Spatial Multiplexing MIMO 5G-SDR Open Testbed Implementation

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Abstract. Future 5G networks will demand high increases in capacity which are not acquirable by existing 4G implementations. The objective of this paper is to propose an open testbed solution in order to perform applied studies for 5G New Radio, using SDR, optimal parameter configuration, vendor equipment benchmarking, real life consistent tests for radio equipment behavior and create the possibility to extend the current platform to be able to accommodate future technical needs. GNU Radio, provides the opportunity to create software-defined radios based on virtual signal processing blocks using low-cost external RF hardware or simulation-like environment. This offers the opportunity to telecom mobile operators to set up the networks at the highest capabilities and also to have a clear vision before making strong investments in new equipment.

Keywords: 5G · SDR · MIMO · Massive-MIMO · Testbed · New Radio · Embedded · GNU Radio · Case studies · Benchmarking · IoT · RF

1 Introduction

Applications of multiple input, multiple output (MIMO) technology such as massive MIMO can provide enormous gains in capacity and spectral efficiency by using large numbers of antennas. Software-defined radio (SDR) is a radio communication system where physical hardware modules and components implemented in hardware (e.g. mixers, filters, amplifiers, modulators/demodulators, detectors, etc.) are instead developed as software blocks on computers or embedded systems. Flexible yet affordable SDRs are able to turn a standard PC into a next-generation wireless tool. The future telecom networks are not only characterized by faster data throughputs and higher capacity, but the seamless, real-time interaction between end-users and billions of smart devices. 5G wireless technology promises a high-reliability and all-connected world. New bands and wider bandwidths will be used, new beamforming technology and use cases can be approached and 5G New Radio (NR) equipment require adequate design, reliable prototypes and tough tests challenges to be ready for large-scale deployments.

This paper is proposing a testbed solution to analyze and test technologies and equipment, addressable to universities, vendors and also to telecom mobile operators. The testbed offers the possibility to run a number of customized tests, set and try different parameters in order to understand better the equipment capabilities or to set a

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mobile networks at their truly potential in 5G New Radio context. Mobile operators are targeting massive 5G deployments in the near future, to keep up with the competition. Before making investments, mobile operators have to test equipment in laboratory and also in real life field scenarios. Also, some mobile operators are requiring custom made equipment with certain parameters and it is absolutely necessary to have access to a benchmarking framework to be able to choose the right vendor.

The proposed test framework was built taking in consideration many theoretical concepts presented in Sect. 2, like MIMO channel models, channel capacity and signal detection at the reception. Section 3 is dedicated to the testbed setup approach and it describes how the system was implemented, the technical objectives and what kind of hardware equipment and software packages were used. The experimental results and how the data was interpreted are presented in Sect. 4. The conclusions, future work and objectives are exposed in Sect. 5.

2 Theoretical Prerequisites for MIMO SDR Testbed Development

Theoretical characteristics are necessary to be understood in order to implement a MIMO testbed system. The radio channel, MIMO channel capacity, statistical models for the MIMO channel, the modulation techniques used for transmission, the detection algorithms used to separate the data streams that reach receiving antennas, the parameters and platform models together with the secondary modules specific to each desired function are some of the main prerequisites underlying the current work.

The second step is the deepening process of GNU Radio simulation environment on the Ubuntu Linux operating system and its available functions.

Some of the theoretical concepts and equations used in the software processing blocks development are described in the following subsections.

2.1 MIMO Statistical Channel Model

To characterize SISO systems (single input, single output), the spread delay and the Doppler effect have to be considered. The first may be interpreted as the difference between the arrival time of the earliest multicast component received and the time of arrival of the last significant multicast component, this notion being used to characterize the radio channels. Doppler displacement refers to the fact that when a user is in motion, his speed causes a frequency shift of the transmitted signal. Several signals crossing different paths and areas may have Doppler displacements that differ from each other, corresponding to different phase shifts [1].

The difference between Doppler displacements between different components of a signal leads to the occurrence of a fading channel known as Doppler spread. Multiple antennas for broadcast and reception are used in MIMO systems (multiple input, multiple output). The correlation between the broadcast antenna and the receiving antenna is a very important aspect of the MIMO channel. This depends on the angle of incidence of each multipath component [12].

2.2 MIMO Channel

The MIMO channel must be described for all antenna pairs, transmitter-receiver. For M broadcasting antennas and N receiving antennas, the MIMO transmission channel can be represented by an N × M size matrix shown in Eq. 1 [1].

This matrix is:

$$\mathbf{h}(t,\tau) = \begin{bmatrix} h_{11}(t,\tau) & \cdots & h_{1M}(t,\tau) \\ \vdots & \ddots & \vdots \\ h_{N1}(t,\tau) & \cdots & h_{NM}(t,\tau) \end{bmatrix} \quad (1)$$

$h_{NM}(t, \tau)$ is the variation in pulse response in time between the m input of the transmitting antenna and the n output of the receiving antenna. Each pulse response is the cascaded effect of the transmitting antenna, the propagation medium and the receiving antenna. The spatial and temporal correlation between the signals received at different antennas is reflected in the matrix elements.

MIMO channels can be physical or analytical. Physical models are based either on physical theory (geometry) or on physical measurements. They are specific to a type of environment or area (urban, suburban and rural) and are used in network planning. Analytical models are independent of the physical implementation area and are often used for system creation, comparisons, and tests.

Physical models can be subdivided into deterministic and stochastic. Deterministic models are specific to the external environment and are derived from the physical radio propagation processes: reflection, diffraction, shading, etc. Stochastic models are more generic than deterministic models. It is based on data used in the absence of a database of application environments, specific propagation parameters. Probabilistic models can be built for these parameters. These models are more computerized. The SCM model, the spatial channel model, is a stochastic model [1].

The MIMO channel matrix was used to create the MIMO channel model block in GNU Radio.

2.3 MIMO Channel Capacity

Multicast propagation has long been considered an impediment because of the fact that the signal is affected by fading. To eliminate this problem, diversity techniques have been introduced. The theory of information has shown that by multiple propagation, multiple antennas at both transmit and receive can produce multiple parallel channels that can operate simultaneously in the same frequency band with the same transmit power. Antenna correlation varies drastically depending on the obstacles encountered by the signal in its propagation path, depending on the distance between the transmitter and the receiver, depending on the configuration of the antennas and the Doppler displacement. Recent research has shown that multicast propagation actually contributes to the capacity.

The increase in spectral efficiency offered by MIMO systems is based on the use of spatial diversity in both emission and reception. The high spectral efficiency obtained with an MIMO system is due to the fact that in an obstacle-rich environment, the signal from each transmitter appears uncorrelated to the receiving antennas. When the signals go through uncorrelated channels, the signals from the transmitting antennas have different spatial characteristics. The receiver can use these differences between spatial characteristics to separate signals from different antennas simultaneously and at the same frequency.

The most important idea in MIMO is that different signals can be sent using the same frequency band and there is the possibility of correct decoding at the receiver. It is like creating a channel for each of the transmitters. It can linearly increase the capacity of MIMO channels by carefully adding a larger number of transmitting antennas. It is more beneficial to transmit data using several different power channels smaller than one high power one [3].

In practice, the capacity of a N $\times$ M MIMO system when the channel is known, is shown in Eq. 2 [3]:

$$C_{MIMO} = B \cdot \log_2 \left| \det \left[I_N + \frac{SNR}{M} HH^* \right] \right| \text{bps/Hz} \tag{2}$$

2.4 Signal Detection for MIMO Systems with Spatial Multiplexing

There are different detection schemes for MIMO systems such as ML (maximum-likelihood), which require computational resources over the power of most practical systems. To reduce the complexity of MIMO detection techniques, equalization techniques such as zero-forcing (ZF) and minimum mean square error (MMSE) can be used.

MIMO systems are used to support very high data transfer rates, but the power balance and performance requirements are maintained for SISO systems. The MIMO channel at the reception is inverted to minimize total interference from other transmitted signals. The ZF filter output is the function of the data to be detected and the reception noise [4].

The best detector that minimizes the probability of error is the ML detector. This is hard to implement in practice due to the complexity of the algorithm. The paper results are based on ZF and MMSE algorithms. They need less computational power.

The reception of data that is transmitted serially through the dispersing media is a complex operation due to the emergence of ISI.

MIMO systems that use spatial multiplexing can transmit data at higher speeds than systems that use spatial diversity. However, spatial demultiplexing or signal detection at reception is a difficult task for MIMO systems that use spatial multiplexing (Fig. 1).

The MIMO system of N_R x N_T antennas is considered. The matrix H is defined as the channel matrix with the h_{ji} element representing the channel gain between the transmitting antenna "i" and the receiving antenna "j", $j = 1, 2, \ldots, N_R$ and $i = 1, 2, \ldots, N_T$. The data from a spatially multiplexed user are represented as $\mathbf{x} = [x_1, x_2, \ldots, x_{NT}]^T$, respectively the received data $\mathbf{y} = [y_1, y_2, \ldots, y_{NR}]^T$, x_i and y_j represent the signal transmitted from the antenna i, respectively the signal received at the

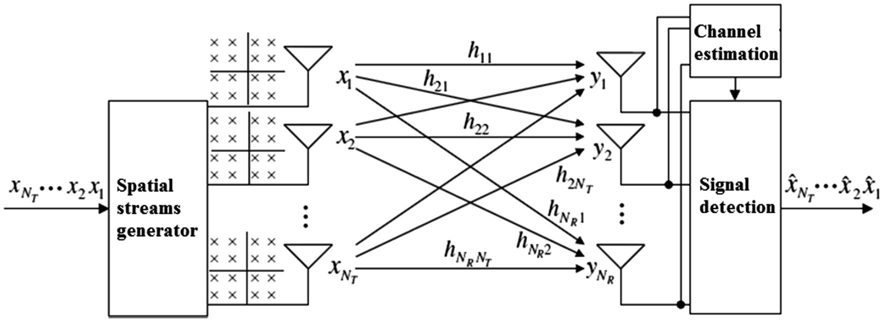

Fig. 1. Spatial multiplexing MIMO system [5]

antenna j. It is defined z_j as Gaussian white noise with the variant σ_z^2 at the receiver antenna j and $\mathbf{h}_i$ represents the second column vector of the H channel matrix [5].

$$\mathbf{y} = \mathbf{Hx} + \mathbf{z} = \mathbf{h}_1 x_1 + \mathbf{h}_2 x_2 + \ldots + \mathbf{h}_{NT} x_{NT} + \mathbf{z}, \mathbf{z} = [z_1, z_2, \ldots, z_{NR}]^T \tag{3}$$

Taking in consideration the two presented detection algorithms, a Matlab implementation was developed for this paper and a BER comparison for 2 × 2 MIMO system is shown in Fig. 2.

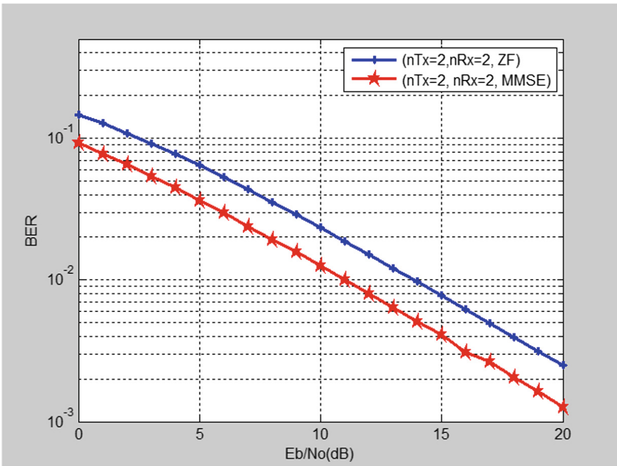

Fig. 2. BER for 2 × 2 MIMO system (BPSK and MMSE)

The graph shows that compared with Zero Forcing detection, at a 10^{-3} BER, MMSE detection has an improvement of 3 dB.

Also, for the real life tests, presented in the following sections, ZF and MMSE detection algorithms were implemented and used.

3 Testbed Setup Approach

In order to develop a SDR platform to integrate MIMO technology, a software and a hardware testbed was deployed. An open-source software, called GNU Radio [6], with a variety of applications, particularly SDRs, was used. Open-source software attracts contributors because of the cost advantage. At the same time, more compelling benefits, like enhanced security, quality, flexibility and customizability, exist. The hardware used for the testbed is made by National Instruments and the product is called USRP [7].

The term USRP comes from "Universal Software Radio Peripheral". USRP products are radio equipment managed by software running on computing units (PCs). These were designed, built and sold by the American company Ettus Research, which is part of National Instruments company. USRP boards can be connected to a computer via a high-speed USB or Gigabit Ethernet cable, through which the computer-programmed software is able to control the physical platform to transmit or receive data. The USRP family has been designed for accessibility, and most of the programs that are used to use physical platforms have free access and the ability to contribute to their development. To control these platforms, a UHD driver with a free license is used. Most of the time, USRP boards are used with the GNU Radio software suite, which allows the creation of complex radio system programs, but also with LabVIEW.

GNU Radio provides the possibility to design a series of signal graphs to model all the operations required for the processing of radio signals. Following these simulations, the data obtained were analyzed and presented in the form of comparative graphs.

MIMO techniques using spatial multiplexing increase the complexity of the receivers, so they are combined with the OFDM modulation technique to effectively eliminate the problems caused by the multipath channel. The IEEE 802.11n standard, issued in 2009, uses the MIMO-OFDM technique. Other areas of application of this technique are in the field of mobile telephony, through the 3GPP, HSPA and LTE standards.

The USRP family of products includes a variety of models that use a similar architecture. A motherboard provides the following subsystems: clock generator and synchronization, FPGA, ADC converters, DAC, external computer connection interface and power regulator. These are the basic components that are required for signal baseband processing. For other operations such as filtering or conversions, some boards are attached to the motherboard by two slots, called daughterboards. This modularity property of the USRP platform serves many applications.

In the basic configuration, the FPGA performs various signal processing operations, which ultimately offers the translation from analog real signals to complex digital signals in the baseband. In most cases, these complex samples are transferred from applications running on an external processor on the operating computer. The FPGA code is free of license and can be modified to allow for high speeds or slow processing operations [7] (Figs. 3 and 4).

The signal received from the radio frequency module is brought into the base band and then converted to digital format using an ADS62P44 ADC converter, which performs a signal sampling at a rate of 100 Mbps, with a 14-bit precision. Two signals

Fig. 3. Central panel of USRP N210 SDR platform [7]

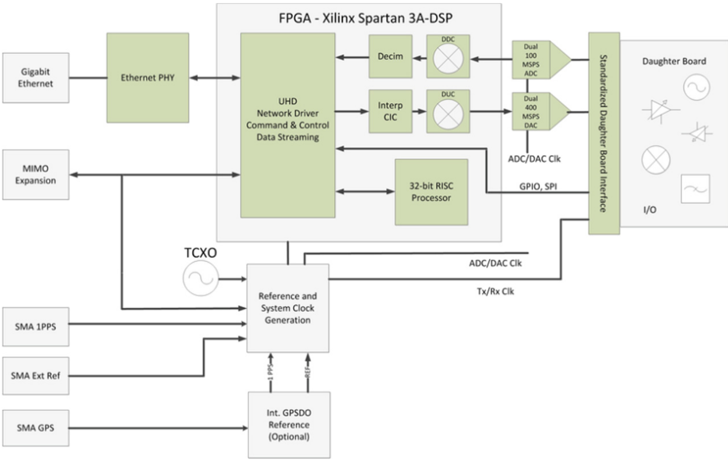

Fig. 4. USRP N210 block diagram [7]

are obtained, one in phase (I) and one in quadrature (Q). The IQ digital signal is further processed by the FPGA module. In this module, filtering and decimation take place. There are three cascaded filters, a CIC filter (cascaded integrator) and two HB filters. Decimation takes place at a rate of 2 for HB filters and at a rate between 1 and 128 for the CIC filter; with cascading, a rate of between 4 and 512 is achieved. For data transfer to be supported by the Ethernet interface that is limited to 1 Gbps, a decimation of at least 4 is required.

GNU Radio is a suite of free software licensed by Eric Blossom in 1998. This software coupled with hardware such as the USRP N210 allows the creation of a complete SDR platform. GNU Radio can also be used as a standalone simulation program. The operating system recommended for GNU Radio is Linux. It can also be installed on other operating systems such as Mac OS or Windows using the Cygwin application, but total functionality is not guaranteed. It is used for personal, academic or commercial use.

Most GNU Radio applications are written in Python, and C++ is used to implement signal processing blocks. Python commands are used to control all parameters of the USRP module, such as transmission power, gain, frequency, antenna used, etc., certain aspects being editable while the application is being executed. GNU Radio performs all signal processing. It can be used to write applications that receive or transmit data.

GNU Radio is built on two structural entities: signal processing blocks and signal graphs. The blocks are structured to have a number of input and output ports, consisting of small signal processing components. When the blocks connect to each other, a spreadsheet is formed. The GNU Radio blocks can be divided into several categories: sources, modulators, operators, filters, viewing tools, etc. Sources are blocks that contain only outputs and represent the starting point of a signal graph. Sinks or rescue or display blocks have only inputs [7].

Graphs are created either as hierarchical blocks or as top blocks. Top blocks are found in all graphs and are used to define some parameters and have no inputs or outputs. Hierarchical blocks coexist with top-level and contain a number of inputs and outputs. Communication between blocks is achieved using different types of data flows. For a data stream to be successfully initialized, the data type between two blocks, the output of a block and the input of the next one must be the same.

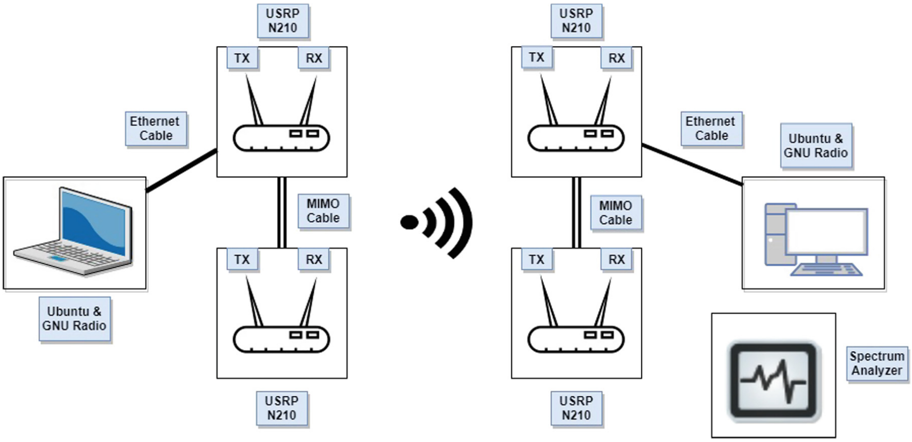

Fig. 5. Testbed block diagram

The purpose is to analyze in GNU Radio environment using the test platform built with USRP N210 and WBX/XCVR2450 submodules, the 2 × 2 MIMO system, shown in Fig. 5. The chosen development environment was GNU Radio Companion, in which transmission and reception, each running on a different computer, were implemented (Fig. 6) (Table 1).

In order to achieve the desired setup, two USRP N210 boards each having a WBX transceiver module were used. The chosen operating frequency was 2 GHz. Each WBX module has two antennas accordingly to the selected frequency band. It is very important that at least a USRP board has a Jackson GPS module installed, because even if the antenna is not connected to it, the program execution routine will check its existence. After all hardware connections have been completed on the USRP boards, they can be fed in DC at a voltage of 6 V.

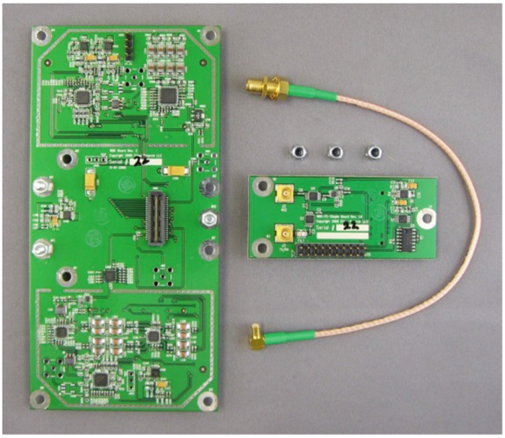

Fig. 6. WBX submodule

Table 1. PCs specifications

Name	Configuration
PC1 - laptop	Intel Quad Core i7 2.8 Ghz, 8 GB dual RAM
PC2 - desktop	Intel Core 2 Duo 2.4 Ghz, 4 GB dual RAM

In order for the two USRPs to be a MIMO system, it was necessary to connect a MIMO cable between the two boards, which allows the synchronization of the clock from the master board to the slave board. To link the computing unit to MIMO, it was necessary to connect a cable between the Ethernet interfaces of the computer and the USRP master board. Using this cable and using the IP protocol and the UHD driver installed on the computer, the signal graph implemented in GNU Radio Companion could be run successfully.

The next step was to enter the IP addresses for each Ethernet interface. USRP boards come from the factory with fixed IP 192.168.10.2 but can be easily changed. A wired connection must be enabled on the computer interface and an IP address on the same network as the USRP address, for example 192.168.10.1, must be entered.

Once all of these steps have been executed, you can verify that your computer sees the USRP as attached running the command: "uhd_find_devices".

Only one antenna on each board is able to transmit data. The second one is for receiving data, in order to create a duplex communication system (Figs. 7 and 8).

In order to transmit data from one board to another and to implement the complete testbed scenario, GNU Radio was used and different functions blocks were created and programmed. Some of the blocks were part of GNU Radio library of signal processing blocks written in C++. Those blocks include signal sources, data rescue blocks, and filters. Processing blocks are stuck together using Python.

In Fig. 9, the transmission part was designed, the blocks were created and the parameters were set according to the desired signal.

Fig. 7. Transmission and Reception 2 × 2 MIMO

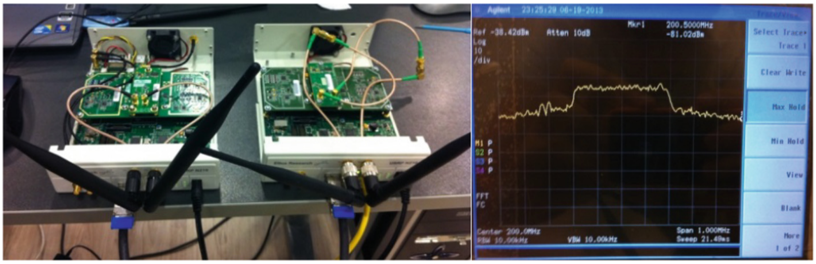

Fig. 8. OFDM live spectrum on spectral analyzer

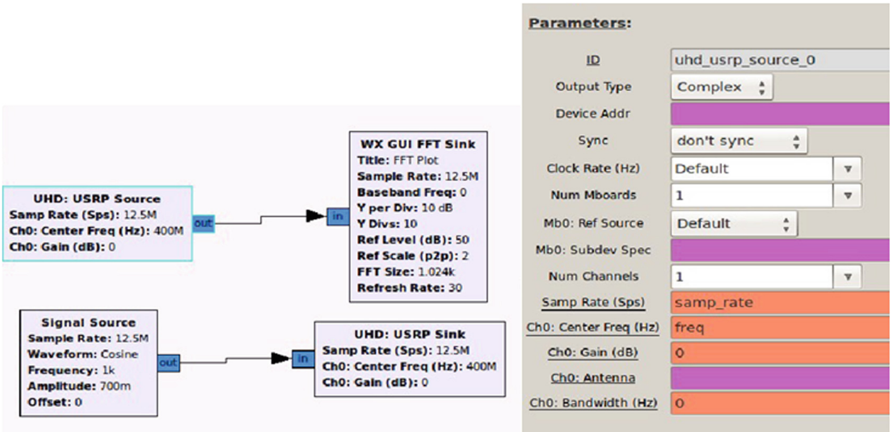

Fig. 9. Data transmission and reception – signal graph and characteristic parameters

By entering the property menu of a source USRP block, the following parameters can be selected: Block ID, type of output data (received), clock, number of motherboards, number of channels, sampling rate, carrier frequency, gain, name of the receiving antenna, bandwidth.

The UHD driver links the software that processes data to the GNU Radio environment and the USRP physical card. Parameters that can be selected are: Output data type, USRP board IP address, Number of motherboards, Synchronization type, Number of radio channels, Sampling frequency, Frequency of carrier to be transmitted, Name of antenna reception and earnings.

Figure 10 represents the setting of two receiving channels corresponding to the two antennas of the RF module, each USRP board was modeled by an individual block.

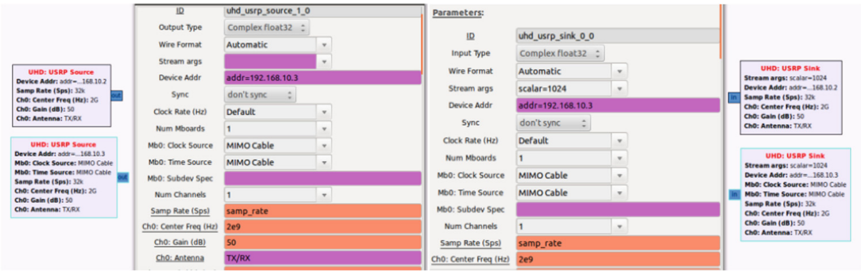

Fig. 10. Parameters of receiving and transmitting blocks using four USRP platforms

To create a 2 × 2 MIMO system with 4 USRP board, different IP addresses on the motherboards that are connected by the MIMO cable have to be set, the synchronization source for the second card as the MIMO cable has to be selected, and the same procedure is followed at the receiving side. This type of implementation requires two computing units (PCs).

4 Preliminary Experimental Results for MIMO 5G Ready SDR System in GNU Radio

To be able to observe the maximum capacity and the error rate of a MIMO channel that uses two transmitting antennas and two receiving antennas, two individual transmission paths were modeled in GNU Radio, using OFDM modulated random data sources transmitted through a Gaussian white, additive, virtual noise channel. After the demodulation, the received data was compared to the data emitted by an error rate calculation block. To find the error rate of the entire 2 × 2 MIMO channel, the arithmetic mean between the two parallel rates is made and the data is stored in a file.

In Fig. 11, OFDM modulated signal spectrum was captured. Next, the components in time domain, phase (I) and quadrature (Q) can be observed. Depending on the number of tones used, the spectrum of the OFDM signal may appear narrower or wider, shown is Fig. 12.

It is difficult to implement a MIMO 2 × 2 system in the GRC Companion simulation environment due to the lack of already implemented detection blocks. It is considered the signal graph in Fig. 13. The existence of four random data sources is explained by the need to emphasize how on each receiving antenna nR_x1 and nR_x2,

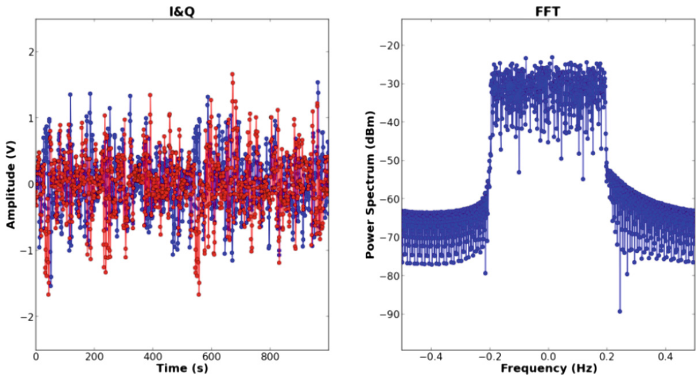

Fig. 11. Spectrum of OFDM modulated signal - phase and quadrature components

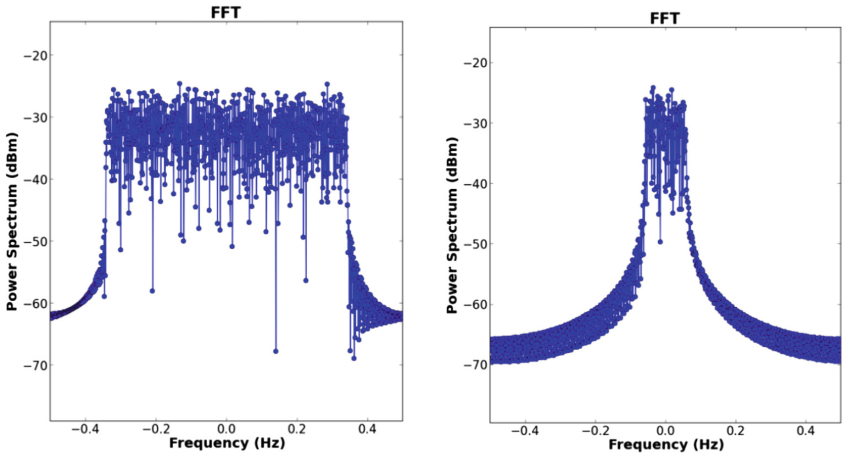

Fig. 12. OFDM spectrum, 350 tones vs. 50 tones

data from each of the two transmit antennas nT_x1 and nT_x2, arrives. Two data streams per each transmission antenna were generated. A transmission path was designed through a "channel model" block [8] that introduces propagation attenuation. The two data streams coming from the two antennas are affected by the same noise, so the three-input summation block was used in which the two paths and the total noise are accumulated. The same procedure was used for the second receiving antenna. Being in a simulation environment, the data is digital and the analog-to-digital converter is not necessary in this situation. Two additional blocks have been introduced for each receiving antenna: removing the OFDM specific cyclic prefix and applying the FFT transform. At this point, a Zero-Forcing or MMSE detection algorithm can be applied using either a Python script or Matlab.

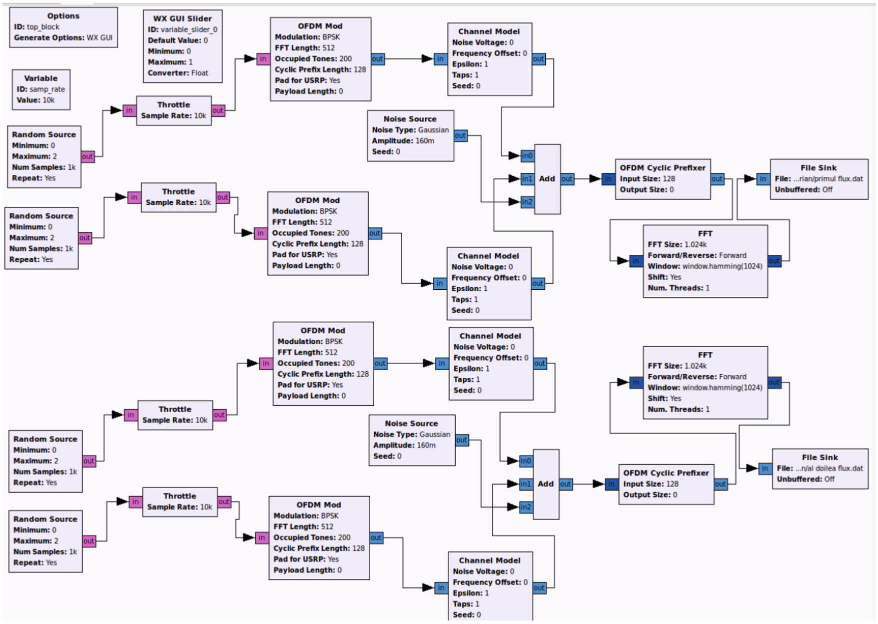

Fig. 13. Signal graph for analyzing 2 × 2 MIMO transmission

4.1 Data Detection and Error Rate Analysis Using Python

By installing the GNU Radio program using the script presented, users are provided with a number of libraries that allow to display the captured data and trace curves of interest. For the MIMO system a new library called gr-off was added, where the ZF detection algorithm is implemented in Python. Using this source and importing the obtained data as input to the another script, called berawgn.py, which was modified to display the bit error rate for a SISO, 2 × 2 and 3 × 3 MIMO systems, the graphs in Fig. 14 were obtained using 16QAM modulation.

The more complicated the modulation technique, the risk of error increases and the BER is higher for the same signal-to-noise ratio. The higher the SNR, the BER decreases. A value of 15 dB (SNR) was considered for this report. The BER increases with the number of antennas, but not much, which leads to the advantage of using a multi-antenna MIMO system, achieving a higher transfer rate with the disadvantage of increasing BER. For 16QAM modulation, considering a SNR of 14 dB, the BER value is higher in case of 3 × 3 MIMO compared to SISO, because the complexity of the system also increases.

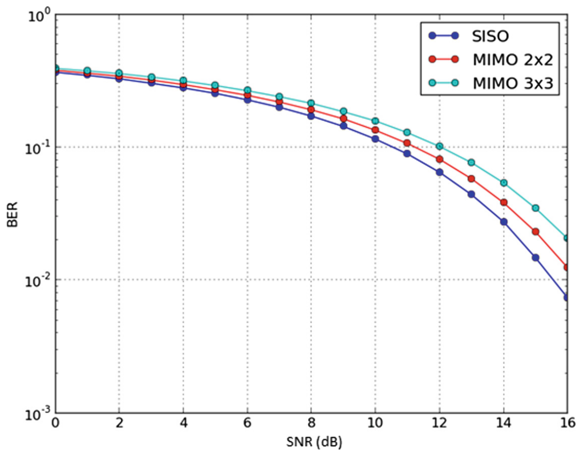

Fig. 14. BER vs. SNR (dB) for 16QAM modulation

4.2 Analysis of Bit Error Rate and MIMO Channel Capacity in Matlab

A series of simulations for SISO, MIMO 2 × 2 and 3 × 3 systems were performed using Zero-Forcing and MMSE detection algorithms. For this paper, 16QAM modulation was analyzed.

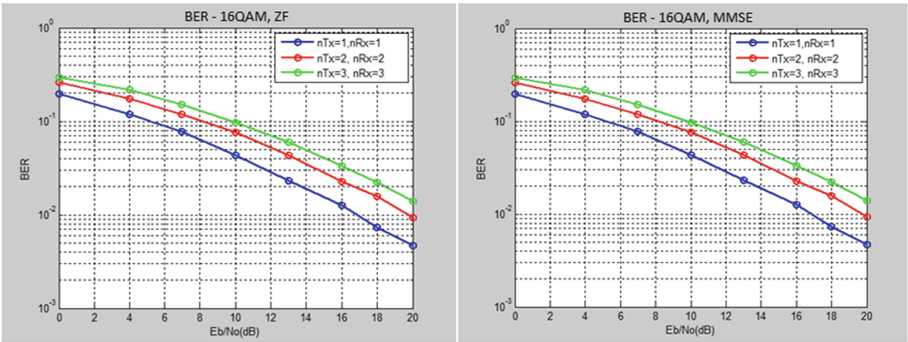

Fig. 15. BER vs. E_b/N_0 using 16QAM modulation, ZF detection and MMSE

Analyzing the graphs in Fig. 15, the following conclusions can be drawn:

- BER values based on E_b/N_0 are similar for the three transmission systems to those obtained running the Python script.
- The higher the number of transmit and receive antennas, the transmission rate increases, but the BER is negatively affected.
- Using the MMSE detection algorithm, the BER obtained for a multi-antenna system is very close to that obtained with a SISO system.

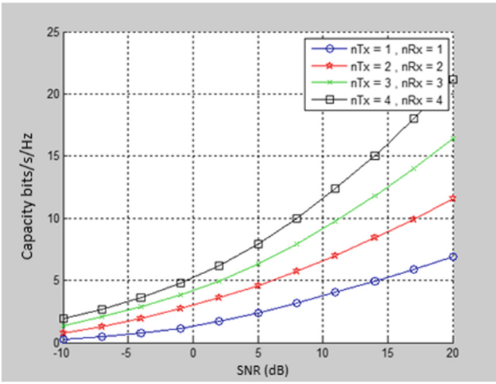

Fig. 16. MIMO Channel Capacity vs. SNR

The capacity obtained by analyzing the four systems starting with SISO and ending with MIMO 4 × 4 is higher as the number of antennas increases, shown in Fig. 16, but there is an empirical limit of the maximum number of antennas that can be used due to strong interference and high error rate. Massive-MIMO and beamforming will address this issue in 3GPP Release 15 and 16, 5G related.

4.3 Data Transmission Capabilities Test

In order to test the system data transmission capabilities, two separate source file blocks in ".txt" format, containing characters, modeled the sources. It is noticeable in Fig. 17 that the byte type (pink color) was chosen.

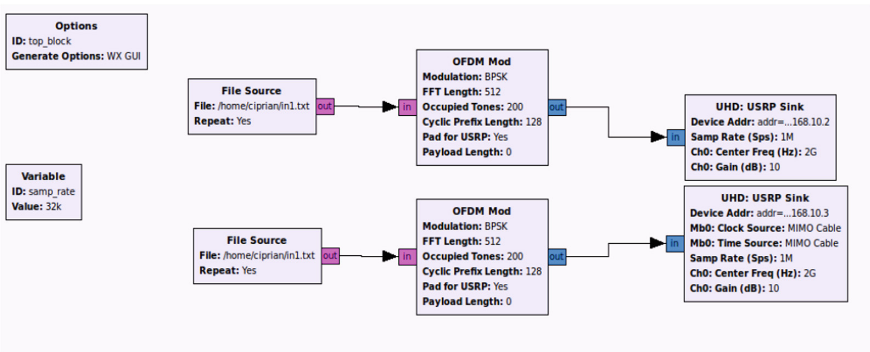

Fig. 17. Block selection for transmission signal graph (Color figure online)

The data stream must be subjected to an OFDM modulation process, which has a 128 prefix, a FFT window length of 512 samples, and the modulation of the symbols is BPSK. In order to transmit them with broadcasting antennas, USRP sink blocks are needed. The information is sent to the block chain of 2 × 2 MIMO system, previously presented. After the detection and the demodulation process is performed, the data was stored in "out.txt" file and the following results shown in table x were obtained (Table 2):

Table 2. Received data

Modulation	Number of sent packets	Number of received packets	Number of good packets	Packet loss rate	Errored packets rate
BPSK	655	653	644	0.31%	1.68%
QPSK	655	641	447	2.14%	31.75%
16QAM	655	580	379	11.45%	42.13%

The best modulation in terms of error resistance is BPSK, but it is the slowest, achieving a required transmission time of 8.371 s. QPSK is the following modulation, but it introduces large errors. The weakest modulation for laboratory conditions was 16QAM, with a transmission time of 2.647 s.

5 Conclusions and Future Work

Next generation wireless networks require significant capabilities to accommodate more users at higher data rates, offering better reliability with less power consumption. In order to prototype large-scale antenna systems that can be mass-produced and deployed in real-life telecom networks, experimental testbeds have to be built to enhance current technology for further achievements. One key use-case present in future 5G New Radio is represented by MIMO technology. The current paper proposed an open testbed platform developed with National Instruments SDR equipment, but unlike other papers and experiments based on similar hardware that are using LabVIEW design software, herein the software processing units are created in GNU Radio, which offers an enormous freedom degree to address many technical needs.

The proposed testbed results prove confident results regarding MIMO capabilities and also a solid starting point in developing a high-scale future Massive MIMO testbed based on simplified design flows for high-performance processing technology and hardware evaluations. The 2 × 2 MIMO testbed is easily scalable to larger number of antennas MIMO setups using connectable hardware and also taking in consideration hardware system with built-in programmable interfaces to avoid the connection to computers. At the same time it offers the possibility to prototype technologies and setups that can be used on large-scale deployments in 5G future networks.

The current work demonstrates that using SDR solutions and minimal RF physical equipment, vendors and mobile operators can perform tests for different scenarios and use cases. Different setups can be arranged according to mobile operators' requests.

This kind of approach using SDR capable equipment and customized software interfaces is the beginning of a future objective, the development of a complete air interface with higher order modulations schemes using Massive MIMO [9] for 5G New Radio [10] and it can add high value to 3GPP Release 16 [11] on aspects proposed in 3GPP Release 15 regarding 5G specifications.

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