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Measurement of Ionospheric and Atmospheric Structures Using Navigation Satellite Signals Captured with Software-Defined Systems

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ABSTRACT

The sensitivity of satellite navigation signals to ionopheric irregularities and lower troposphere structures has led to their widespread adoption to monitor and study ionosphere activities and lower troposphere properties both through ground-based networks and receivers on low earth orbiting (LEO) satellites. As we enter a new era of satellite navigation, multiple constellations of global navigation satellite systems (GNSS) are offering unprecedented global coverage. Modern GNSS signals with their resilient signal design and diverse frequency coverage are offering new opportunities for more accurate measurements of ionosphere and troposphere effects. Advances in GNSS receiver technology also lead to better data collection system design and signal processing. This paper will present recent efforts in improving our multi-GNSS data collection system for autonomous operations, latest data collection experiments, and some results on ionosphere and troposphere scintillation measurements.

Key words: Ionosphere, troposphere, GNSS, scintillation.

1. Multi-GNSS Data Collection System: Recent Improvement and Deployment

The pre-requisite to meaningful interpretation of GNSS measurements to infer ionospheric and tropospheric phenomena is accurate understanding of the propagation medium's impact on the signal parameters. Since GNSS receivers are originally intended for navigation purposes, their signal processing engines are not optimized to measure atmospheric effects and their outputs may contain processing artifacts [1-2]. High quality, unprocessed data and carefully designed signal processing algorithms are needed to uncover the distortions imposed on the signals by atmospheric events. Our event-driven data collection system is designed for this purpose. Figure 1 illustrates the architecture of the system.

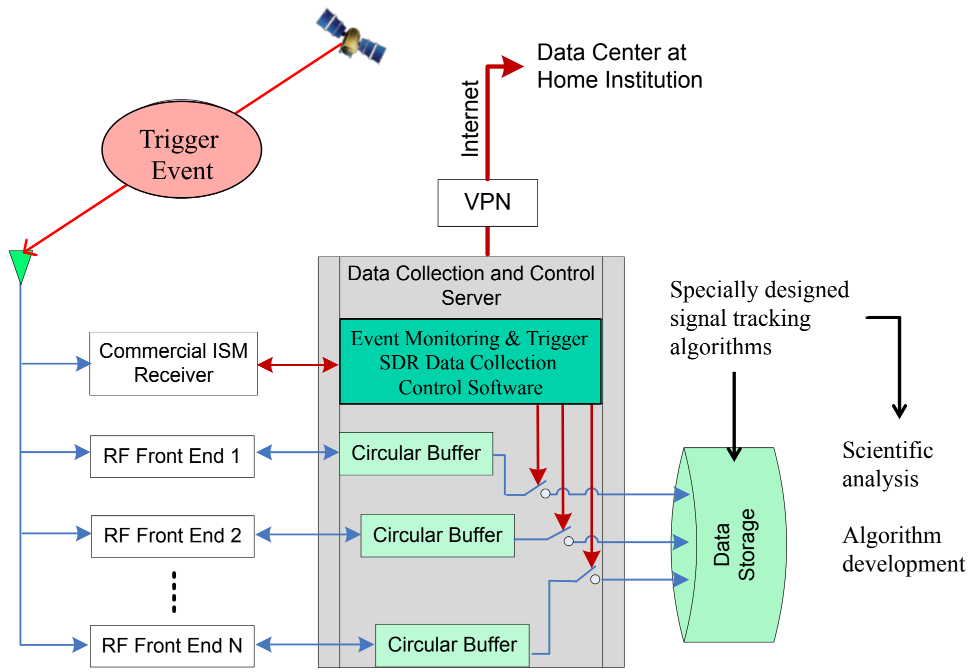

Figure 1**.** Illustration of an event-driven software-defined multi-GNSS data collection system architecture.

The system consists of an array of reconfigurable software-defined radio (SDR) front ends, which generate IF data streams to fill the circular buffer on the data collection server. A commercial receiver generates measurements based on input signals from the same multi-band antenna. These measurements are processed by our Event Monitoring & Triggering software. The results are used to control the transfer of SDR circular buffer contents to a RAID storage array when qualified events occur [3]. The Virtual Private Network (VPN) interface allows remote monitoring and configuration of the system. Since it was first deployed in Alaska in 2010, the system has undergone continuous improvement. Recently, we introduced a more effective event trigger based on machine learning algorithms [4], the use of multi-band signal frequency folding to reduce the number of SDR front ends needed, and more robust remote control and configuration processes. The presentation will discuss these improvements in more details.

2. Recent Experiments, Data Processing Techniques, and Sample Results

The data collection system has been deployed at various locations in high and low latitudes and accumulated over 1 petabye data during ionosphere activities and low elevation troposphere radio occultation events. Recently, we conducted a 10-day mountaintop radio occultation (RO) experiment on Haleakala in April 2019. Figure 2 shows the concept of the mountaintop RO experiment. A mesh antenna with 25dB gain was steered towards rising and setting GNSS satellites whose ray paths propagate through the moist lower troposphere. The dual-polarization antenna outputs were recorded by two identical data collection systems described in Figure 1. The purposes of this experiment are (1) to capture GNSS signals with strong water vapor scintillation effects for studies of moist lower troposphere properties, (2) to study the ocean surface reflection signatures in the received GNSS signals, and (3) to probe low latitude ionospheric disturbance in the southern portion of the local sky.

Parallel with the effort to develop data collection instrument is a continuously expanding suite of advanced receiver signal processing algorithms. This presentation will highlight a recently validated multi-carrier aiding GPS carrier tracking algorithm which ensures robust and accurate estimation of the ionosphere and troposphere effects on satellite signal parameters [5]. The algorithm has been applied to process both strong equatorial ionospheric scintillation data and the Haleakala water vapor scintillation data. The results have revealed interesting features in these signals and their underlying physics. The presentation will discuss the challenges of the signal processing and some of the findings through analysis of the processed results.

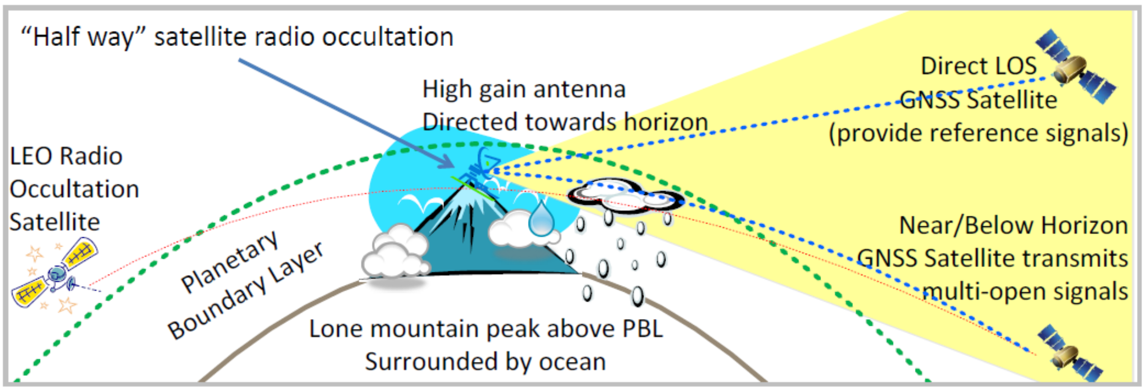

Figure 2**.** Conceptual description of the mountain top radio occultation experiment. The experiment was carried out in April 2015 on the peak of Haleakala, Maui. A 2m diameter high gain dish antenna was steered toward rising and setting GNSS satellites near the horizon. The signals captured by the antenna were input to the data collection systems depicted in Figure 1.

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