

Analysis of Downlink Propagation from Geostationary Orbit Satellite Antenna Using Long Short-Term Memory

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Electromagnetic waves undergo refraction and reflection at an interface between media with distinct atmospheric refractive indices. The Earth's atmosphere can be modeled as layered media, each having distinct refractive indices, which significantly impact the propagation characteristics of electromagnetic waves in satellite communication, particularly in the lower atmosphere. These characteristics can be accurately predicted using the spatial distribution of the three-dimensional atmospheric refractive index, which is derived from meteorological parameters such as temperature, atmospheric pressure, and relative humidity. Since upper-air meteorological data are provided by only a limited number of observation stations worldwide, spatial interpolation is utilized to estimate values at unobserved locations. In previous studies, upper-air meteorological data and spatial interpolation were utilized to model the spatial distribution of atmospheric refractive indices, which were then used to predict the propagation characteristics of geostationary satellite antennas. However, in previous studies, the number of data samples used for spatial interpolation was relatively small, resulting in limited reliability of the predictions. In particular, the accuracy of atmospheric refractive index predictions in regions without upper-air meteorological data has not been sufficiently validated. In this study, a method to improve the accuracy of predicting atmospheric refractive indices at unobserved points using Long Short-Term Memory (LSTM) was proposed. And using the predicted atmospheric refractive indices, an analysis of downlink propagation characteristics from a geostationary orbit satellite antenna was conducted.

The atmospheric refractive index at a specific time was forecasted using a LSTM trained on historical time series of upper-air meteorological datasets. To address the time series forecasting problem as a supervised learning task, the sliding window technique was applied to transform the time series of atmospheric refractive indices into multiple training sets consisting of input and output windows, enabling the LSTM to learn the relationships between them. After hyperparameter tuning during LSTM training and validation, the predictive performance of LSTM was evaluated by comparing the atmospheric refractive indices at time points with available measurements to those predicted by traditional time series forecasting methods. The results confirmed that the LSTM predictions showed the closest agreement with the measured values. As a result, the predicted atmospheric refractive indices were utilized to analyze the downlink propagation characteristics from a geostationary orbit satellite antenna using ray tracing and geometrical optics.

In this study, the predicted atmospheric refractive indices at the current time, obtained using LSTM, were utilized to improve the predictive performance of spatial interpolation. The accuracy of these predictions was validated by comparing them with measured values in regions without upper-air meteorological data. Using the atmospheric refractive indices predicted by spatial interpolation along with the additional samples, it was confirmed that the predictive accuracy of downlink propagation characteristics from a geostationary orbit satellite antenna could be improved.

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