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# New RFI Threats for Future Microwave Sounders: Development of New RFI Detection Strategies for 5G Signals

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**Abstract:**

NOAA's current operational LEO weather satellites operate microwave sounders that provide crucial measurements to produce weather forecasting worldwide. Weather forecasts are determined by meteorological models using measurements performed by the microwave Advanced Technology Microwave Sounder (ATMS) from S-NPP, NOAA-20 and NOAA-21 under the Joint Polar Satellite System (JPSS) program. Two others will launch in 2027 (J4) and 2032 (J3). The Near Earth Observing Network (NEON) program, the follow-on to JPSS, will run from 2030-2050 and plans to launch 9 Sounders for Microwave-Based Applications (SMBA). Among the new features, SMBA will include hyperspectral capability and RFI detection capability.

The recent development of 5G wireless technology could impact weather forecasts since the frequency range used by 5G signals is close to frequencies used for atmospheric temperature and water vapor sounding. Even though 5G signals might not emit directly at the frequencies of the window and temperature sounding channels, signal leakage into adjacent science frequencies can create Radio Frequency Interference (RFI). This work focuses on understanding 5G signal structure and developing a new RFI detection strategy. The detection method is developed for an ideal case assuming 5G signal emission within the science frequency band, with the main purpose of evaluating the potential of this new method to detect 5G signals

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## ........1 Introduction

The recent development of 5G wireless technology and the expansion of the 5G network could have a direct impact on weather forecasts since the frequency range used by 5G signals is closed to frequencies used for atmospheric temperature and water vapor sounding. Even though the 5G signals might not emit directly at the frequencies of the window and temperature sounding channels (23.8 GHz, 50-52 GHz), some part of the signal could leak into adjacent science frequencies creating Radio Frequency Interference (RFI). Figure 1 presents the zenith opacity as function of frequency with the indication of the ATMS channels location with the black lines [1]. The colored boxes illustrate the frequency range identified as potential RFI threats. As shown in red in Figure 1, 5G FR2 band covers frequencies close to ATMS channels 1 and 2, potentially creating RFI in those channels. More recently, Space X was authorized to downlink data using 81-86 GHz which could impact ATMS channel 16. Additionally, Space X received authorization to use 47.2-50.2 GHz and 50.4-51.4 GHz for Earth to Space transmission, potentially creating RFI in ATMS channels 3 and 4 . The rest of this study will focus on FR2 5G signal and the development of a detection approach for those signals.

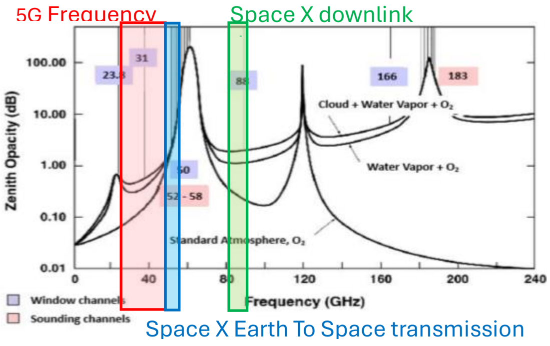

*Figure 1: Potential RFI threats for microwave sounders illustrated by the colored*

## ........2 5G signal Characteristics

Understanding the unique characteristics and structure of 5G signals is crucial for developing effective RFI detection methods. This section examines the 5G signal's spectral properties, time-domain characteristics, and the complex hierarchical frame structure that defines 5G transmission protocols.

### 2.1 5G Signal: Time and Frequency Characteristics

The 5G signal exhibits characteristics that make it particularly challenging for traditional RFI detection methods. Figure 3 a) shows a simulation of a realistic 5G signal for the frequency band FR2 (24.35 GHz – 52.6 GHz) in the uplink configuration. The waveform demonstrates the broadband nature of 5G signals, with significant sidebands that could potentially impact microwave sounder channels particularly when transmitting in adjacent bands. As shown in Figure 3 b), the time samples of the 5G signal follow a Gaussian distribution, making them statistically similar to the white noise that is naturally measured by radiometers. This similarity poses a particular challenge for traditional RFI detection methods using statistical approaches.

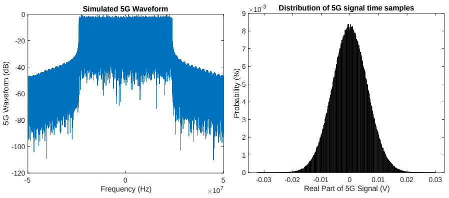

*Figure 2:a) Simulated FR2 5G waveform in the uplink configuration, b) Distribution of the time sample of the 5G signal*

### 2.2 5G NR Signal Frame Structure

To be able to develop new detection strategies, one has to look at the actual structure of 5G signal to find particular charactetristics that can be used for detection. 5G signal implements a flexible frame structure designed to provide faster data rates and lower

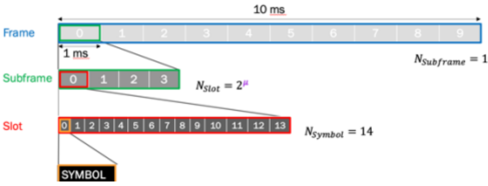

*Figure 4: Schematic representaion of the 5G signal structure*

latency. Fig. 4 illustrates the hierarchical organization of the 5G NR signal structure, where each 10 ms frame is composed of 10 subframes of 1 ms duration. Each subframe is further divided into slots, with the number of slots determined by the scalable numerology parameter $\mu$. Each slot contains 14 OFDM symbols, allowing for dynamic resource allocation based on service requirements.

Each frame of 10 ms contains 10 subframes, with each subframe divided into slots containing 14 OFDM Symbols. In each slot, to prevent for InterSymbol Interference (ISI), a Cyclic Prefix (CP) is created. The CP is essentially an identical copy of the last portion of the OFDM symbol appended before the OFDM symbol. The CP corresponds to the red part in Figure 5. The length of the CP varies with the SCS but the use of its cyclic pattern is investigated to detect the presence of 5G signals.

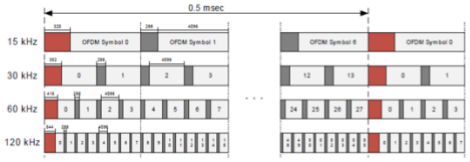

*Figure 5: Illustration of the Cyclic Prefix of the OFDM symbols as function of the SCS*

## ........3 Detection Method

This study aims to evaluate the potential of detecting 5G signals in radiometer measurements by exploiting the cyclic structure of 5G signals. The simulation is designed for an ideal case with several key assumptions. First, it is assumed that 5G signals are emitted in the frequency range for science (temperature or water vapor sounding). To simplify the initial analysis, only signal from a single base station is considered in this study. Finally, the 5G waveform in this model consists of all symbols for one subframe, and this analysis specifically focuses on signals in the uplink configuration.

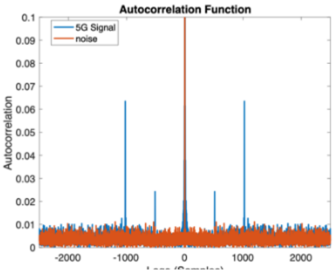

*Figure 6: Autocorrelation function of a 5G signal (blue) and a white Gaussian noise (red)*

The detection method leverages the cyclic structure of OFDM symbols and their cyclic prefix through a comprehensive process. The first step involves calculating the autocorrelation of the signal, followed by a detailed analysis of the autocorrelation function to identify unique features characteristic of 5G signals. This two-phase approach allows us to exploit the inherent periodicity in the 5G signal structure. Figure 6 demonstrates the distinct differences in autocorrelation functions between a pure 5G signal and noise. The 5G signal (blue) exhibits characteristic peaks at specific lag values, while the noise signal (red) only shows a central peak at zero lag. This clear differentiation in autocorrelation patterns forms the basis for our detection strategy.

Fig. 7 shows the autocorrelation function of 5G signals for different subcarrier spacing (SCS) and sampling frequency ($F_s$) combinations. The plot reveals significant peaks at specific lag values that correspond to the cyclic structure of the OFDM symbols. The symbol spacing is determined by:

$$\Delta l_{symbol} = \frac{t_{symbol}}{T_{sampling}}, \text{ where } t_{symbol} = \frac{1}{2^{\mu} * 15\ kHz} \text{ and}$$

$$T_{sampling} = \frac{1}{F_{sampling}}$$

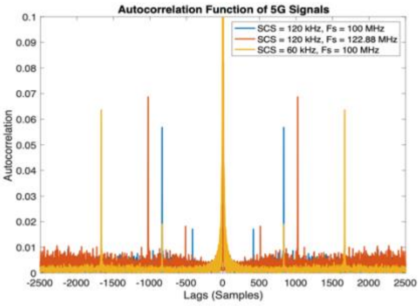

*Figure 7: Autocorrelation funtion of 5G signals for different SCS and $F_s$*

These peaks appear because OFDM symbols have a cyclic property due to the cyclic prefix, resulting in strong correlation at lags corresponding to the symbol spacing for instance: $\Delta l_{symbol} = 833$ or $\Delta l_{symbol} = 1024$ or $\Delta l_{symbol} = 1666$ depending of the SCS and $F_s$.

Given that $F_s$ is known and that there are only a small number of possible subcarriers, the position of these peaks in the autocorrelation function can be predicted and used as a reliable indicator for detecting the presence of 5G signals.

## ........4 Initial Results:

This section presents the initial findings from applying the proposed 5G signal detection method to simulated data. The effectiveness of using autocorrelation analysis to identify the cyclic structure characteristic of 5G signals is assessed, with particular focus on detection performance under varying signal-to-noise ratio conditions. The results demonstrate both the potential and limitations of this detection approach, providing insights into its practical applicability for radiometer interference monitoring.

### 4.1Test Set up

The detection method follows a three step processing approach to identify 5G signals within radiometer measurements. The process begins by calculating the autocorrelation function of the considered signal. Next, the algorithm identifies significant peaks in the autocorrelation function, specifically those with amplitude exceeding 0.01. Finally, these peak locations are compared against the theoretically possible locations calculated from the sampling frequency and subcarriers parameters. For successful 5G signal classification, two key criteria must be met simultaneously. First, the signal must exhibit multiple peaks beyond the primary peak at lag 0. Second, these peak locations must align with the predicted positions based on the established signal parameters. Our evaluation methodology utilized a comprehensive test dataset constructed from three different signals: a reference 5G waveform, a white Gaussian noise signal representing typical radiometer measurements for a fixed scene and a composite signal.

The composite signal is the addition of the white Gaussian noise and the 5G waveform with a variable ampliture which represents the signal-to-noise ratio (SNR) varying from -20 dB to +10 dB. The detection method was evaluated across 200 noise realizations and 60 SNR levels to ensure statistical significance.

### 4.2 Detection

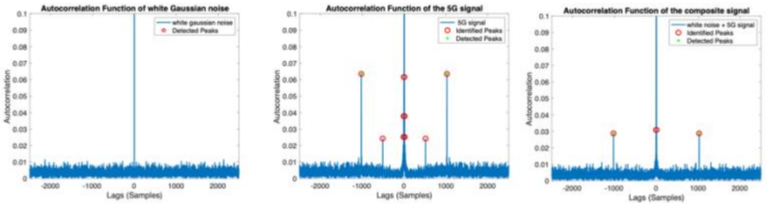

*Figure 8: Initial results of the detection approach applied to: a) a gaussian white noise , b) a pure 5G signal and c) a composite signal. Identified peaks are indicated by the red circles, peaks used for detection are marked by green crosses.*

To evaluate the effectiveness of the detection method, tests across three distinct signal scenarios were conducted. First, a pure white Gaussian noise was analyzed to establish a baseline response. Next, a pure 5G waveform was examined to characterize the ideal detection case. Finally, a composite signal was tested by combining both noise and 5G waveform with SNR = 0 which indicates that the 5G signal has the same power as the white Gaussian noise. The results, shown in Figure 9 demonstrate the method's ability to distinguish between different signal types.

For the white Gaussian noise case (left panel), only the expected central peak at lag 0 is visible. The pure 5G signal (center panel) exhibits multiple distinct peaks (red circles) and two at the predicted lag values (green crosses), which are successfully identified by the detection algorithm. In the composite signal case (right panel), where the 5G signal and noise have equal power (SNR 0 dB), the characteristic peaks are still observable but with reduced amplitude compared to the pure 5G signal. This amplitude reduction indicates that detection performance degrades with increasing SNR, necessitating a comprehensive evaluation of detection performance across different SNR values.

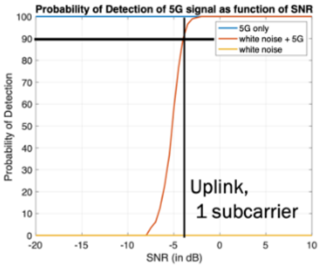

*Figure 10: Detection Sensitivity as function of SNR.*

To assess the sensitivity of the detection to the SNR, a Monte Carlo simulation is implemented with $-20\ dB\ \leq SNR\ \leq 10\ dB$ and 200 realizations of the white Gaussian noise. It is noted that this simulation would need to be extended but this was done to provid the trend of the detection sensitivity as function of SNR. The results are presented in Figure 10 for uplink configuration with one subcarrier. The results indicate that a detection probability of 90% can be achieved for $SNR\ \geq -4\ dB$. This study was also performed for a 5G signal containing 2 subcarriers and similar results were obtained. These results demonstrate consistent detection capability across different subcarrier configurations, suggesting the method's potential to be effective for different variations in the 5G signal structure.

## ........5 Discussion :

This initial study presents an ideal scenario that differs significantly from the operational space environment. In this controlled analysis, several hypothesis were considered: 5G signals emitted directly in the temperature sounding frequency range, the analysis was limited to a single base station and examining complete subframe symbols in the uplink configuration. However, implementing this detection method in space presents additional challenges. In operational conditions, 5G signals are expected to primarily be emitted in adjacent frequency bands, potentially resulting in low SNR. The complexity is further increased by the presence of thousands of base stations and users within each radiometer footprint, raising questions about the characteristics of aggregated 5G signals. Additionally, while 5G signals won't be synchronized with radiometer measurements, however the extended integration time of the radiometer may enhance detection probability. The radiometer in space will also measure a mix of configurations simultaneously, including both uplink and downlink transmissions with varying numbers of subcarriers, adding further complexity to the detection challenge. Further studies with more complex and realistic scenarii will have to be performed to evaluate the possibility of using this approach to detect 5G signals.

## ........6 Conclusion :

Satellite observations of the atmosphere by passive microwave sounders are crucial for weather forecasts, providing unique 3D measurements of atmospheric temperature and humidity. The introduction of new frequency allocations adjacent to microwave sounder measurements poses a risk of RFI in several sounding or window channels, which could lead to potentially degrading weather forecast accuracy. This study has demonstrated a promising detection method for 5G signals in the uplink configuration by exploiting the cyclic structure of the 5G waveform, showing that the autocorrelation function reveals distinctive features that enable detection of 5G signals in white Gaussian noise. While the method has shown effectiveness for signals with $SNR\ \geq -4dB$, these results are obtained for an ideal case, and further analysis is needed to address more realistic scenarios.

## References

[1] C. H. Lyu, E. Kim, L. M. Mccormick, R.V. Leslie, I.A. Osaretin, I.A., "JPSS-1 ATMS postlaunch active geolocation analysis," IEEE Transactions on Geoscience and Remote Sensing, vol. 59, no. 11, pp. 9462-9471, 2021.