, with their Himawari hosted DCPR, will be an interested observer for the TES-11 experiments but are not able to directly participate.

1.1 Mission Goals

The mission goal of TES-10, to *prove that DCS messages can be transmitted from a LEO platform and received on the ground through the GOES DCS transponder systems without error,* was achieved on August 20, 2020, with a successful data transmission decoded at the Microcom facility in Hunt Valley, MD.

The mission goals of TES-11 are:

1. Demonstrate that DCS messages of varying sizes can be reliably transmitted from a LEO platform and received on the ground through the GOES and Meteosat DCPR systems, error-free.
2. Additional performance characterization of the LEO transmitter interoperability with the four DCPRs.
3. Demonstration of an extended message transmission and/or potential future operational scenarios involving LEO DCS UHF transmitters.

The operations for TES-11 share similar but different 'phases' of the TES-10 operations driven by the TES-11 Sun-synchronous polar orbit, participation of the Meteosat platform and desire to demonstrate aspects of potential future operational scenarios as well as on-orbit performance characterization using the two different DCS platforms:

- The number of commands available to configure the Microcom DCS transmitter on-board TES-11 have been significantly expanded allowing operation in modes and frequencies not possible with TES-10
- The TES-11 payload will have time and date information at power up due to having a lithium battery backup clock.
- The number of transmissions that can be queued for future execution has been increased from 4 with TES-10 to 64 for TES-11
- The polar Sun-synchronous orbit will allow long periods of visibility where Doppler correction is not needed; Phase I and Phase II will utilize Doppler correction off and Doppler correction on (respectively)
- Phase III will investigate use cases where data transmission occurs when TES-11 can be viewed by two different systems.
- Phase IV will investigate additional details of demodulation performance for each of the systems.

For TES-11 we will have capability to conduct multiple campaigns, involving GOES and Meteosat together, to demonstrate the concept for DCS to provide practical, continuous, and global communication from LEO satellites.

1.2 Success Criteria

The activity detailed in the following sections demonstrates a significant step towards operational use of DCS by a satellite. There are four Data Collection Platform Relays (DCPRs) to consider:

- GOES-W and GOES-E for the United States (collectively GOES)
- Meteosat-11 and Meteosat-9 (as alternate) for Europe (collectively Meteosat); participation from Meteosat 9 is considered optional.

1.2.1 Primary Mission Success

1. TES-11 successfully transmits a message to at least two of the four DCPRs (hosted on GOES and Meteosat; at minimum one of GOES and one of Meteosat) and the message is received error-free by the associated ground-based DCS demodulators and is retrieved by the mission operations team.
2. Goal: Demonstrate the above at least 5 times
3. Goal: TES-11 will reach at least three DCPRs within one orbit.
4. Goal: TES-11 will successfully transmit messages that will be received simultaneously by a GOES and Meteosat hosted DCPR.
5. Goal: TES-11 will successfully transmit single messages that will be received error free by a Meteosat and by a GOES hosted DCPR using an iDCS channel.

6. Goal: Demonstrate long duration error free message transmission and reception, e.g., 1 minute uninterrupted. Must be done within hardware limits.

1.2.2 Minimum Mission Success

1. Successfully completing (1) above

1.2.3 Supplemental Mission Goals

In addition to the **Primary** mission goals, we include the supplemental mission engineering goals:

1. Direct transmissions from TES-11 to El Segundo and Dundee Earth stations to record and characterize the transmission signal integrity.
2. Transmissions from TES-11 and error-free reception by designated DCPRs using different channels, and different data rates or formats. Successful switching between channels, data rates, and formats.
3. Successful tracking of Doppler-corrected transmissions by GOES and Meteosat ground demodulators.
4. Successful completion of all phases of the TES-11 Con Ops.
5. Collect sufficient information to enable a more efficient design for a satellite specific DCS transmitter.

2 LEO DCS EXPERIMENT CONCEPT

The DCS transmitter is placed onboard the TES CubeSat to transmit data from the CubeSat to a GOES, Meteosat or Himawari DCS receiver that downlinks the data to demodulators located in the GEO satellite's associated ground station. Because the DCS transmitters and associated frequency plan have been designed for transmission from the ground to GEO, no consideration for Doppler was addressed in the frequency plan operation of the DCS. In LEO, the Doppler shift near 400 MHz from the CubeSat in LEO to a receiver located at GEO can approach and exceed 10 kHz in magnitude. In comparison the channel width of DCS and iDCS channels are significantly less than the Doppler shifted signals at their point of reception, Doppler compensation was designed into the DCS transmitters placed in LEO for these proof-of-concept experiments. We note that for most future operational scenarios, Doppler correction of the transmitter signal would be generally avoided in favor of design to allow error-free reception of Doppler shifted signals.

2.1 Operational Summary

The experiment consists of TES-11 small sat (DCS transmitting satellite) in LEO transmitting test sequences to be received by any of the participating GEO-based Data Collection System Platform Radio (DCPR) in the 402 – 403 MHz uplink band. The DCPRs that can receive TES-11 signals are located on GOES-West, GOES-East and Meteosat. The DCPR translates the signal received from TES-11 in the DCS uplink band to the DCS downlink band and retransmits the signal near 1.6 GHz. The test message is then decoded after being received by any of several DCS ground stations that may receive the downlink from GOES or Meteosat.

When the 1.6 GHz downlink signal is received by the ground station it is decoded by a demodulator unit tuned to the specific channel of the DCS transmission. The signal demodulators utilized in the experiment at GOES ground stations will include modified units capable of decoding signals with Doppler drift up to ~ ±15 Hz/s to allow for proper decoding of non-Doppler compensated TES-11 transmissions to GOES DCPRs. For Meteosat, demodulators may handle up to ~ 7.5 Hz/s Doppler drift allowing for decoding of signals in most but perhaps not all TES-11 transmission scenarios.

2.2 TES-11 Orbit Description

The TES-11 will be placed in a Sun synchronous polar orbit with nominal altitude of 565 km. Unlike TES-10, the orbit for TES-11 provides several opportunities for transmission to the geosynchronous DCPRs without Doppler correction, and for extended periods of time. For highly inclined orbits, when the plane of the orbit is nearly perpendicular to the line-of-sight for a GEO-based receiver, the magnitude and drift of the Doppler from the LEO is small enough to remain within the bounds necessary for error-free reception of the DCS message. These windows of opportunity will exist for each GEO roughly once (or twice) within each 24-hour period for each GEO (GOES-E/W, Meteosat 11, and 9). Himawari is not participating, but its location will be monitored to minimize any potential for interference to their DCPR.

2.3 Frequencies for use with GOES and MeteoSat DCS Receivers

2.3.1 GOES Frequencies

The TES-11 GOES tests will utilize Channel 429. Channel 429 was chosen for the GOES tests due to its location adjacent to several random-access channels both above and below it in frequency. The DCS random access channels users must accept slightly higher probability of transmitted signal ‘collisions’ and RFI due to the random vs. timed nature of DCS transmissions on the Channel. Accordingly, potential RFI to random access channels adjacent to Channel 429 due to Doppler shift and drift of TES-11 signals will be consistent with the normal rules of operation of Channels in that region.

2.3.2 MeteoSat and iDCS Frequencies

The testing will utilize International DCS frequencies and selected Meteosat channels. There are 11 iDCS channels, numbered accordingly, on each GOES and METSAT. Each channel is 3kHz wide.

Table 1. International DCS Channel Table

Channel	Center Frequency (MHz)	Channel	Center Frequency (MHz)
1	402.035500	7	402.053500
2	402.038500	8	402.056500
3	402.041500	9	402.059500
4	402.044500	10	402.062500
5	402.047500	11	402.065500
6	402.050500		

For the purposes of the METSAT campaign iDCS Channels 3−9 (inclusive) will be designated *alert mode* channels, that is, channels open to brief random transmissions. The center frequency of Channel 6 is the target frequency for all METSAT-bound LEO transmissions.

The three channels on either side of Channel 6, Channels 3/4/5 below and Channels 7/8/9 above, accommodate the frequency offsets of Doppler-uncorrected transmissions.

With these "guard channels" in place, Doppler-corrected transmissions in Phase II can be received by the selected Meteosat correctly and without causing unacceptable interference to the other Meteosat. However, all other satellites in view of the transmitting TES-11 will receive the transmission frequency shifted within the range of channels 3−9. It is also anticipated that Doppler-corrected transmissions in Phase I or Phase II will not interfere with ongoing ground-based alert mode transmissions.

3 RECOMMENDATIONS FOR CONSIDERATION BY CGMS WORKING GROUP 1

This project has validated that satellites can use DCS. The concept is being validated for international DCS support and a more operational use of the system concept. Discussion is needed to decide as to the approval and implementation of satellite use of DCS and under what regulatory controls.

Regulatory controls and protections will need to be considered by the CGMS and the DCS hosting agencies once this second test is successfully concluded. An agreement will need to be reached regarding the permitted use of DCS by satellite systems and under what conditions. It is expected that the task group on Data Col-lection Services under WG-I will prepare for the agreement discussion at CGMS-51.

4 CONCLUSION

DCS systems have come under pressure from small satellite constellation companies that seek additional usable RF spectrum and wish to increase use of this band for their space operations. We expect that satellite use of the DCS system will alleviate some of this risk and may further strengthen the value of protecting the system.

Satellite use of the DCS also fosters a new means for collecting and distributing meteorological and climatology data. This can be done using DCS equipped smallsats in polar orbits. Additionally, should a commanding capability be implemented in GOES, this DCS equipped smallsat could also relay these commands from other DCS systems.

The initial concept for Satellite use of DCS has been successfully validated through TES-10. We can now say that the concept is valid and that DCS can be utilized to some definable degree by satellites. The launch and operation of TES-11 will provide a more significant validation of the operational challenges of this concept. The TES-11 demonstration will be complete by the end of 2023 if our launch occurs as expected. An additional experiment involving both TES-11 and TES-12 as dual DCS hosting satellites may be possible in 3rd QTR of 2023.

Once this second stage of our project is completed, then the more important and challenging phase of determining the policy for permitting DCS use by satellites and under what conditions by the respective organizations and CGMS on this matter should begin.