DETECTION OF5G SIGNALS: FROM SIMULATION TO MEASUREMENTS

Alexandra Bringer [1], Balthasar Indermuehle[2], Gregory Hellbourg[3], Edward Kim[1]
(1) NASA Goddard Space Flight Center, MD, USA
(2) CSIRO Space and Astronomy, Australia
(3) CalTech Astronomy, CA, USA

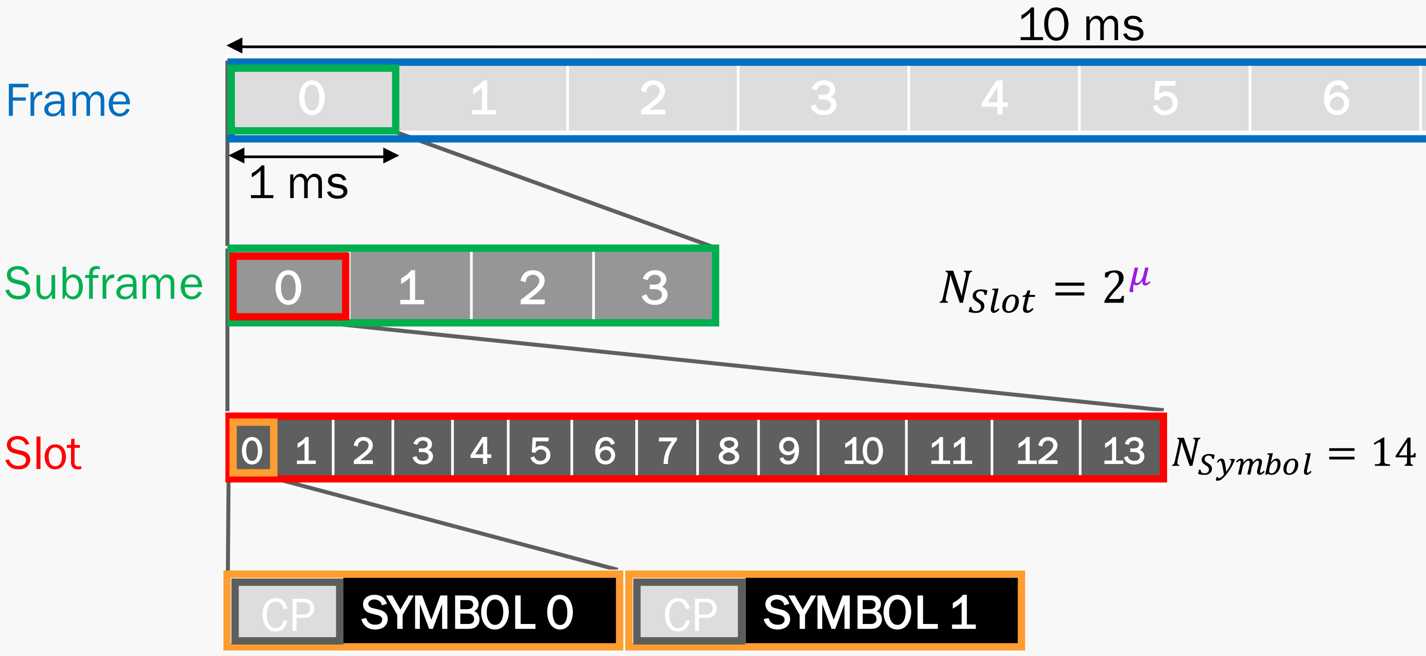
RFI 2025
10/21/2025

Motivations

- Radio Frequency Interference (RFI) presents a growing challenge for passive remote sensing for both Earth Observation (EO) and Radio Astronomy (RA) applications.
- The rapid deployment of fifth-generation (5G) wireless networks, particularly in Frequency Range 1 (FR1: 410 to 7125 MHz) and millimeter-wave frequencies (FR2: 24.25 to 71.0 GHz), could potentially become a significant source of RFI that might degrade measurements for both RA and EO
- In RA, 5G signals can contaminate spectral line observations, particularly in FR1, while also raising the noise floor for continuum observations.
- For EO, 5G signals could leak into the adjacent science frequencies, which in turn could corrupt atmospheric water vapor and temperature sounding measurements and could have severe impact on the fidelity of weather forecasts.
- Our previous research established a detection methodology for 5G signals based on their inherent modulation characteristics and structure. The study evaluated the feasibility of identifying the presence of 5G signals within standard microwave radiometer measurements by exploiting the cyclic structure of the 5G carrier signal.
- This current study extends our previous simulation-based research by applying the detection methodology to measured 5G signals. Preliminary results of the detection methods on measured 5G signals will be presented in the next slides.

Previous Work: 5G SIGNALS

- One key aspect of this flexible 5G frame structure is its time-frequency resources allocation method. The 5G frame structure is based on a slot and symbol-based design. This means the 5G network can dynamically adjust the duration of each time slot based on the service's needs.
- A schematic representation of 5G signal frame structure is presented below:



- The 5G NR Signal structure is presented for 1 Frame of 10 ms
- Each Frame is composed of 10 subframes of 1 ms each
- Each Subframe is divided into slots. The number of slots is variable and depends on the scalable numerology μ (or SubCarrier Spacing)
- A cyclic prefix (CP) is located before each OFDM symbol. The duration of the CP is variable so that each slot contains 14 symbols

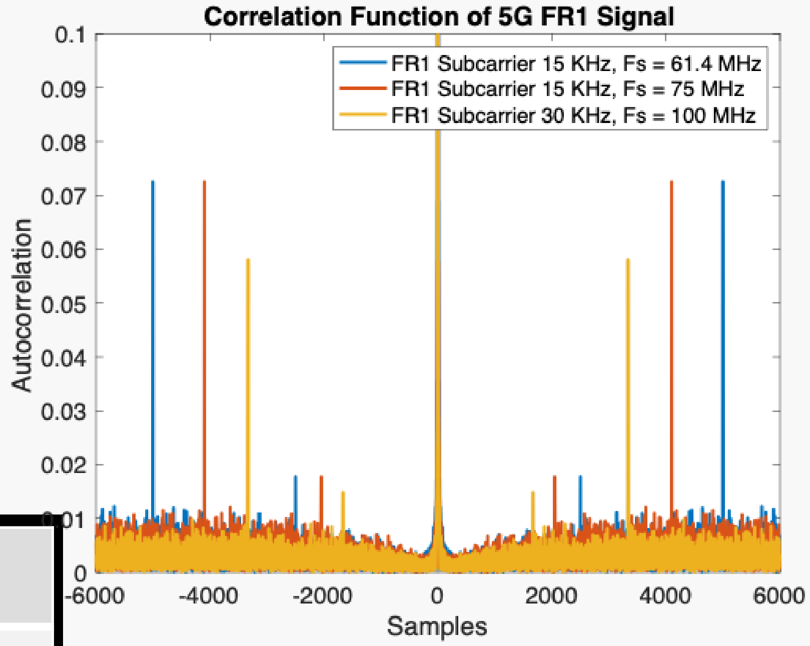
Detection Method designed to use the cyclic structure of 5G signals

Previous Work: DETECTION METHOD

- The detection method was developed and tested on simulated 5G signals only in a first step.
- This simulation was performed on a simplified case and follows these assumptions:
  - 5G signals are emitted in the frequency range of the instrument measurements
  - Only 1 base station is considered in this first step
  - The 5G waveform considered in this step is made of all symbols for 1 subframe (~1 ms)
- The detection method is based on identifying significant peaks in the autocorrelation of the 5G signals. The main peak positions can be estimated by:

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

- The peaks appear in the autocorrelation function because OFDM symbols have a cyclic property due to the cyclic prefix. Therefore, the strongest correlation occurs at lags corresponding to the symbol length:

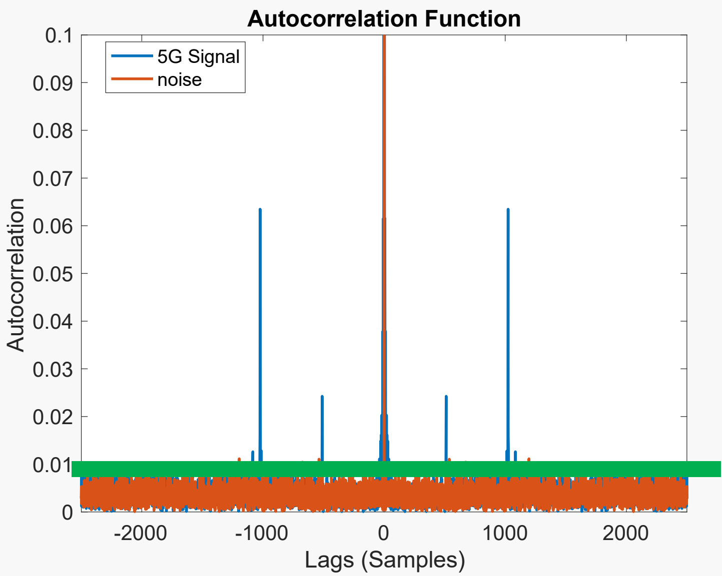


	$\mu = 0$, $F_{sampling} = 75\ MHz$	$\mu = 0$, $F_{sampling} = 61.44\ MHz$	$\mu = 1$, $F_{sampling} = 100\ MHz$
Δl_{symbol}	5000	4096	3333

Given that the $F_{sampling}$ is known and the small number of subcarriers, the position of the peaks in the autocorrelation function can be predicted and used to detect 5G signals

PREVIOUS WORK: INITIAL RESULTS

- The detection method is then following this processing steps:
  - Calculate the autocorrelation function of the considered signal
  - Identify peaks in the autocorrelation function with an amplitude > 0.01
  - The locations of the peaks are compared to the possible locations calculated from the sampling frequency and the subcarriers

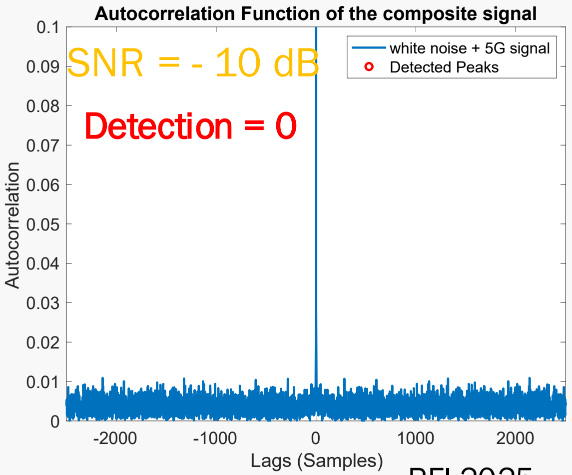


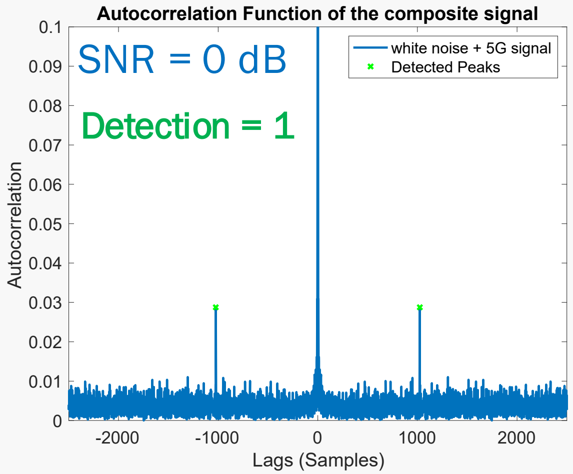
DETECTION

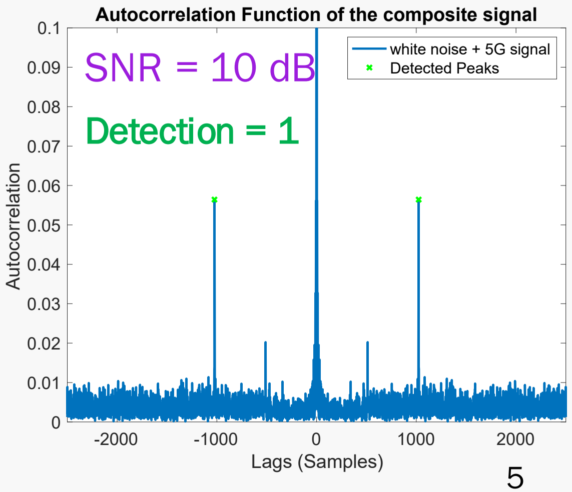
- 5G Signal is then detected if:
  - There are more than 1 peak (at lag 0)
  - If the peaks are located at one of the possible locations

- After demonstrating the potential of the detection method on pure 5 G waveforms, the detection was applied on a mixed signal:
  - White noise + 5G signal

- A preliminary sensitivity study shows that the performance of the detection is getting better when SNR increasing as expected







FROM SIMULATION TO MEASUREMENTS

- Previous work Summary:
  - Developed a detection method for 5G signals using the cyclic features of the 5G signals
  - Demonstrated the potential of this detection method of 5G simulated waveforms
  - Applied the detection method to more "realistic" signals (5G signal + white noise) and shows that the performance of the detection increases when SNR increases

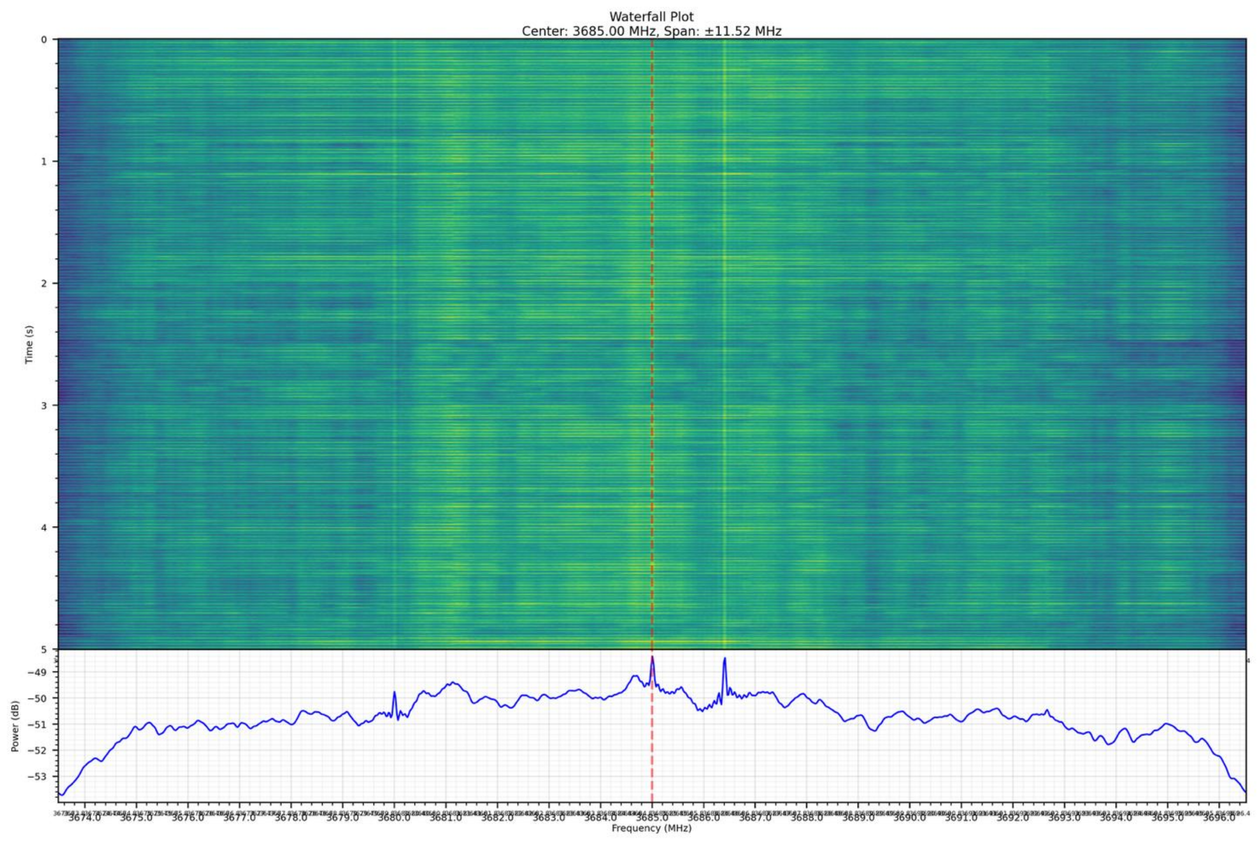
SIMULATION ONLY

- This work Summary:
  - Acquire 5G real signals over FR1 frequencies
  - Process these signals to produce shorter snippets of signals
  - Test the detection algorithm on these 5G real signals
  - Perform a sensitivity analysis to evaluate the performance of the detection method

MEASUREMENTS

MEASUREMENTS OF 5G SIGNALS

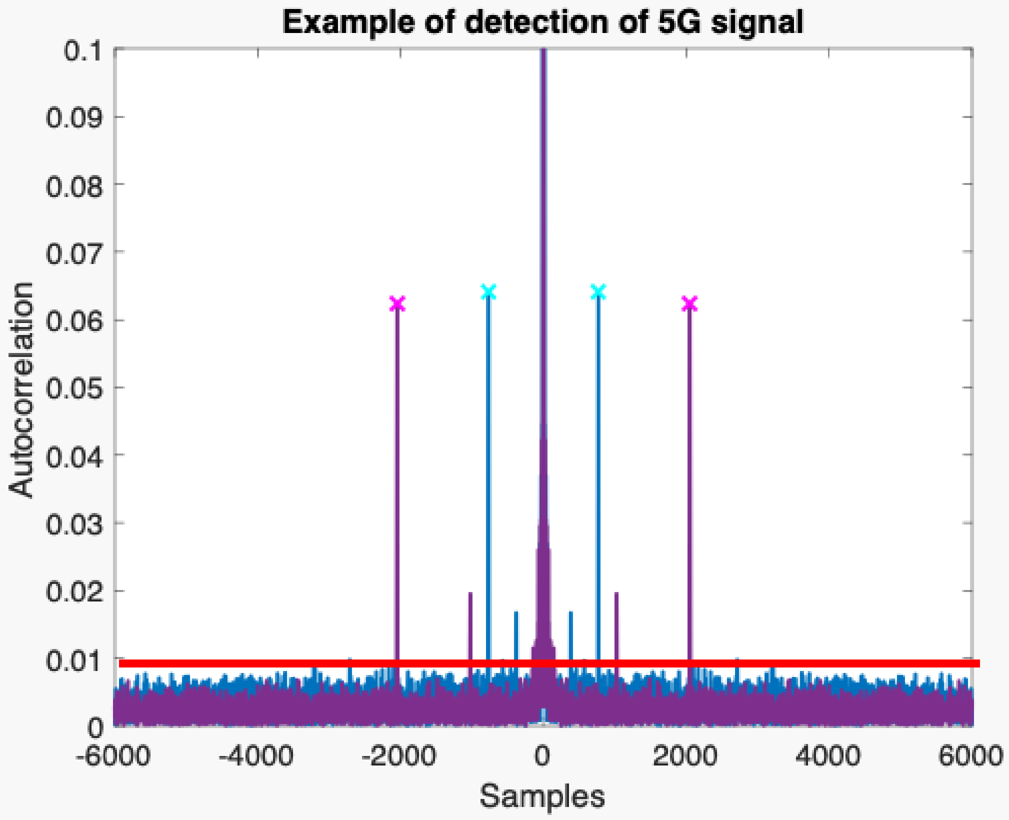
- The experimental dataset comprises time series of raw I and Q signals across 16 frequency bands spanning the 4G and 5G FR1 frequency range:
  - 4 measurements were performed in the 4G bands to investigate the performance of the detection method for both TDD and FDD
  - 5 measurements in the 5G FR1 were performed using a bandwidth of 23.04 MHz
  - 7 measurements in the 5G FR1 were performed using a bandwidth of 61.44 MHz
- These different characteristics allow us to test the performance of the detection method over multiple parameters (4G vs 5G, TDD vs FDD, bandwidth…)



Example of the spectrogram measured for the center frequency 3685 MHz and Bandwidth = 23.04 MHz

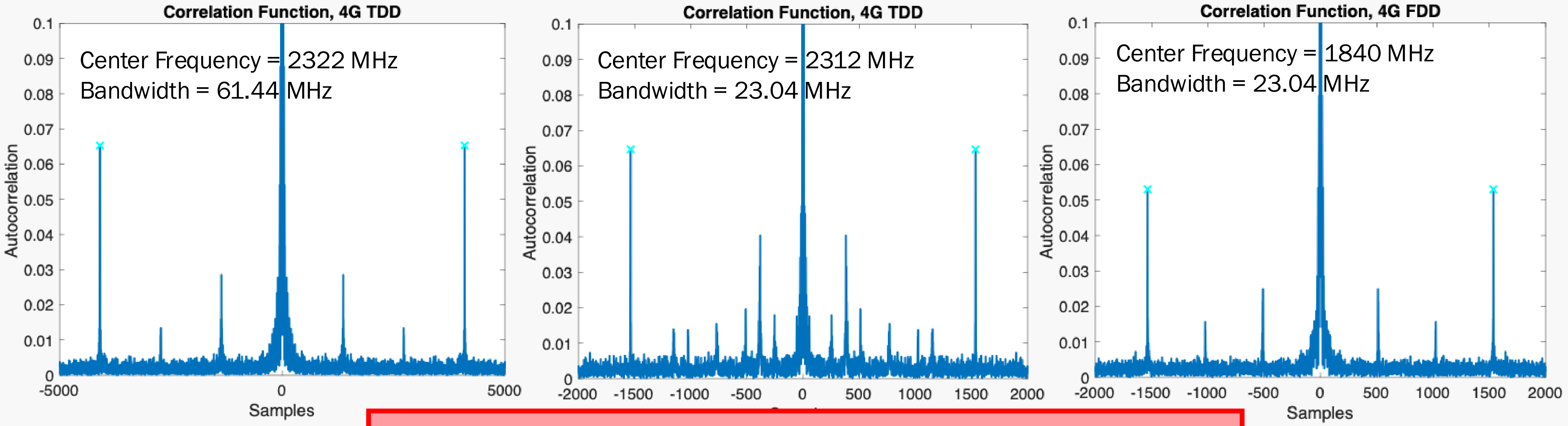
DATA ANALYSIS:

- The data processing first involved segmenting the time series into 10 ms snippets, which correspond to typical order of magnitude of integration times of spaceborne radiometers and the duration of a full 5G frame.
- To get preliminary results, the detection method was applied on 500 snippets for each frequency range.
- The starting time of the snippet was selected randomly to avoid biasing the detection method
- The figure presents an example of detection for two snippets of two different center frequencies: 3685 MHz with a sampling frequency of 23.04 MHz and 3685 MHz with a sampling frequency of 61.44 MHz
- The detection algorithm identified the peaks marked by crossed in both correlation functions, indicating the presence of 5G signals.
- The difference in peak positions between the two correlation functions aligns with the predictions based on subcarrier spacing and sampling frequency relationships.
- This demonstrates the potential of the developed algorithm to identify the presence of 5G signals.



DATA ANALYSIS: 4G vs 5G

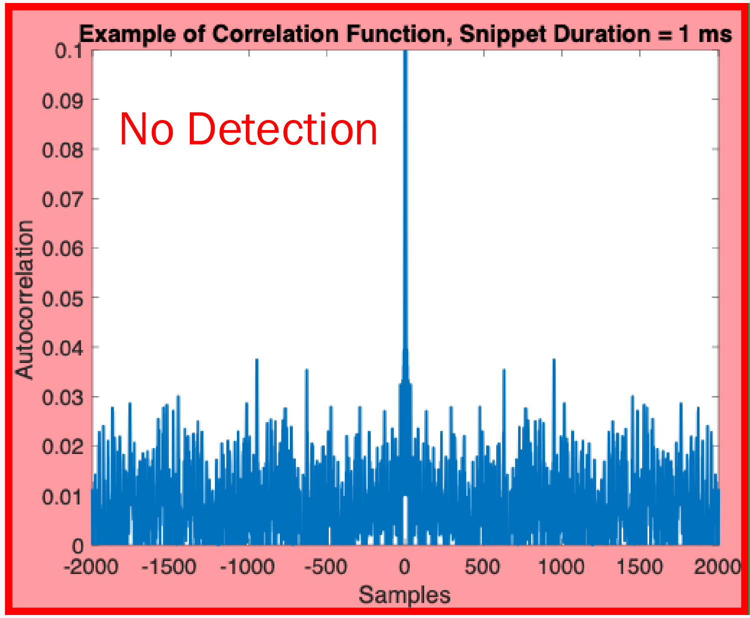
- The 4G and 5G signals present a similar structure. Therefore, some measurements were also performed in the 4G band so that the detection method can also be tested on the 4G signals.
- The same data processing is applied to the different type of 4G signals (TDD, FDD):
  - Randomly select 10 ms snippets
  - Calculate the autocorrelation function
  - Find peaks and compare them to expected positions
- All correlation functions (below) also present significant peaks at the expected locations. Some secondary features can also be observed, further investigation needs to be done to assess if those can be used in the detection algorithm to provide more information about the snippet.

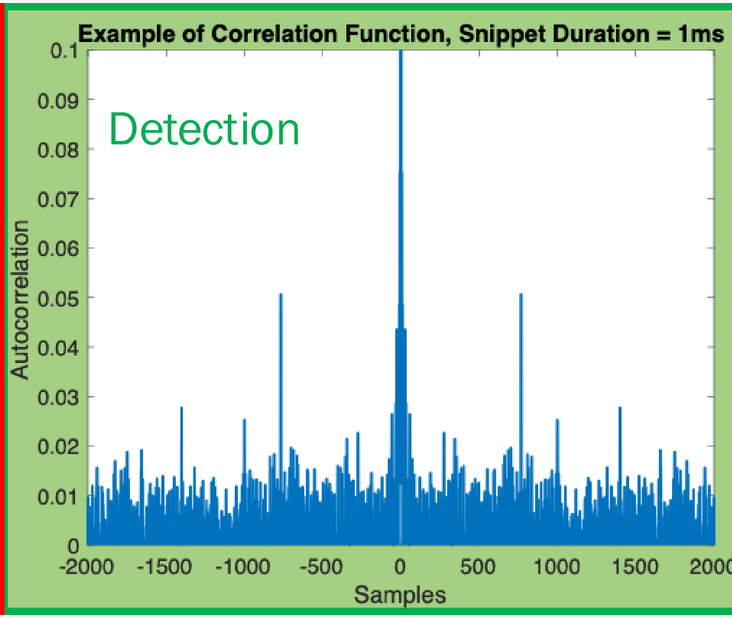


The same detection technique can be used for 4G signals

DETECTION RESULTS:

- The analysis of the randomly selected 10 ms snippets of the time series for each center frequency indicates that the detection method seems efficient to identify the presence of 5G signals when the snippet duration is ”long” and the SNR is high
- The next step of this study was then to shorten the duration of the snippets to 1 ms (duration of a subframe) and apply the detection algorithm again.
- The figures present two examples of the correlation function of the 5G signal with a center frequency of 3685 MHz when only using a 1ms snippet.
- In some cases (left), the correlation function presents slightly higher peaks but their position don’t match the position expected by the detection method. Therefore, there is no detection
- In other cases (right), the correlation function presents the distinct peaks at the expected locations and therefore the 5G signal is detected

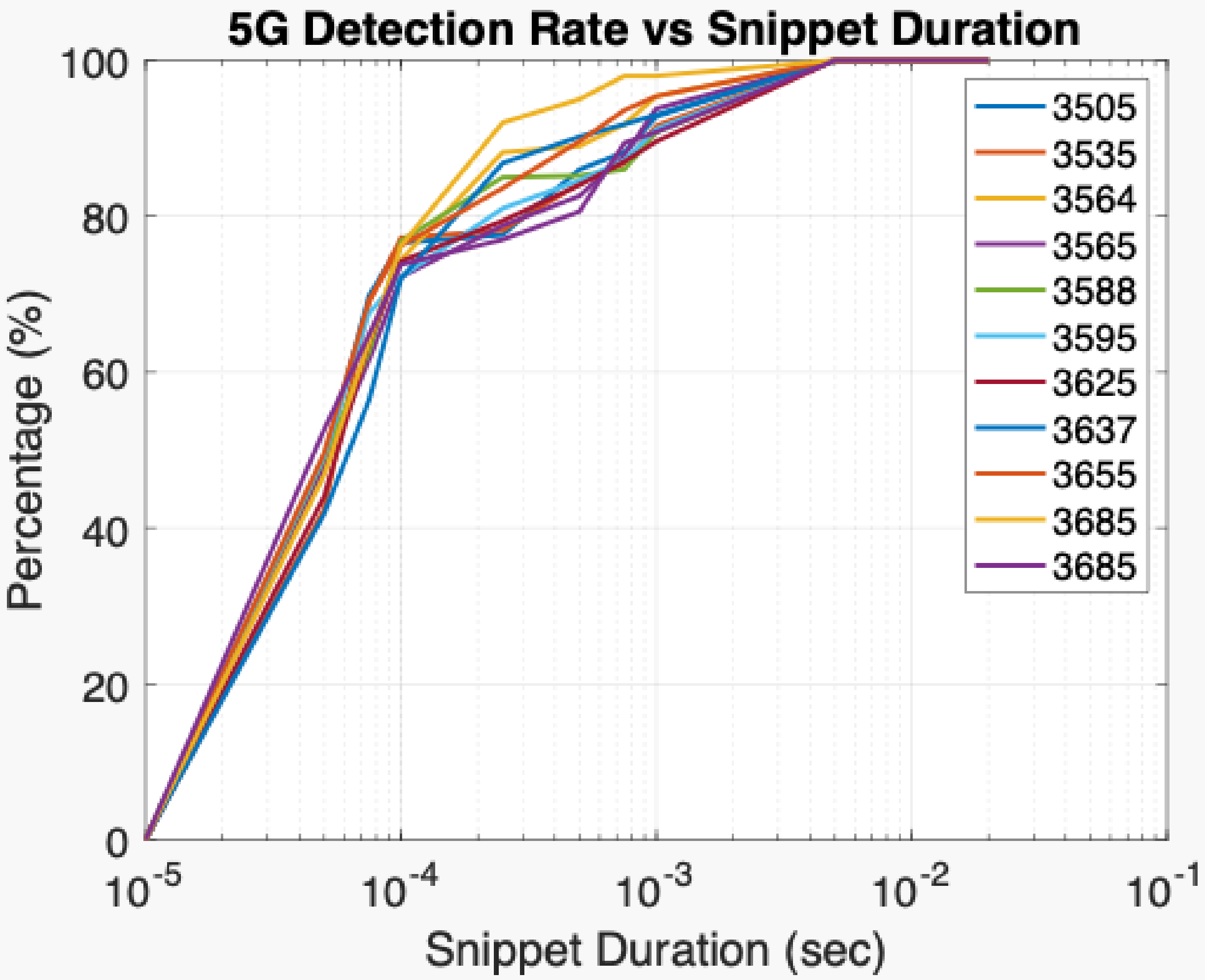




The Performance of the detection method depends on the duration of the snippet

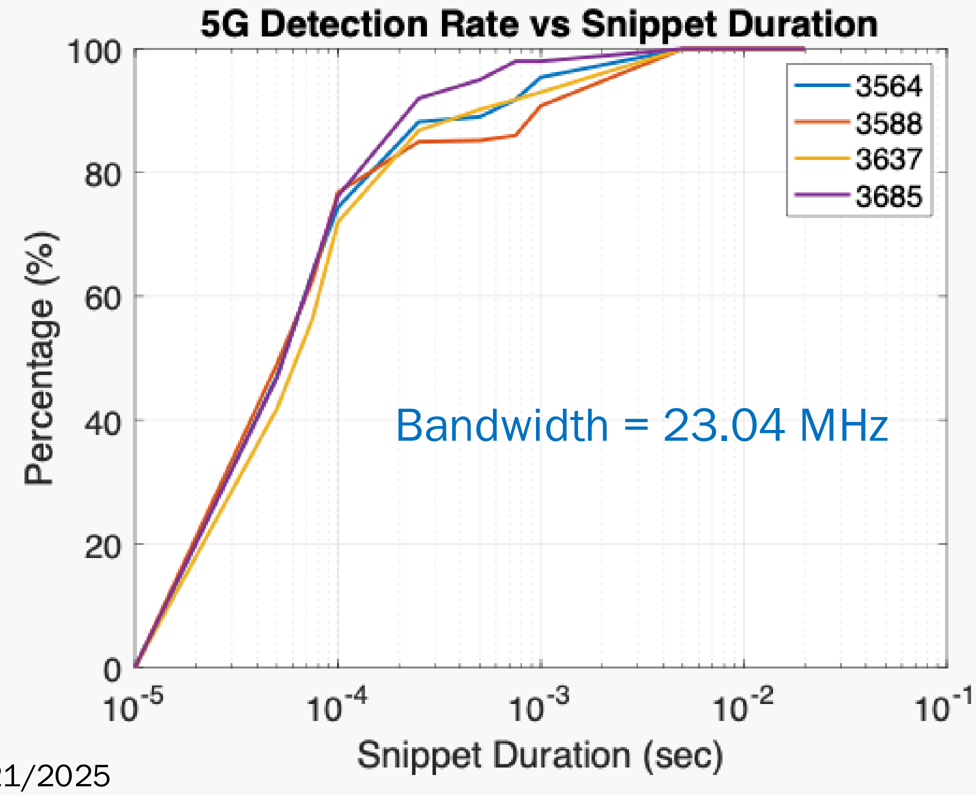
SENSITIVITY ANALYSIS:

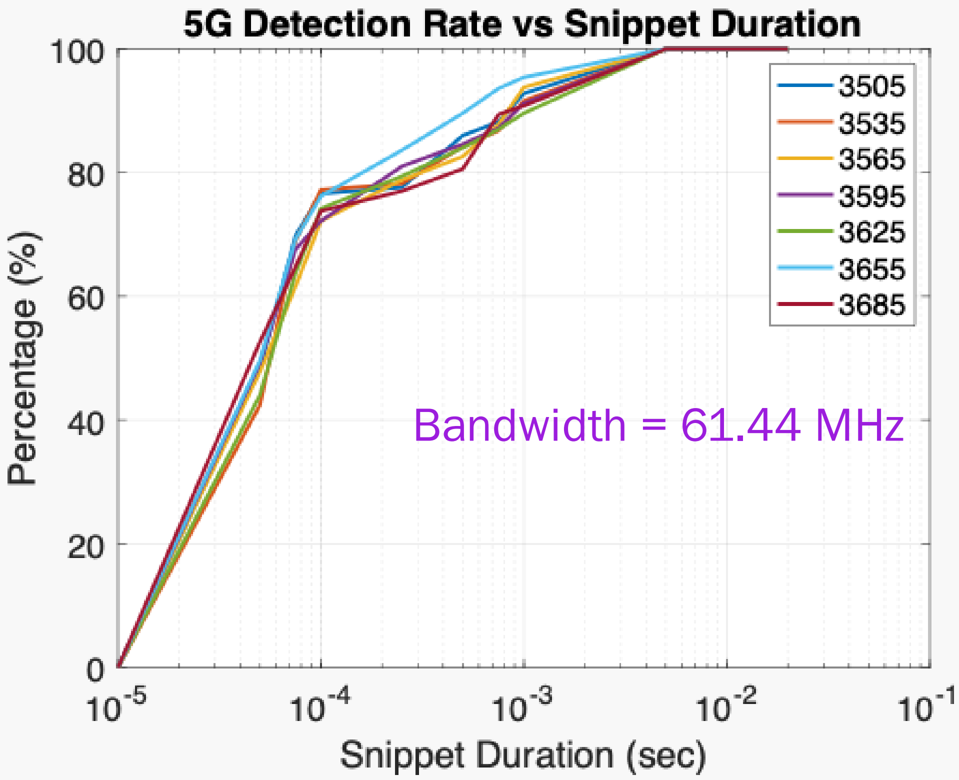
- As illustrated in the previous slide, the performance of the detection method depends on the duration of the snippet. The next step is to conduct a sensitivity analysis to evaluate the performance of the detection method as function of the snippet duration.
- This sensitivity analysis was performed by varying the snippet duration from 0.01 ms to 20 ms for each center frequency and over 500 randomly selected snippets.
- The figure presents the detection percentage as function of the snippet duration.
- The detection method is performing well on snippets longer than 1 ms (detection > 90%).
- The percentage of detection is highly variable when the detection is applied on snippets lasting between 0.1 ms and 1 ms.



SENSITIVITY ANALYSIS:

- Analyzing in more details of the percentage of detection, it was found that the curves can be separated in two groups as indicated in the figures below
- The detection method seems to perform better on signal with a smaller bandwidth than on a signal with a wider bandwidth. This can be explained by the fact that more noise is included in addition to the 5G signal which makes the detection more difficult for snippets with shorter duration.





SUMMARY AND FUTURE WORK

- From these preliminary results, it seems like the detection method performs well for detecting the presence of 5G signals if the snippet is long enough. It was also shown that the detection method can be used to detect the presence of 4G signals.
- This first sensitivity study indicates that the detection is successful in more than 90% of the cases if the snippet lasts at least 1ms.
- It was also shown than the detection method performs better on signal with a smaller bandwidth than on wider snippets.

Summary

- The sensitivity will be extended a larger number of snippets to have a better statistic representation.
- The previous slide seems to indicate that the detection depends on the signal bandwidth. A sensitivity study will be performed to confirm this observation. A channelization of the 5G signal will be implemented and the performance of the detection will be assessed as function of the channel bandwidth.
- In this study, the detection method is applied assuming that the 5G signal is emitted in the frequency range of interest. The next step will be to assess the performance of the detection method when the 5G signal is emitted in adjacent bands to the frequency band of interest.

Next Steps

Questions / Collaboration ?

- Feel Free to contact me:
  - *alexandra.bringer@gmail.com*