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A Canadian Network of Arctic Ground Stations for Operations and Research

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Abstract

Since 2018, C-CORE has been developing and operating a niche network of remote sensing ground stations. The stations located in Inuvik and Happy Valley Goose Bay have been used to operationally retrieve data from multiple imaging satellites for Canadian and international customers.

The stations are operated remotely with custom acquisition planning, telemetry and data acquisition, and transmission and data communications. All functions are fully automated and do not require routine interactive operations. A management function is available from a cloud resident hybrid with fully distributed supervisory operations that removes the need for a conventional operations centre.

The remote operation has led to the creation of state-of-the-art operational systems including C-CORE's SmartTerminal™ that allows management and planning for multiple satellite systems, across multiple ground stations from one interface. It supports dynamic scheduling with multiple satellite operators and incorporates diverse ground equipment. It provides optimal pass allocation to antennas and ensures efficient use of every aperture.

C-CORE is using its operational stations to advance several new technologies: TReND™ (a satellite predictive health tool) and ADAPT™ (a data integrity/security tool) are two current advancements.

C-CORE's TReND™ system provides machine learning based tools to examine pattern of life of satellite telemetry to predict operating health. TReND™ was developed by C-CORE to reduce satellite operations costs and an initial technology demonstration was supported by the Canadian Space Agency.

C-CORE's ADAPT™ data security system provides operational provisioning of data from inception through to transmission and data utilization. ADAPT is a state-of-the-art data provisioning system that combines cryptographic and ledgering systems at the disk access level to packet-wise encode and track data. The ADAPT system has demonstrated secure and provisioned data access and transmission in both interior client systems and external cloud applications.

Both TReND™ and ADAPT™ will be integrated into the ground station network as part of an operational demonstration with an upcoming CubeSat mission. This paper outlines developing technologies that the network has tested and describes how the emerging operational systems for satellite health, data protection, and multi-mission planning are improving downlink services.

Keywords: ground station, information security, satellite health prediction, information management

Nomenclature

This section is not numbered. A nomenclature section could be provided when there are mathematical symbols in your paper. Superscripts and subscripts must be listed separately. Nomenclature definitions should not appear again in the text.

Acronyms/Abbreviations

ADAPT	Advanced Detection and Prevention of Tampering
CSA	Canadian Space Agency
DAG	Directed Acyclic Graphs
DND	Department of National Defence
DRDC	Defence Research and Development Canada
EO	Earth Observation
HVGB	Happy Valley Goose Bay
IDEaS	Innovation for Defence Excellence and Security
MTAD-GAT	Multivariate Time-series Anomaly Detection with Graph Attention Networks
SSO	Single sign-on

TReND	Telemetry Real-time Anomaly Detection
TT&C	Telemetry, tracking, and command

1. Introduction

Critical infrastructure components of ground systems include more than robust antenna systems to bring satellite data to Earth. Since 2018, C-CORE has been employing high resolution remote sensing ground stations to capture data for operational clients. The operational data and telemetry systems, the core ground station operations, provide the infrastructure necessary to demonstrate next generation technologies. The goal of the niche network of ground stations is to increase the utility of space borne data and to find cost savings in high resolution data access.

At inception of the ground station services C-CORE began by innovating the platform itself. The sites use standard parabolic dishes for transmission and reception, but the infrastructure problem has been solved differently. Instead of sinking pylons into the permafrost, the ground stations rely on self-balancing mechanisms that have become more standard in infrastructure solutions. Currently the work is to continue innovating by creating and testing technologies that have impact on the ground, technologies for the transmission and reception of data through space, and technologies to provide additional services in satellite systems.

Moving from the ground up, current research and development includes mission and ground station management, information security, and satellite health. The C-CORE team has been working with funding from the Canadian Space Agency (CSA) and Canada's Department of National Defence (DND) Innovation for Defence Excellence and Security (IDEaS) program to implement and demonstrate next generation functionality for space and ground systems. C-CORE's research in this domain has been targeted to improving the utility of satellite Earth Observation (EO) data.

As work in the thematic area of tactical data and telemetry communications continues, the migration of satellite information services to include next generation mobile and personal communications will be tested with the ground infrastructure. This includes understanding the challenge to ensure that high resolution satellite EO data is both available for tactical use and not a burden to the local communications systems. The goal of the network is to continue to allow a test bed for next generation technologies based on continuous operation growth.

2. Discussion

The following sections provide a brief overview of the product development paradigm including the operational test bed for technology demonstration.

2.1 Ground Stations

C-CORE maintains two operational ground stations: one in Inuvik, NT, and the other in Happy Valley Goose Bay (HVGB), NL.

These high-altitude ground stations are strategically positioned to support the next generation of satellite missions. Inuvik ground station is located within the Arctic Circle, which is an ideal location for polar-orbiting satellites, where up to 12 passes per day for each satellite can be contacted. HVGB ground station is currently the only ground station on the planet to provide coverage on the high northeastern part of North America. This location is ideal for time critical satellite data for eastern North American, Atlantic Ocean, and Polar passes. Both ground stations support extensive downlink capabilities, including X-band, S-band, and UHF downlink. The coverage from this network is shown in Fig. 1. Ground station pictures are shown in Fig. 2 and the location characteristics are given in Table 1.

Fig. 1. West (Inuvik) and East (HVGB) ground station coverage.

The operation of ground station is fully remote and automated for custom acquisition planning, telemetry and data acquisition, and transmission and data communications. The management is available from a cloud resident hybrid with fully distributed supervisory operations that removes the need for a conventional operation centre [1].

Both ground stations have demonstrated the capability to send command transmissions, and receive telemetry, tracking, and command (TT&C). They have been operated to receive and process a variety of satellite data, including optical and radar imagery, as well as the greenhouse gas measurements. In 2023, they routinely provide services in the order of 3,500 passes monthly over the two stations, with an average pass completion success of 99.67%. C-CORE is now working to tailor ground station services for Defence Research and Development Canada (DRDC) for multiple missions.

The ground stations are configured to work with optional processing on reception or bent pipe architectures depending on data requirements. The infrastructure to move data from the remote environments include fibre optics cabling and satcom applications.


Fig. 2. C-CORE Inuvik (left) and HVGB (right) ground station.

Table 1. C-CORE ground station locations

Site	Lat/Long	Elevation	Antenna Size	Bands
Inuvik	133 W 33 0.58, 68 N 19 9.12	97 m AGL	3.4 m	X-, S-
HVGB	60 W 19 47.22, 53 N 17 46.26	21 m AGL	5.0 m	X-, S-

2.2 SmartTerminal™

SmartTerminal™ is a software platform purpose-built for intelligent, multi-mission planning, with a goal of supporting single sign-on (SSO) for streamlined access and control. It provides a single pane of glass to manage multiple antennas across diverse ground station environments, enabling centralized oversight of satellites, users, and systems from one unified interface.

The system is engineered to monitor ground stations, schedule satellite passes, generate monthly availability reports, and efficiently control multiple sites and antennas. SmartTerminal™ is designed to manage all aspects of ground station operation and eliminate the need for a traditional control room through a cloud-enabled architecture. It also includes hardened control environments to support secure communications for protected and classified applications.

SmartTerminal™ is highly agile—built to interface with a wide range of ground station equipment and capable of ingesting scheduling data from multiple external systems. This flexibility supports integration with various satellite operators and mission control systems.

The close integration of multiple antennas across multiple stations allows for optimized asset utilization, ensuring maximum coverage and efficiency across the network. This networked approach could enable redundancy through dynamic cross-site tasking, allowing ground stations to back each other up and maintain operational continuity.

An integrated API allows external programs and users to submit control requests and monitor progress in real time, all within a secure and extensible framework. SmartTerminal™ is designed to support scalable operations in both commercial and protected mission environments.

SmartTerminal™ is a software package engineered specifically for intelligent multi-mission planning (Fig. 3). It is designed to monitor ground stations, schedule satellite passes, generate monthly availability reports, and efficiently control multiple sites and antennas. The system controls all aspects of ground station operation and provides a cloud enabled control system that can eliminate the need for a traditional control room environment. The system also includes hardened control environments to ensure robust secure communications protocols for protected applications.

SmartTerminal™ handles ground station schedules with multiple users, multiple satellites, multiple ground stations, and multiple antennas from one interface. There is an API for external programs and users to be able to control program requests and monitor progress.

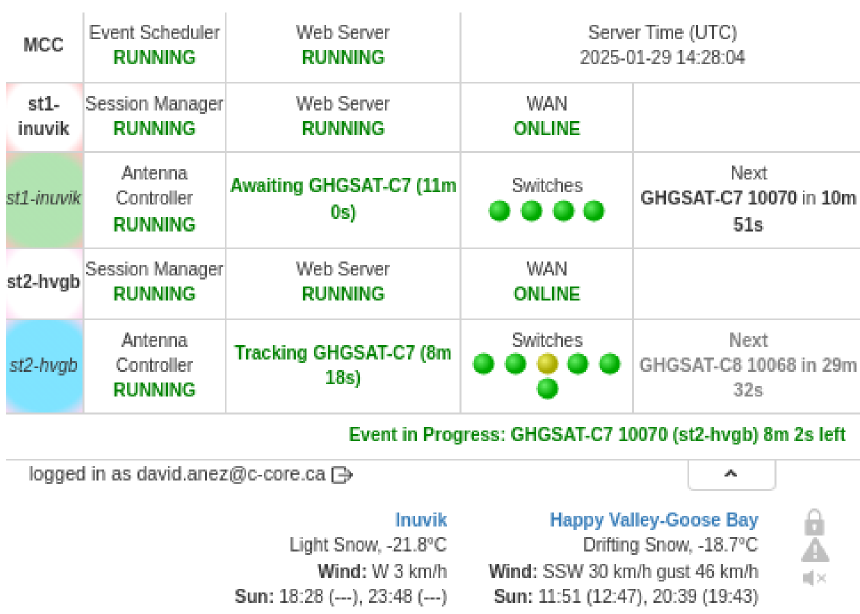

Fig. 3. SmartTerminal™ Interface.

2.3 ADAPT™

In the EO industry, maintaining the integrity and trustworthiness of satellite-collected data is crucial. Ensuring the provenance and protection of remote sensing data is essential for accurate modelling and decision-making. In this context, provenance refers to the history or origin of the data, including how it was collected, processed, and modified over time. However, EO data faces significant risks, including tampering, unauthorized modifications, and accidental corruption as it moves through various processing stages and organizational boundaries.

The ADAPT™ (Advanced Detection and Prevention of Tampering) system was developed to address these challenges by providing end-to-end data integrity throughout the lifecycle of a data source [2]. Unlike traditional security measures, ADAPT fundamentally changes how data security is approached by making the signal immutable. It employs cryptographic services and advanced file system technologies to ensure that any modifications to the data are recorded, preserving the data's integrity and provenance.

ADAPT integrates blockchain technology and cryptographic file storage techniques to create a secure, auditable system for EO data. The system uses cryptographic checksums and blockchain to record all data interactions immutably, ensuring traceability and verification of authorized modifications. It provides comprehensive provenance tracking by recording transaction records on a blockchain [3], creating a high-confidence chain of custody for the data. By employing content addressing and Merkle Directed Acyclic Graphs (DAGs) [7], ADAPT segments and encrypts data into immutable blocks, enabling secure file retrieval and robust verification of data integrity. Additionally, ADAPT allows data to be shared over open networks without loss of integrity, ensuring that only authorized users can access and modify the data. All of these processes happen transparently to the user, who interacts with the system in a familiar way and are able to use existing software tools to analyse and create new products.

The ADAPT system was developed through collaborative projects with the CSA and Canada's DND. It has been demonstrated to work effectively in both cloud-based and server-based environments, providing secure data ingestion and processing capabilities. The system's performance has been shown to be superior to state-of-the-art cryptographic and conventional filesystems, with minimal added overhead.

Beyond EO, ADAPT's capabilities make it valuable for various applications, including scientific data management, regulatory compliance, and secure data sharing in critical infrastructure sectors. Its scalable, secure, and flexible architecture ensures trusted, verifiable, and tamper-proof data storage and transmission, making it a next-generation technology for data integrity assurance.

2.4 TReND™

Spacecraft anomalies significantly impact the availability and performance of EO satellite systems [4]. Traditional anomaly detection methods rely on simple telemetry threshold monitoring, which is often reactive and insufficient for identifying complex trends or signatures indicative of potential anomalies. Groups like the CSA have identified the need for innovative solutions to enhance anomaly detection and prediction capabilities, leading to the development of the Telemetry Real-time Anomaly Detection (TReND) system.

Current anomaly resolution processes are time-consuming, especially for new anomalies without predefined recovery procedures [5]. These processes involve investigation, development, simulation, and execution of recovery steps, during which the satellite may produce degraded or no products. Additionally, the vast volumes of telemetry data generated are too extensive for manual analysis by satellite operators. There is a need for automated, real-time analysis tools capable of detecting and predicting anomalies to minimize outages and prevent unrecoverable anomalies.

The TReND system comprises two main components: the Training Code and the Analysis Tool. The Training Code utilizes historical telemetry data to train machine learning models, specifically the Multivariate Time-series Anomaly Detection with Graph Attention Networks (MTAD-GAT) model, which is designed to handle multivariate time-series data as found in satellite telemetry [6]. The MTAD-GAT model leverages graph attention networks to capture complex dependencies and interactions between different telemetry channels, enabling effective anomaly detection and prediction. These trained models are then used by the Analysis Tool to detect anomalies in operational telemetry data. The system is designed to process telemetry data faster than it is generated, ensuring timely anomaly detection. The Training Code trains machine learning models using archived telemetry data and requires a GPU for efficient processing. It involves user interaction to select and evaluate the telemetry data for training, and the output includes trained model files and metadata, which are used by the Analysis Tool. The Analysis Tool applies the trained machine learning models to recent telemetry data to identify anomalies. It reads telemetry data, processes it, and generates reports highlighting potential anomalies. Both short-term (single satellite pass) and longer-term reports are produced in human-readable and JSON formats, facilitating easy interpretation and integration with other systems. This automated process significantly enhances the operational efficiency and reliability of EO satellite systems.

The TReND system addresses the limitations of traditional anomaly detection methods by providing automated analysis of telemetry data. Key benefits include enhanced anomaly detection, as TReND can identify complex trends and signatures in telemetry data across satellite subsystems that may indicate potential anomalies, allowing for proactive measures. It also reduces outages by detecting and mitigating anomalies early, helping to minimize the duration of outages and ensuring continuous satellite operation. Additionally, it improves safety and extends the operational life of spacecraft through early identification of anomalies, enabling pre-emptive actions. The system is scalable and can be adapted to support multiple satellite missions with appropriate modifications to the input and configuration code.

The TReND system represents a significant advancement in the field of satellite telemetry analysis. By leveraging machine learning and real-time data processing, TReND offers a robust solution for detecting and predicting spacecraft anomalies, ultimately contributing to improved satellite performance and reliability. Future work may focus on refining the machine learning models and expanding the system's capabilities to support a broader range of satellite missions.

3. Conclusion

Since 2018, C-CORE has been developing and operating a niche network of remote sensing ground stations. The stations located in Inuvik and Happy Valley Goose Bay have been used to operationally retrieve data from multiple imaging satellites for Canadian and international customers. The remote operation has led to the creation of state-of-the-art operational systems including C-CORE's SmartTerminal™ that allows management and planning for multiple satellite systems, across multiple ground stations from one interface. It supports dynamic scheduling with multiple satellite operators and incorporates diverse ground equipment. It provides optimal pass allocation to antennas and ensures efficient use of every aperture. C-CORE is using its operational stations to advance several new technologies: TReND™ and ADAPT™. Both TReND™ and ADAPT™ will be integrated into the ground station network as part of an operational demonstration with an upcoming CubeSat mission. This paper outlines developing technologies that the network has tested and describes how the emerging operational systems for satellite health, data protection, and multi-mission planning are improving downlink services.

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