Modeling HF Communications with RayTRIX and IRTAM

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Geophysicists' attention has focused on prompt and accurate forecasting of trans-ionospheric high-frequency (HF) signal propagation conditions since the onset of HF broadcasting in the 1930s. Fast forward to modern days, HF communications remain a requested capability in several human activity categories, most importantly, in rapid high-reliability messaging, but also in lifeline rescue/covert missions, soldier-to-headquarters battlefield reporting, and arguably most widespread, for amateur ham radio chats. The capability to select the optimal frequency for communications requires knowledge of the ionospheric weather and signal propagation models. One of the critical parameters of such frequency management is the maximum usable frequency (MUF): the highest signal frequency that can be used for transmission between two points via the ionosphere. In 2010, the real-time task force of the International Reference Ionosphere (IRI) working group came up with a concept of assimilative modeling of the ionosphere by means of *model morphing*, in which IRI, a quiet-time climatology specification, is manipulated into an agreement with available sensor measurements for a weather nowcast. The predictive capabilities of the IRI-based Real-Time Assimilative Model (IRTAM), one of the IRI real-time task force projects, were thoroughly studied to reveal its significant spatial forecast advantage: IRTAM implemented a 24-hour 4D data assimilation scheme sensitive to a spectrum of natural variabilities of the ionosphere on the large-to-planetary spatial scales. The IRTAM specification suited very well as the background ionosphere definition for real-time signal propagation modeling and frequency management.

Modeling HF signal propagation typically requires significant computing resources due to its underlying brute-force evaluation of the ray launch angles at which the transmitted signal, traced through the ionospheric plasma, can reach the receiver location. Such “homing” algorithms require a large candidate pool of the ray angles for each operating frequency, resulting in ~ 1 minute computation time per frequency. However, a simplified HF signal modeling approach exists that yields an analytical solution to the ray propagation task that avoids the homing expense. In this approach, the ionospheric channel is represented by a horizontally homogeneous plasma distribution that uses a set of quasi-parabolas to define the 1D vertical profile of electron density. In its simplest case, only three quasi-parabolas are used, one per ionization layer of the ionosphere at the mid-point of the radio link. Such composite quasi-parabolic (CQP) representation, in combination with the parallelized computation using specialized Graphics Processing Unit (GPU) hardware, is operated by Lowell GIRO Data Center, called RayTracing

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through Realistic Ionosphere Explorer (RayTRIX). The computation time of RayTRIX CQP system needed to synthesize an oblique ionogram for a given HF radio link is well below 10 seconds, making it a viable solution to prompt radio frequency management for a network of HF domain users. Technical details of IRTAM, CQP, and RayTRIX operations and potential use cases will be discussed.

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