

SOFTWARE RADIO TESTBED FOR 5G AND L-BAND RADIOMETER COEXISTENCE RESEARCH

Walaa Al-Qwider, A. M. Alam, Md Mehedi Farhad, M. Kurum, A. C. Gurbuz, Vuk Marojevic

Mississippi State University, Mississippi State, MS, USA

ABSTRACT

Passive remote sensing through microwave radiometry has been utilized in Earth observation by estimating several geophysical parameters. Because of the low noise floor associated with the instrument (i.e., radiometer), the received geophysical emission is sampled in a protected band dedicated to remote sensing. This protected L-band occupying 1400-1427 MHz is also exciting and ideal for science because of lower attenuation from the atmosphere. This reason has also made this microwave region ideal for next-generation (xG) wireless communication. 5G cellular systems support two frequency ranges FR1 (0.45 GHz–6 GHz) and FR2 (24.45 GHz–52.6 GHz). Although operating bands are prohibited from conducting any up-link or down-link operations in the protected portion of the L-band, out-of-band (OOB) emissions can still have a significant impact on passive sensors because of the high sensitivity requirements related to science. This study will demonstrate a unique physical testbed that has the capability to observe in-band and OOB emissions in a protected anechoic chamber. Flexibility on transmitted waveforms and the potential to analyze raw measurements (IQ samples) of radiometers will help in designing onboard radio frequency interference (RFI) processing along with the coexistence of communication and passive sensing technologies.

Index Terms— Passive coexistence, 5G NR, SMAP, RFI, Deep Learning, Radiometer

1. INTRODUCTION

Radio access and management of the RF spectrum are becoming increasingly important with the emergence of 5G wireless networks and future 6G networks, which are expected to support increasingly diverse and challenging service demands. Society depends heavily on wireless technologies for commerce, transportation, health, science, and defense, with emerging technologies such as the Internet of Things (IoT) and UAVs further increasing this dependence. Radio astronomy, remote sensing, and other passive RF sensing services are also indispensable in modern society. These sensors utilize microwave radiometry to estimate geophysical parameters

and provide critical information for agriculture as well as meteorological forecasting [1, 2].

A highly sensitive microwave radiometer can measure low-power natural emissions. Moreover, it is crucial for the sensing to be developed in a frequency range that has minimal interaction with the atmosphere. That is why International Telecommunication Union (ITU) has protected the 1400-1427 MHz RF spectrum dedicated to remote sensing and radio astronomy. The microwave region of the spectrum still remains attractive for the next generation of wireless networks, such as 5G. Frequency ranges dedicated for 5G, such as FR1 (0.45 GHz–6 GHz) and FR2 (24.45 GHz–52.6 GHz), can affect the protected band through out-of-band emissions or by transmitting in-band illegally [3]. Unwanted signals in this protected L-band are known as radio frequency interference (RFI). The growth of active wireless systems is contributing to this RFI, and the dynamic features of these signals make it difficult to take any robust defensive mechanisms [4].

While additional spectrum is being considered for better efficiency in wireless communications, including millimeter wave spectrum. Techniques such as massive multiple input multiple output (MIMO) antenna systems are being developed for higher spectrum efficiencies along with better spectrum reuse. This leads to sharing technologies more important than ever to enable scaling in wireless communications services while protecting passive RF systems.

The spectrum coexistence between wireless communications and passive sensing is, therefore, an increasingly important area of research and development. The overarching problem of this research, supported by the National Science Foundation under the SWIFT program (Award 2030291) is to explore ways and develop algorithms for the co-existence of active wireless communication and passive sensing. This paper will demonstrate a physical testbed featuring a customizable 5G NR system that can transmit different transmission patterns and a radiometer that is similar to those used for remote sensing from satellites for Earth exploration. The radiometer is a highly sensitive receive-only device that is carefully designed to detect natural RF signals which are very weak. This testbed will be used for collecting ground truth data to characterize RFI and validate new spectrum coexistence techniques between 5G New Radio (NR) and remote sensing systems.

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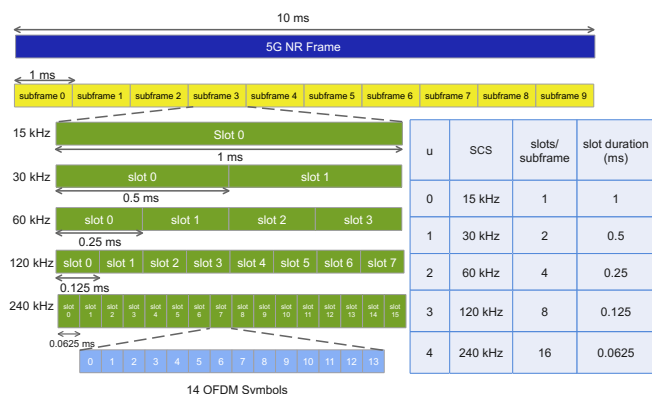


Fig. 1: 5G NR frame structure.

2. 5G NR FRAME AND CARRIER STRUCTURE

5G NR is the new radio access technology developed by the 3rd Generation Partnership Project (3GPP) for the 5th generation mobile network. The 3GPP provides all the technical details behind the 5G NR in the 3GPP specification series: 38 series. In this section, we are going to briefly illustrate the frame and the carrier structure in 5G NR. It is important to understand these two concepts as they play an important role in resource allocation in mobile communication.

The NR time frame is 10 ms divided into 10 subframes of 1 ms each (Figure 1). 5G NR offers 15, 30, 60, 120 and 240 kHz subcarrier spacing (SCS) which is known as numerology and controls the structure of the NR subframe. Each NR subframe is divided in one or more slots, depending on the numerology. The orthogonal frequency division multiplexing (OFDM) symbol is the minimum scheduling unit in NR, and the number of OFDM symbols per NR slot is independent of the SCS; it is 14 OFDM symbols for normal cyclic prefix (CP) and 12 in the case of extended CP. While the subframe is 1 ms for all SCSs, the number of slots per subframe and the duration of the OFDM symbol depends on the SCS. As we double the SCS, the number of slots per subframe is doubled and the symbol duration decreases to one-half. Figure 1 shows the NR frame structure and how it depends on the SCS [5].

The frequency domain in the 5G NR is characterized by the carrier structure which can be of different bandwidths up to 400 MHz. The smallest frequency resource in NR is the resource element (RE) which is characterized by the subcarrier in the frequency domain and the OFDM symbol in the time domain. The smallest frequency resource unit that can be allocated to a user is the resource block (RB). The NR RB contains 12 consecutive REs, irrespective of the SCS. Different RBs can be allocated to different users within the transmission time interval (TTI) and reallocated across TTIs; each RB is allocated to at most one user within one TTI. The bandwidth occupied by one RB depends on the SCS being used, as the SCS increases, the bandwidth occupied by a RB increases

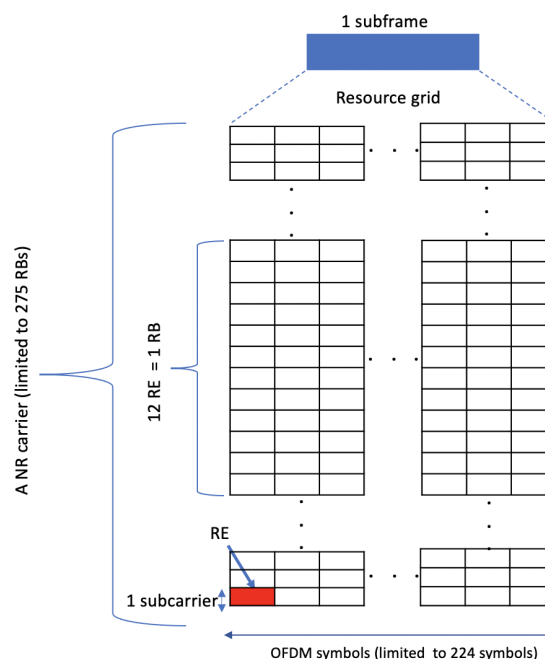


Fig. 2: 5G NR carrier structure (resource grid).

proportionally. The 5G NR resource grid is characterized by one subframe in the time domain and the full carrier bandwidth in the frequency domain. For each numerology and carrier, we have only one resource grid. The number of RBs in the resource grid depends on the numerology used. A single NR carrier is limited to 3300 active subcarriers which yields 275 RBs being the maximum number of RBs per resources grid. Figure 2 shows the full structure of the NR carrier.

3. TESTBED DESIGN

3.1. 5G NR transmitter

We start with the design of a custom 5G NR transmission system that has control over the frame and RB allocation and the transmission power to study the interference on the remote sensing receiver. The 5G waveform transmission is done in three main steps. First, we generate the custom 5G NR waveform using MATLAB 5G Toolbox, which is compliant with the 3GPP specifications; the output of this step is in the form of in-phase and quadrature (IQ) samples. We take the IQ samples and convert them using another MATLAB function to binary points so they can be transmitted using GNU Radio. To transmit the waveform, we use GNU Radio which performs the needed digital signal processing to prepare the waveform to be sent over the air, and we use SDR as the interface between the GNU Radio and the transmitter antenna. A full decryption about the 5G waveform generation and transmission testbed can be found in [6].

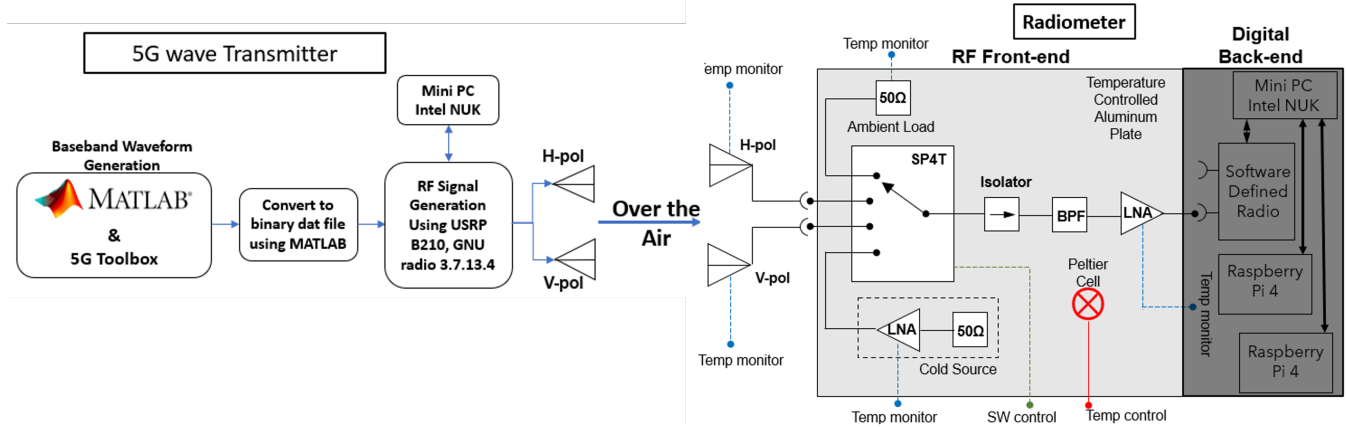


Fig. 3: 5G-Radiometer Testbed

3.2. Radiometer Design

A dual (Horizontal and Vertical) polarized software-defined radio (SDR) based radiometer operating in protected L-band (1400 - 1427 MHz) has been designed and built [7]. This radiometer is temperature-controlled and uses two port internal calibration for each measurement cycle with 1000 ms integration time while recording full 27 MHz bandwidth data. The SDR-based system allows us to have control over the full data acquisition parameters, such as bandwidth, sampling frequency, and integration time. The radiometer has been internally calibrated using liquid nitrogen, having a physical temperature of 77.4 K, and dry ice, with the physical temperature of 194.7 K, and used sky and electromagnetic (EM) absorber measurement for external calibration to convert the raw antenna count measurement to brightness temperature. Figure 4 shows the dual-polarized radiometer setup.

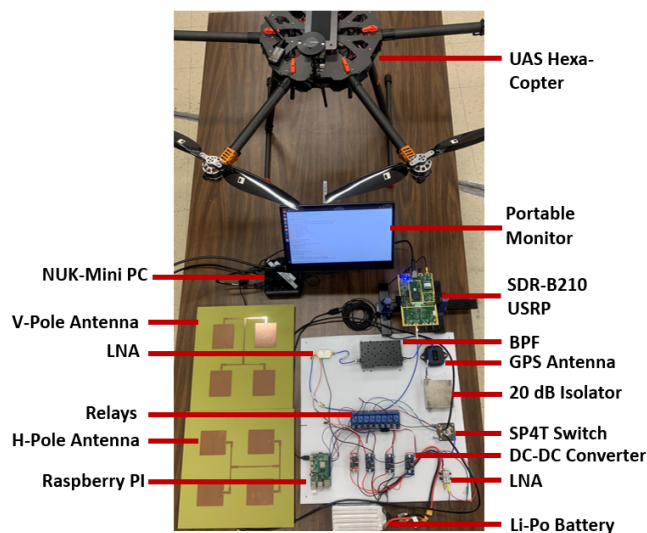


Fig. 4: Radiometer setup on a bench-top platform.

3.3. Radiometer Digital Back End Processing

The developed radiometer has the capability of receiving raw IQ samples with a 30 MHz sampling rate. Each polarization consists of 250 ms of integration time (i.e. $250 \times 4 = 1000$). This huge number of digital IQ samples enables the radiometer's back-end processing to perform domain transformation through short-time Fourier transform (STFT) and generate spectrograms. These spectrograms help to decipher the time-frequency features. This possesses the potential to design both learning-based and statistical on-board RFI detection and processing unit. Figure 3 represents the 5G signal transmitter and radiometric receiver system.

4. RESULTS AND DISCUSSION

We conduct our over-the-air transmissions in a specialized anechoic chamber, ensuring a controlled environment for testing. These transmissions take place within the L band, which is a protected frequency range. We generate different 5G waveforms and transmitter them over the air, and the radiometer receives this waveform using the H-pol and V-pol antenna. The aim of this experiment is to study the effect of the transmitted 5G waveform on the radiometer side. Figure 5 shows the spectrogram of the frame transmitted from our 5G base station and the spectrogram of the frame sensed by the radiometer. The left spectrograms show a 1 ms 5G transmission frame (subframe), which is repeated for as long as the experiment lasts. The right subfigures are captured by the radiometer which switches between vertically polarized receive antenna, horizontally polarized receive antenna, hot source, and cold source every 250 ms. The plots show a 9 ms capture, which is the time needed by the radiometer to sense the spectrum. Sample 1 is continuous full-band transmission at -20 dBm with the quadrature phase shift keying (QPSK) modulation scheme. Sample 2 is similar to Sample 1 except that it employs the quadrature amplitude modulation with 16 symbols (16QAM). Sample 3 keeps the same power allocation for each OFDM subcarrier, with QPSK, but allocates every other sub-band over the 5G system bandwidth of 25 MHz. Here we

divided the 25 MHz into 14 sub-bands. Sample 4 uses this same partition but transmits in all sub-bands at the full and half power levels. Sample 5 uses the same sub-band division and full power to transmit on the seven even sub-bands in the first 0.25 ms, in the seven odd sub-band in the second 0.25 ms, and then again in the even sub-bands, and so on.

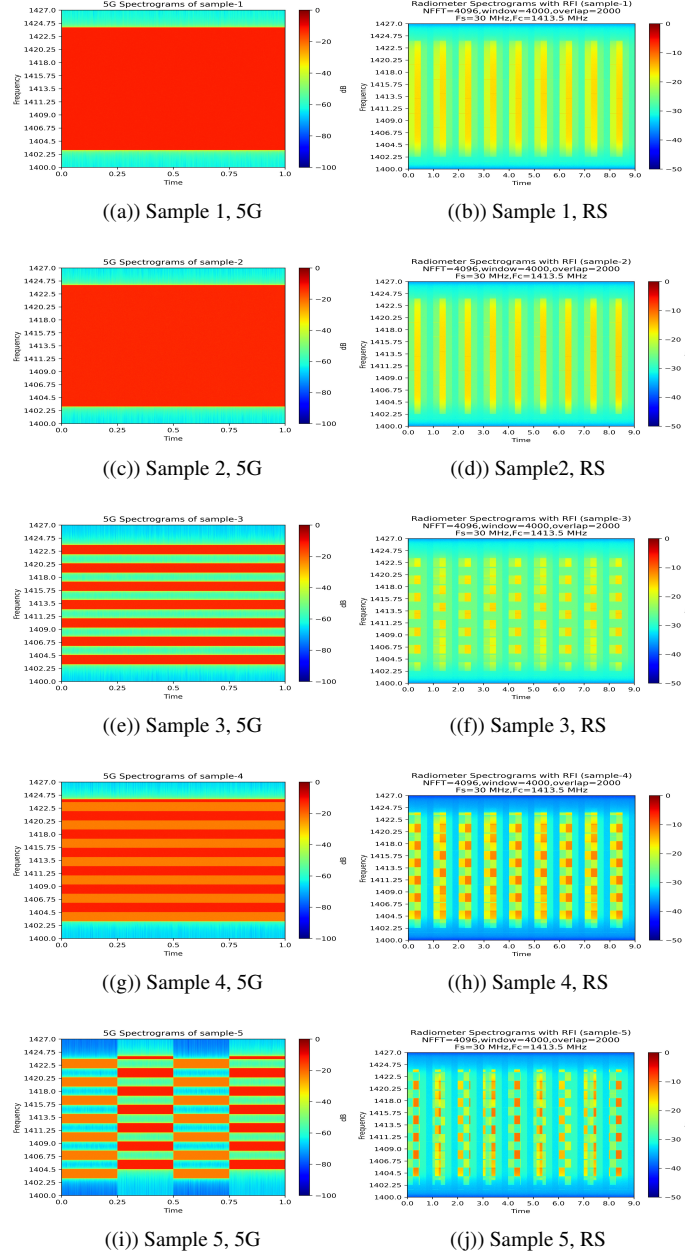


Fig. 5: Spectrograms of received data from L-band radiometer while 5G transmission is present

5. CONCLUSION AND FUTURE WORK

In this work, we design a wireless testbed to study the effect of the 5G NR waveform on the radiometer working in

the protected L-band. This testbed should help in real-time test the different algorithms that are developed to enable the coexistence of the active 5G NR transmitter with the passive radiometer. We are working on developing an artificial intelligence-based [8, 9] method for spectrum coexistence and this testbed is going to be used for the test phase of this developing work.

6. REFERENCES

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