CGMS-52-WGI-WP-06
V1A, 19 March 2024

Prepared by WGI
Agenda Item: 5.1
Discussed in WGI

Report from the CGMS WGI Task Group on Low Latency Data Access

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1 WGI COMBINED REPORT: DIRECT BROADCAST SYSTEMS AND LEO COORDINATION OF ORBITS TASK GROUPS

1.1 About CGMS

The Coordination Group for Meteorological Satellites (CGMS) is the group that globally coordinates meteorological satellite systems. This includes protection of orbit assets, contingency planning, improvement of quality of data, support to users, facilitation of shared data access and development of the use of satellite products in key application areas.

The coordination is pursued from an end-to-end perspective, through development of multi-lateral coordination and cooperation across all meteorological satellite operators in close coordination with the user community such as WMO, IOC-UNESCO, and other user entities.

EUMETSAT is the permanent secretariat of the CGMS and responsible for securing the annual plenary session, following up of plenary actions, guiding CGMS during the inter-sessional periods between plenary sessions, guiding the CGMS working groups, and general management and administration.
There are five CGMS Working Groups: WG I on satellite systems and operations; WG II on satellite data and products; WG III on operational continuity and contingency planning; WG IV on support for end users; and SWCG on space weather coordination.

The Direct Broadcast Task Group and the LEO Coordination of Orbits Task Group belong to the WG-I, more information can be found on the CGMS website.

1.2 Document Structure

- **Section 1** (present section): Provides a review of the CGMS actions assigned jointly to the Direct Broadcast and LEO Coordination of Orbits task group for CGMS-52;
- **Section 2:** Contains Terms of References (ToR) of the Low Latency Data Access from LEO Meteorological Satellites Task Group;
- **Section 3:** Contains the response to actions WGI/A51.07 and WGI/A51.08 via production of a SWOT analysis;
- **Section 4:** Contains the response to action WGI/A51.09 via production of a Low Latency Data Access from LEO Meteorological Satellites Best Practices document;
- **Section 5:** Contains material in response to “Future information technologies - internet-of-things items”;
- **Section 6:** Contains recommendations and actions for CGMS-53.

1.3 Actions for CGMS-52

TG	AGN item	Action #	Description
LLDA	5.1	WGI/A51.06	Merge the Direct Broadcast Systems and LEO Coordination tasks groups into a single "Low latency Data Access from LEO Satellites" task group, with Andrew Monham and Antoine Jeanjean as Co-chairs. Finalise the draft Terms of Reference with inputs from WGI and taking into account the specific goals from the CGMS Position Papers, in particular the "Future Information Technologies" and "Future Observing (Hybrid) Space Infrastructures". Present the finalised ToRs for endorsement to CGMS-52. The work of the TG should include keeping the SWOT analysis current (process to be noted in the ToRs). As part of the merge, update and present the list of members, create a new mailing list LWGI_LLDA@LISTSERV.EUMETSAT.INT, remove old mailing list.
LLDA	5.1	WGI/A51.07	Distribute a summary of the SWOT analysis on Low Latency Data Access from LEO meteorological satellites to the remaining CGMS Working Groups.
LLDA	5.1	WGI/A51.08	Analyse potential role of satellite platform as a service (SPaaS), considering current and expected providers, internet connection speed, hosted instruments specifications (size/weight/power), orbit type, satellite lifetime and cost breakdown. Report to CGMS-52.
LLDA	5.5	WGI/A51.09	Merge the LEO (Global) and DB (regional) best practices into a single "Low Latency Best Practices" document proposed to be structured as follow: • Common BPs for both regional and global missions • BPs specific for DB • BPs specific for global mission Present the merged BPs for endorsement to CGMS-52.

Table 1: Low Latency Data Access Task Group Actions for CGMS-52

2 WGI/A51.06 LOW LATENCY DATA ACCESS TERMS OF REFERENCE (LLDA TOR)

In response to WGI/A51.06, the LEO ToR and Direct Broadcast WGI objectives were used as inputs to produce the Latency Data Access Task Group ToR in this section.

1. To provide a forum for CGMS agencies to address improving LEO satellite systems low latency data access from both a global and regional perspective, harnessing common emerging technologies and taking account of the evolution of the commercial and agency space systems. It is foreseen that historical boundaries between global and regional mission requirements and architectures may be substantially eliminated. This shall include analysis of:
    a. Novel methods to achieve global data coverage and access;
    b. Temporal coverage over a given geographic area;
    c. Low latency data delivery;
    d. Reducing pass scheduling conflicts;
    e. Maximising the amount of instrument observation collected;
    f. Reducing risk of radio frequency interference;
    g. Fixed temporal separation between instrument observation;
    h. Reduced risk of satellite proximity;

2. To address technical and operational aspects of direct broadcast services (present and future) of mutual or global interest for the CGMS agencies;

3. To promote standards and interoperability and operational procedures to the CGMS agencies for the benefit of the user community of their direct broadcast services and the associated regional retransmission services;

4. To explore impact of space-based data relay systems. Specific studies may be actioned by WGI to the LLDA TG to assess impact of new technologies on enabling innovative solutions to achieve low latency data access from LEO weather satellites;

5. The LLDA task group report to CGMS WGI;

6. The LLDA task group will nominate a chair. It will meet at least once a year, and more if necessary, and will pursue its work by correspondence between its meetings.

Current LLDA TG are Andrew Monham and Antoine Jeanjean acting as co-chairs. The TG will meet at least 3 times per year. The TG has a specific mailing list: L-WGI_LLDA@LISTSERV.EUMETSAT.INT.

7. The LLDA yearly documents deliverables consist of:
   - Item 1: Report from the CGMS WGI Task Group on Low Latency Data Access of LEO satellites (EUMETSAT)
   - Item 2: Operational systems status report of LEO satellites + status of implementation of best practices (CMA)

- Item 3: Operational systems status report of LEO satellites + status of implementation of best practices (EUMETSAT)
- Item 4: Operational systems status report of LEO satellites + status of implementation of best practices (NOAA)
- Item 5: Best Practices for Low Latency Data Access of LEO Satellites - latest version and new proposals (EUMETSAT)

3 WGI/A51.07/08 SWOT ANALYSIS OF LOW LATENCY DATA ACCESS FROM LEO METEOROLOGICAL SATELLITES

The document "Strengths, Weaknesses, Opportunities and Threats (SWOT) Analysis of Low Latency Data Access from LEO Meteorological Satellites" [CGMS-52-EUMETSAT-WP-13] was produced in response to WGI/A51.07.

This SWOT analysis also contains an analysis on the potential role of satellite platform as a service (SPaaS), in response to WGI/A51.08 where SPaaS are identified as an opportunity.

4 WGI/A51.09 LOW LATENCY DATA ACCESS FROM LEO METEOROLOGICAL SATELLITES BEST PRACTICES

The document "Merge of LEO Direct Broadcast and Coordination of LEO Orbits Best Practices proposal" [CGMS-52-CGMS-WP-03] was produced in response to WGI/A51.09.

5 FUTURE INFORMATION TECHNOLOGIES - INTERNET-OF-THINGS ITEMS

5.1 INTRODUCTION

Background
CGMS-50 plenary (15-17 June 2022) endorsed the proposal by the CGMS Secretariat for considerations for the future direction of CGMS (Ref. CGMS-50-CGMS-WP-20 and CGMS-50-CGMS-WP-38) in view of the changing environment and in order to take stock of the current and future CGMS activities.

Overall there was:
- consistent support for a review of the strategic direction;
- interest in implications of new opportunities and challenges for the CGMS community;
- a need for reprioritisation and focussing of activities;
- a need to review interfaces with other bodies and activities;
- a need that the refocussing shall be strategic rather than entirely bottom up; and
- a need to establish the review focus.

To perform a strategic review of CGMS activities and processes and ensure that CGMS continues to best serve its members and users, in a rapidly changing environment.

This activity is needed to:
- Take into account the impact of the changing environment and user requirements, and the need for CGMS to remain user-driven and operational;
- Take into account changes in CGMS leadership;
- Set the priorities for the next 10 years and beyond; and
- Regularly assure CGMS activities address issues of importance to space agencies and users in the long term.

The CGMS Future Direction theme "Future Information Technologies - Internet-of-Things" item is coordinated under WGI.

Scope

Internet-of-Things can be defined as "*the connection of devices within everyday objects via the internet, enabling them to share data*" (Oxford Dictionary). The scope of Internet-of-Things applications, commonly referred to as IoT is wide, englobing household's appliances to connected cars, airplane, etc.

This CGMS paper narrows the spectrum of IoT applications to focus primarily on IoT for Earth Observation, noting the two following aspects of importance to CGMS WGI:

(i) **IoT applications for LEO satellites**, which enable data connectivity for LEO meteorological satellites. A CGMS WGI application example would be direct broadcast, enabling transfer of payload data from LEO meteorological satellites in near real time.

(ii) **IoT applications for ground-based devices**, which enable data connectivity for ground-based meteorological devices. A CGMS WGI application example would the DCS system, enabling transfer of ground-based weather station data via meteorological GEO satellites.

5.2 Literature Review of Technologies Providing IoT Solutions for Earth Observation

The three main IoT technologies providing IoT solutions for Earth Observation are: (i) GEO relay satellites, (ii) LEO relay satellites and (iii) global network of ground stations. Each of these three technologies are detailed and analysed in this section.

An initial literature review of technologies providing IoT solutions for earth observation was conducted with the CGMS-50-CGMS-WP-08 and CGMS-51-CGMS-WP-06 CGMS WGI papers.

Findings are now summarized in the document "Strengths, Weaknesses, Opportunities and Threats (SWOT) Analysis of Low Latency Data Access from LEO Meteorological

Satellites" CGMS-52-EUMETSAT-WP-13, which will be reviewed and maintained on a yearly basis.

IoT providers enabling connectivity to LEO satellites

5.2.1 GEO IoT providers

Internet on LEO satellite is now a reality with the availability of GEO IoT solutions, providing up to 200 kbps internet to LEO satellites.

Currently, only GEO and MEO data relay can provide connectivity to a LEO meteorological satellite.

The Figure 1 below shows an overview of the GEO data relay service system which consists of:

(A) GEO Relay Space segment;
(B) Ground station as a service from GEO relay operator; or
(C) Ground station operated by CGMS agency.

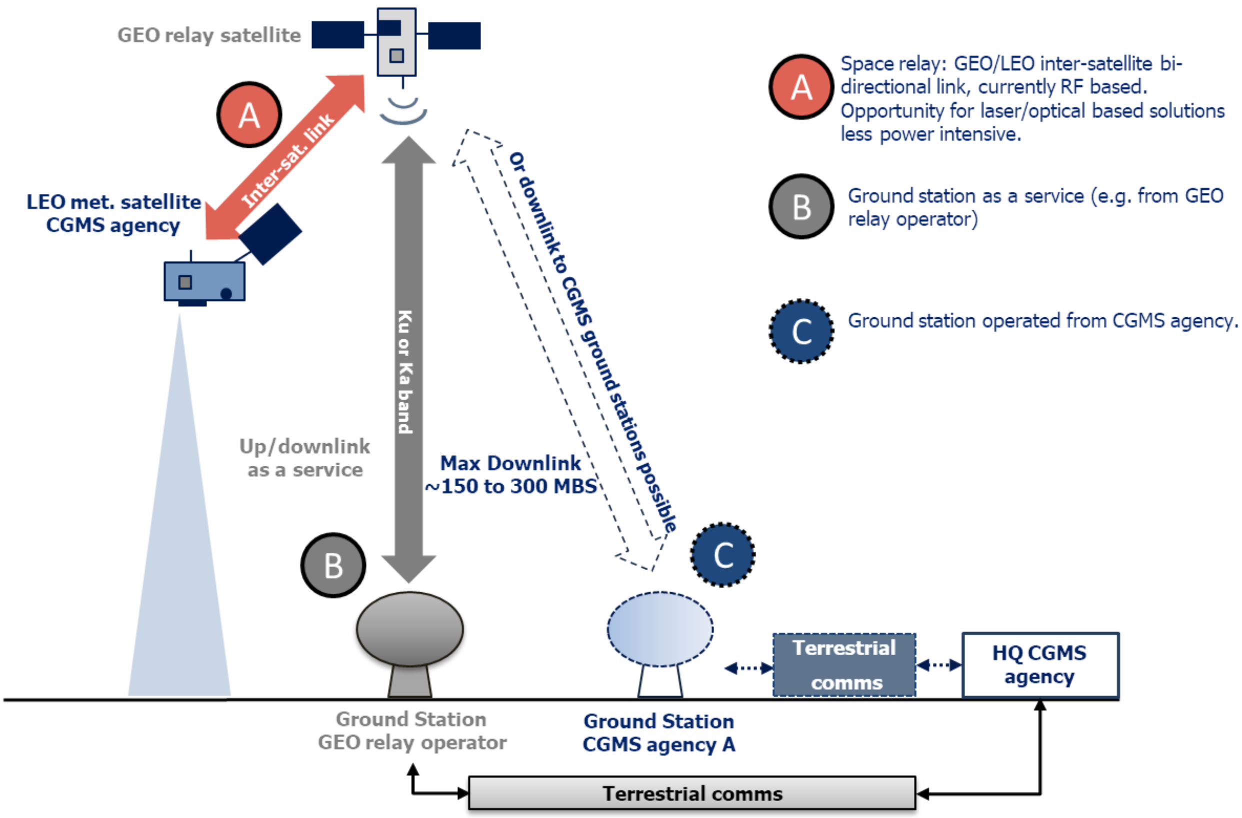

Figure 1: GEO Data Relay Service

The space segment is composed of one or several LEO meteorological satellites and a minimum of 3 GEO relay satellites needed to provide worldwide coverage. Global coverage would most likely be offered from a set of GEO relay operators depending on the globe location. However some operators already offer a full global coverage service (e.g. Inmarsat Global Xpress).

A series of 3 to 4 GEO relay satellite receives data from the LEO meteorological satellite via an inter-satellite link and repatriates it to a ground station. They are two possible LEO to GEO solutions for this:

i. The GEO global beam satellites (used by commercial GEO IoT)
ii. GEO equipped with steerable antenna (e.g. as done for NOAA TDRS and EDRS). These need to be scheduled by the transmitting satellites are not designed to take multiple, parallel transmissions. This solution would be expensive, as only a few satellites could be supported if a RT link is required (rather than transmission of recorded data) when in visibility. Advantage of this solution is support for polar measurements and relatively straightforward to schedule transmissions (equivalent to transmission to a ground station).

The inter-satellite links between a LEO and GEO using beams are RF based signal. For example, IQ spacecom offers a lightweight transponder (200 grams) that provides internet connectivity to the Inmarsat GEO fleet, see Figure 2 below. This capability provides bi-directional connectivity to the spacecraft at 200 kbps.

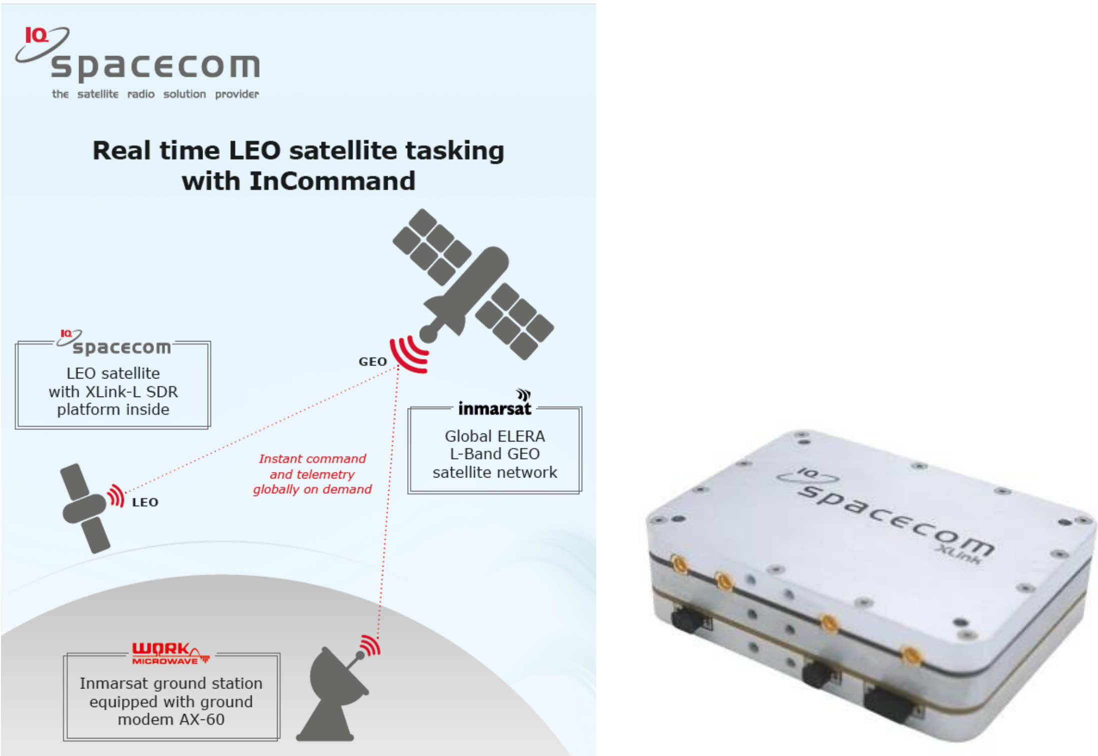

Figure 2: Low cost, lightweight system for instant tasking of small LEO satellites (Inmarsat and IQ spacecom)

<u>Price:</u>
The current price of the GEO relay service for a LEO satellite is approximately 1k/euros/month per GB transferred. The evolution of the GEO relay service cost is expected to decrease as a result of increased competition on the on GEO relay market as well in the MEO / LEO relay market.

A non-exhaustive list of IoT providers to LEO satellites is provided in the Table below:

IoT providers	Constellation	Link to material
Viasat	GEO	ARBALEST program
Inmarsat	GEO	IDRS – see IoT4EO presentation
SES Astra	GEO	Via O3b mPOWER – see IoT4EO presentation
Neosat	GEO	Home webpage

Table 2: GEO IoT providers

<u>DCS:</u>
The Satellite DCS Use Concept Validation project has successfully demonstrated that LEO satellites can successfully interface with the Data Collection System (DCS) receivers (DCPR) and 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 implemented in GOES, this DCS equipped smallsat could also relay these commands from other DCS systems. NOAA/NESDIS initiated this project to determine, successfully, that a satellite can interface effectively within the DCS.

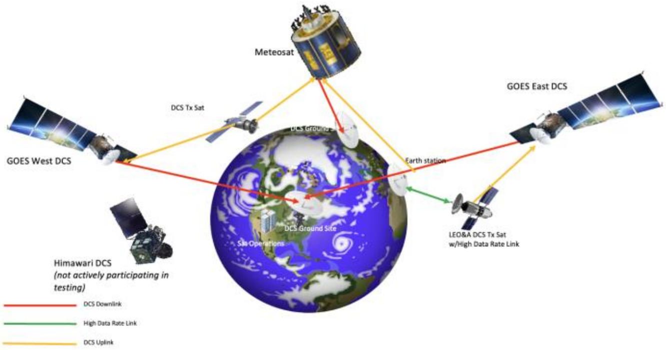

Figure 3 - Satellite use of DCS communications architecture

5.2.2 LEO IoT providers

None.
Current LEO relay constellation, such as Starlink, do not accept space communications from external satellites (e.g. from non-Starlink satellites). It could be that future LEO relay constellation will provide an entry connection point for LEO satellites external to the constellation, although no offers are currently on the market.

5.2.3 Global network of ground stations

Global network of ground stations can provide data connectivity to a LEO meteorological satellite.

5.2.4 DBNET Network

The DBNET network is a dedicated infrastructure for acquisition of direct broadcast that has been growing during the last decades. Although allowing connectivity from LEO satellites, this network is passive (no uplink possibility to LEO satellites).

Today, direct broadcast reception allows for almost full coverage of the globe for the reception of sounding services as shown on Figure 4 below:

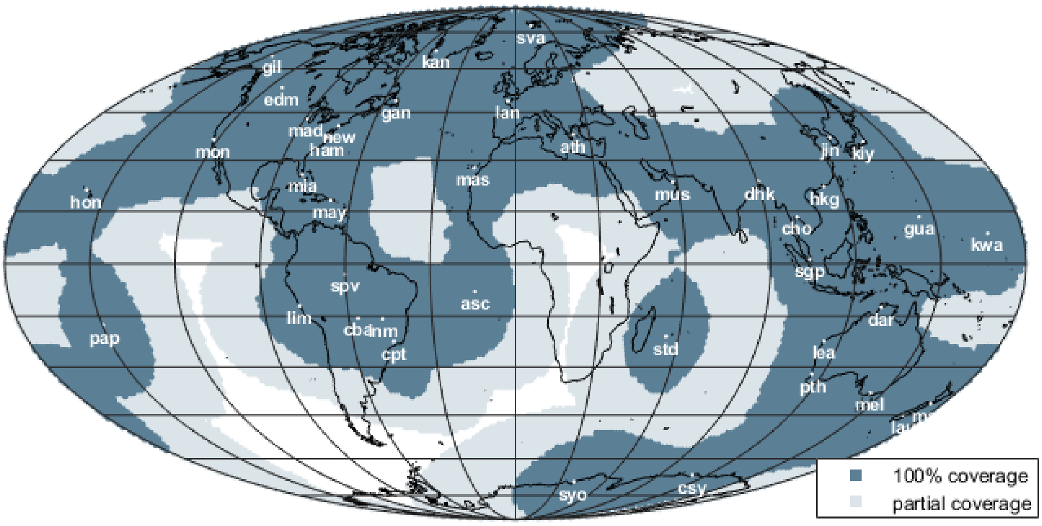

Figure 4: DBNet-ATOVS coverage in October 2022

Reception gaps are seen in white. The reception gap in Africa is expected to disappear via the completion of the SAWIDRA project. One remaining gap would be over the Pacific Ocean.

Accounting for the fact that infrastructure is already deployed, acquisition cost of a LEO pass for a CGMS operating agency ranges at around ~$10 per pass.

5.2.5 Private sector

The Figure 5 below shows a non-exhaustive list of current global network of ground stations offers from the private sector. These stations can offer either passive or active (i.e. downlink with possibility of uplink).
The cost of a pass acquisition from a private ground station is around ~$100 per pass.

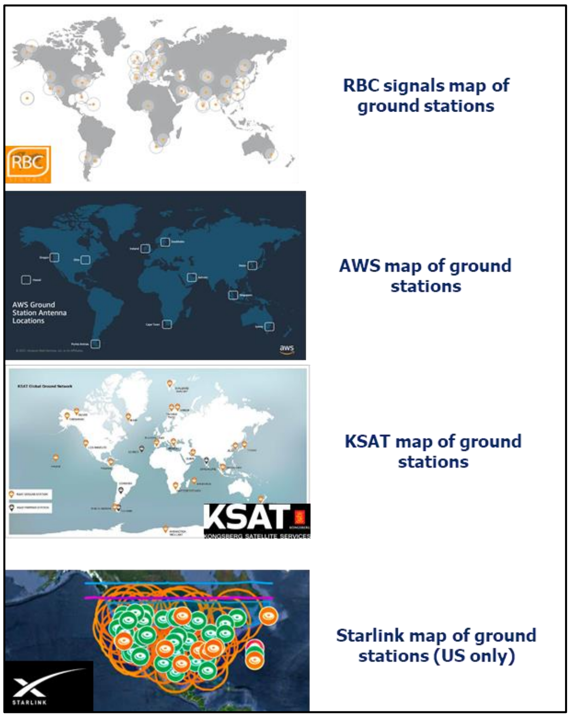

Figure 5: Non-exhaustive list of current global network ground stations

<u>IoT providers enabling for ground-based devices</u>

5.2.6 GEO IoT providers

5.2.6.1 Data Collection System (DCS)

The Meteosat Data Collection and retransmission Service (DCS) enables Data Collection Platform (DCP) Operators to use the Meteosat Meteorological Satellite System to retransmit DCP data collected from remotely located platforms to their own reception stations and to the Global Telecommunication System (GTS) community of the World Meteorological Organisations (WMO). The Meteosat satellites located at 0° and over the Indian Ocean acquire tide-level data from DCPs situated on moored buoys as part of the Tsunami Warning network. The data collected and transmitted by the platform are disseminated using the GTS. Each DCP transmits at 100 bps every 15 minutes, which is adequate for this type of application; however plans are in place for the implementation of High Rate DCPs. These new type of platforms will be capable of transmitting data at 1200 bps. See "THE METEOSAT DATA COLLECTION SYSTEM" document for more information.

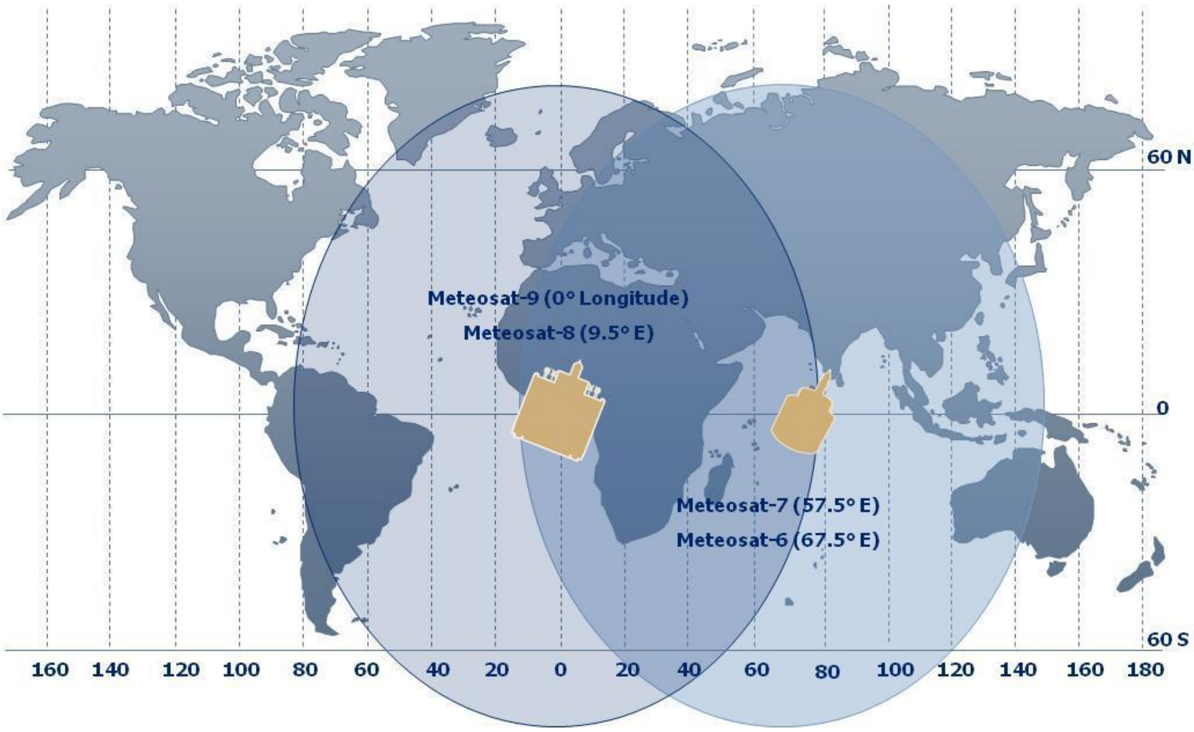

Figure 6: DCS coverage by EUMETSAT's Geostationary Satellite

5.2.6.2 Private sector

The GEO IoT providers market for ground-based devices is well matured. Internet is provided via parabolic antenna, usually provided alongside a modem by the GEO IoT providers. Some GEO IoT providers have services that business to business oriented (e.g. Inmarsat), while others are targeted the general public (e.g. Viasat). The GEO IoT providers to LEO satellite previously listed in Table 2 have also IoT offers for ground based devices.

5.2.7 LEO IoT providers

LEO constellations are a strong competitor to the GEO providors for ground-based devices. Main reason being that the LEO satellites flying in a lower orbit mean that smaller size antenna are required with lower power emissions to connect ground-based devices. However, revisit time can be an issue, especially for new constellations with limited number of satellites, ranging to several hours.

The number of relay satellites for a LEO constellation can range from a small number to several thousand (12000 satellites for SpaceX Starlink V1 system with option to extend to 42000 for Starlink V2 system).

(a) (b) (c)

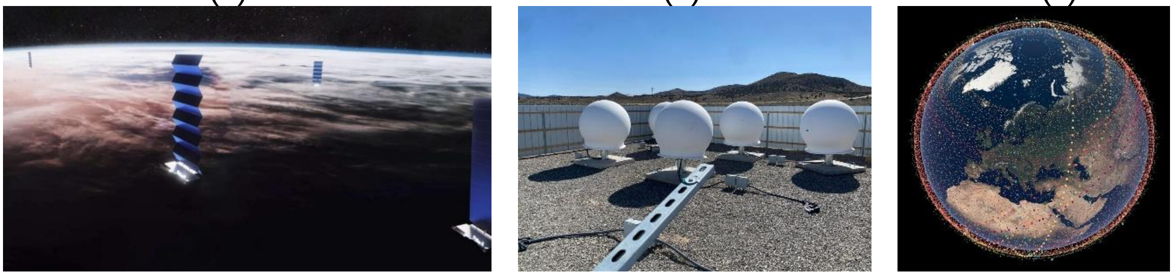

Figure 7: SpaceX Starlink constellation with (a) artist view of constellation (image credit SpaceX) (b) typical Starlink ground station gateway (image credit Reditt) (c) Visualisation of the 30 000 planned satellites from the Starlink Generation 2 constellation as of 2022. Different sub-constellations are illustrated with a different colour (image credit ESO).

Inter-satellite link between satellties are currently RF based, which is the case for Starlink V1.0. However, next generation of Starlink V1.5 and V2.0 satellites will uses laser inter-satellites communication. Laser based communications have the advantages of light weight and lower on-board power consumption but brings a threat of compatibility as they are currently no standards.

The cost of LEO relay is much lower of about 110 dollar for 50 Mbps per month for a personal Starlink user and 5000 dollar per month for a marine corporate user with higher bandwidth of up to 350 Mbps (https://www.starlink.com/maritime). Therefore, accounting for the price of a corporate Starlink user, brings an indicative price of ~$15/Mbps/month for a LEO relay constellation.

For downlink, the Ku and Ka bands are the current standard, which for example used for the MEO and Starlink V1 satellites. However, the V2.0 Starlink satellites will fly in a lower ~350 km orbit and operate in V band.
For LEO constellations, the ground stations are operated by the relay satellites operator meaning that the data access to/from the LEO meteorological satellite is providing as a service.

5.2.8 Common internet providers

This section is to reference the fact that ground-based devices can obviously be connected internet via “common” providers via wifi, gsm, etc.
However, as ground based meteorological devices (e.g. weather stations, probes) are often located in remote areas, analysis in this study will only account for GEO and LEO IoT providers for ground-based devices.

5.3 Potential Applications and Benefits of IoT Solutions For CGMS Agencies

<u>LEO IoT to complement DCS in polar locations</u>
The current DCS system provides a relay solution to ground-based meteorological devices for latitudes up to 75° (see Figure 6). This study encourages the use of LEO IoT providers that could provide coverage for greater northern and southern latitudes (see Recommendation 4).

Each LEO IoT providers has its specificity. For example, a provider such as Astrosat offers very competitive price while revisit time can be several hours due to the low number of satellites. Another provider such as Starlink offers almost continuous data connectivity with bandwidth up to 100 Mbps, although power consumption and antenna size are relatively important. This study therefore recommends to WGI to conduct an analysis to identify the optimum(s) LEO IoT provider that could complement DCS applications in polar locations, considering key elements such as:

- Data rate;
- Cost;
- Power consumption;
- Transponder size.

<u>GEO IoT to open new mode of operations for LEO meteorological satellites?</u>
Internet on LEO satellite is now a reality with the availability of lightweight (200 grams) GEO transponders as COTS, providing up to 200 kbps internet to LEO satellites. The main associated cost of internet provision to a LEO satellite is charged on the volume of data used.
Live connectivity to the LEO satellite provides the potential to open new mode of operations for LEO meteorological satellites for about 90% orbit coverage, when the LEO satellite is outside of the ground segment coverage.

5.3.1 Telemetry & Telecommand

Telemetry and Telecommand (TM&TC) operations for LEO meteorological satellites are traditionally executed via polar stations. Although TM&TC downlink operations are possible via direct broadcast stations, live connectivity to the LEO satellite provides the potential to perform TM&TC uplink operations outside ground segment coverage such as:

- Direct commands to the spacecraft for reconfiguration;
- Application-specific commands.

With an increasing debris environment in the LEO orbits, it is now routine for CGMS operators to perform ‘collision avoidance manoeuvres’. Live connectivity to the LEO satellite provides via GEO IoT solutions would allow to perform these manoeuvres live, outside ground segment coverage.
This study encourages the adoption of GEO IoT solutions for future LEO programs, enabling new mode of operations (see Recommendation 6).

5.3.2 Downlink of LEO meteorological satellites instrument payload

This paper identifies three solutions for repatriating LEO meteorological satellite payload in low latency which are GEO IoT and direct broadcast. Direct broadcast acquisition can be achieved via a network of ground stations which are either subsidised (e.g. most of existing DBNET stations, see section 5.2.4) or commercial (see section 5.2.5).

5.3.2.1 Performance

<u>Timeliness</u>
All solutions offer similar timeliness performance, in terms of reception of raw data to the ground. All timeliness figures between sensing time and acquisition time are within milliseconds.

<u>Coverage</u>

Almost full disk coverage are offered by GEO IoT and DBNET network with some differences. GEO IoT offers full disk coverage except for polar latitudes. DBNET offers disk coverage with exception of oceanic regions and Africa, see Figure 4.

5.3.2.2 Cost

This section compares the cost of repatriating LEO meteorological payload data in low latency. Assumptions for cost estimates are detailed in Table 3 and Table 4 (see Annex I).
It is found that subsidised direct broadcast stations (e.g. DBNET type) offer the best value in terms of money per Gb transmitted for acquiring LEO satellites that have a payload data rate greater than 10 kbps. Assumptions for cost estimates are detailed in Table 3 and Table 4 in Annex I.

FY3D (35 Mbps), JPSS (15 Mbps), METOP (3500 kbps) and Sterna (67kbps) instrument data rate are all above the 10 kbps threshold, therefore direct broadcast offers the best value for money to repatriate current payload data from CGMS LEO satellites.

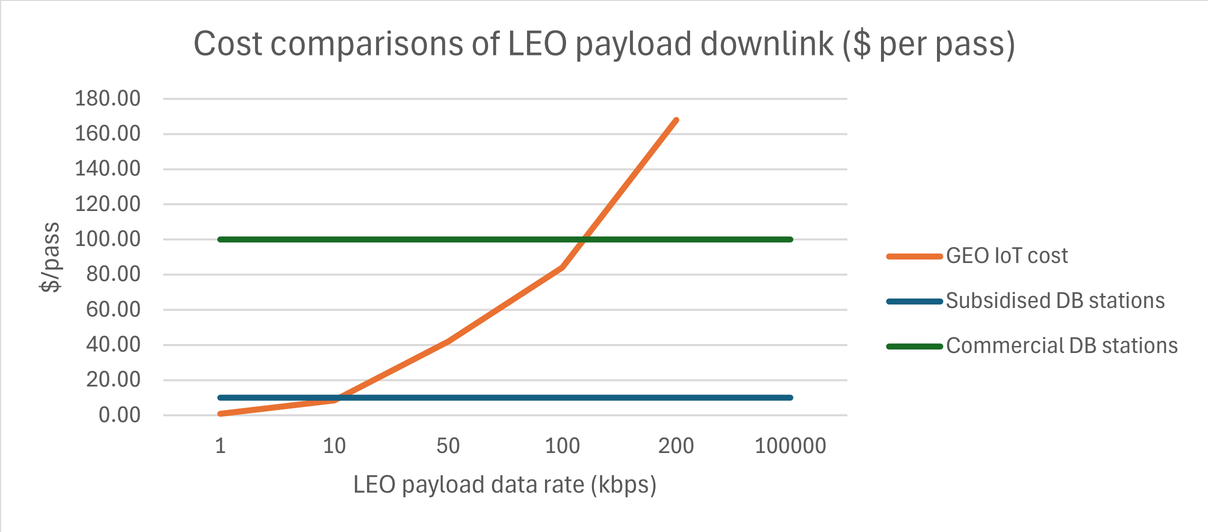

Figure 8: Cost Comparison Analysis of IoT Solutions for LEO Payload Downlink

5.4 Conclusion

This study highlights the rapidity at which the "new space" sector is evolving. Although only a conceptual idea a couple of years ago, internet connectivity to LEO satellites is now a reality with lightweight transponders available as COTS providing 200 kbps link. The LEO IoT market has been disrupted within the last 5 years with the apparition of providers such as SpaceX, offering internet connectivity for ground-based users with up to 100 Mbps at competitive price.

Today, IoT solutions should be seen as opportunities for CGMS agencies. As highlighted in the recommendations section, this study encourages their adoption to either enhance existing system such as DCS or enable new mode operations regarding the use GEO IoT connectivity to LEO meteorological satellites. This study however finds that direct broadcast remains a better value for money solution to GEO IoT for instrument payload downlink.

More generally, this study also raises the question of the CGMS position to follow regarding the emergence of the "new space" sector. With regards to sustained innovations (e.g. LEO IoT for DCS), a first option would be to encourage CGMS agencies their adoption. With regards to disruptive innovations (e.g. satellite platform as a service), an option would be to have some level of coordination performed at CGMS level regarding innovation.
One could indeed see at CGMS level some kind of feedback being brought by agencies trialling or adopting new space technology.

6 RECOMMENDATIONS FOR CONSIDERATION BY CGMS WORKING GROUP I

WGI is invited to consider the following recommendations:

<u>LOW LATENCY DATA ACCESS TERMS OF REFERENCE (LLDA TOR)</u>

1. Take note and endorse the Terms of Reference for the Low Latency Data Access task group presented in Section 2.

<u>SWOT ANALYSIS OF LOW LATENCY DATA ACCESS FROM LEO METEOROLOGICAL SATELLITES</u>

2. Take note and comment on the document SWOT analysis of Low Latency Data Access from LEO Meteorological Satellites [CGMS-52-EUMETSAT-WP-13].

➔ Proposed regular action to review and update SWOT on a yearly basis.

LOW LATENCY DATA ACCESS FROM LEO METEOROLOGICAL SATELLITES BEST PRACTICES MERGE

3. Take note and comment on the draft Merge of LEO Direct Broadcast and Coordination of LEO Orbits Best Practices.

➔ Proposal to publish the document by CGMS-53. The document would benefit from one further round of iteration inside the LLDA task group.

<u>FUTURE INFORMATION TECHNOLOGIES - INTERNET-OF-THINGS ITEMS</u>

4. Take note and comment on Future Information Technologies - Internet-of-Things Items presented in Section 5.
5. Take note and comment on the possibility to use a LEO IoT solution for complementing DCS in latitudes beyond 75° out of reach from the DCS GEO satellites (see Section 0).
6. Take note and comment on the possibility to use GEO IoT connectivity to LEO meteorological satellites, enabling new mode of operations (see Section 0).

ANNEX I COST COMPARISON ANALYSIS OF IOT SOLUTIONS FOR LEO PAYLOAD DOWNLINK

IOT solutions for LEO payload downlink	Cost assumption	Comment
Direct Broadcast – subsidized station	~$10* per pass	Subsidised cost considering ground station infrastructure already built. Estimate only covering station exploitation and maintenance cost. This cost assumption also assumes a full usage of a reception chain with acquisition of all DBNET satellites (around 1000 passes per month).
Direct Broadcast – commercial station	~$100 per pass	Cost considering a direct broadcast acquisition by commercial ground station. Cost assumption for around 1000 passes per month.
GEO IoT	~$1k per GB per month	Flat rate for GEO IoT solution for LEO payload downlink. Costing estimate does not reflect potential cost reductions with high volume of data.

Table 3: Cost assumptions of IOT solutions for LEO payload downlink

LEO data rate (kbps)	Data volume (Kb/pass)	GEO IoT cost ($/pass)
1	840	0.84
10	8400	8.4
50	42000	42
100	84000	84
200	168000	168
100000	84000000	(not possible, max data rate 200 kbps)

Table 4: GEO IoT cost depending on LEO payload data rate. Data volume based on assumption of 14 minutes passes long (840s).