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# Performance Evaluation of Real Time MIMO testBED using NI-2922 Universal Software Radio Peripheral

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***Abstract*—In the recent years, wireless communication integration with mm-Wave spectrum makes fifth generation (5G) gained tremendous research interest, as a result of scarce resources. This challenged the design paradigm of the previous fourth generation (4G) radio access technology. As the key to future 5G systems, Multiple Input Multiple Output (MIMO) on the other hand, offers promising performance enhancement with effective spectrum utilization although, leads to increase in the cost of deploying the system as the number of antenna increases thus, large simulation assessment prevails in the literature which requires further practical implementations, assessment, and validation in real time. This article present a MIMO testBED experimental design, implementation, and evaluation of the system bit error rate (BER) performance with channel capacity using spatial diversity. The system's prototyping utilizes Universal Software Radio Peripheral hardware (USRP NI-2922) together with LabVIEW software toolkits, results obtained shows MIMO system feature spatial diversity to improve BER, as well as system channel capacity.**

***Keywords—Universal Software Radio Peripheral (USRP); Multiple Input Multiple Output (MIMO); testBED; Spatial Diversity (SD); Space Time Block Coding (STBC); bit error rate (BER)***

## I. INTRODUCTION

In the recent years, there has been massive growth in the broadband service subscription giving raised to over 7-billion subscriptions worldwide [1], [2] and this caused significant data traffic in mobile and wireless networks thus, high data rates wireless access demand by end-users is another fundamental challenge in the next generation wireless systems [3]. Meeting these demand, calls for an approach to adapt easily, fluctuations in users demand over time and location hence, 5G systems. 5G wireless systems require a shift in design paradigm in order to meet up with the proliferation growth, as well as providing significant expansion beyond the current 4G systems [4]-[7]. However, before the transition to 5G systems, it is essential, and of significant importance, to practically test and validate the performances of these novel techniques.

As key enable feature of 5G system, Multi antenna MIMO system, due to its ability in meeting up with growing data rate demand, the techniques has a proven reputation for wireless system performances enhancement such as; system data rate, capacity, bit error rate (BER), spectral efficiency, energy and power efficiency [8]-[11] hence, widely adopted in almost all wireless system standards. MIMO Performance improvement came with transmission power and/or bandwidth trade-off, due to wireless channel fading which can be reduced using diversity techniques although, it requires an additional antenna at the transmitter and/or receiver. The multi antenna MIMO scheme exploits channel multiplicity so that replicas of the transmitted signals are combined at the receiver for better assessment. As the replicas are also affected in the channel, nevertheless, they are Signal to Noise Ratio (SNRs) independent and if a number of these replicas are high enough, there exist a probability that some may reach the receiver without deep fading on its signal power.

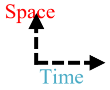
Multiple signal transmission using MIMO reduce chances of fading with an assurance of minimum SNR requirement at the receiver, and this depend on antenna configuration utilized. Diversity techniques simply apply signals coding using space-time domain, so that replicas of these signals are weighted and combined at receiver for strong signal power. A number of diversity techniques are available in the literature [13]-[19]; however, the most common technique employed in 2x2 MIMO system is Alamouti Space Time Block Coding (STBC). This is proven to provide full diversity gain with low complexity. Although, it requires the receiving antennas to be far enough for sufficient decorrelation. In general, MIMO channel coefficients have some correlation which depends on antenna spacing, the lower the antenna spacing, the higher the antenna correlation and hence, lower the MIMO system capacity [10], [13].

It is of paramount importance to evaluate performance in real world scenario using empirical results, as the mostly used propagation models generally limit simulation assumptions. This however, will provide system verification by acquiring experimental results using Software Defined Radio (SDR) testBED. Thus, the MIMO system testBED configuration will be will explore the Software Defined Radio (SDR) hardware and LabVIEW software to practically design, implementation, and evaluation multi antenna MIMO system testBED. Both the software and hardware are trade mark products of National Instruments (NI) which offers solutions for wireless system hardware prototyping, and used by number of research groups [20]-[25]. In addition to the STBC which expand the spatial streams, other implementation like channel estimated via pilot symbols, digital modulation would be included to depict the real world wireless system.

## II. SPATIAL DIVERSITY (ALAMOUTI STBC)

Spatial Diversity (SD) increases robustness in wireless system by an additional antenna at the transmitter and/or receiver using coding. As STBC is mostly used in MIMO system to transmit data stream duplicates across these antennas, the received signal replicas are processed to improve the signal reliability. Meanwhile, signals is mostly affected in the channel due to environmental degradation causing severe fading [12], [21], [22], the processes of assessing, several copies of the received signals results in higher chances of decoding the received signal correctly. STBC and Maximum Ratio Combining (MRC) receiver usually combine all the copies of the received signal in an optimal way and extract much possible information from each of them. As data are first modulated and mapped into corresponding constellation point, consider symbols $\boldsymbol{x_1}$ and $\boldsymbol{x_2}$, The system transmits the first spatial stream as the symbols $x_1$ and $x_2$ in original order form, while the space-time coding which are the second spatial stream transmits $-x^*{}_2$ and $x_1{}^*$. The 2x2 MIMO arrangement illustrating Alamouti STBC system is:

$$\boldsymbol{y} = [x_1 \quad x_2] \rightarrow \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} \rightarrow \begin{bmatrix} x_1 & x_2 \\ -x^*{}_2 & x_1{}^* \end{bmatrix} \begin{matrix} \rightarrow T_{x1} \\ \rightarrow T_{x2} \end{matrix}$$



The matrix rows represent the transmitting antennas and the columns represents the consecutive time slots, these symbols reach the receiver with different levels due to the channel. The received symbols from the transmitted output vector are expressed in form:

$$\boldsymbol{r_1} = [\, h_{11} \quad h_{12}] \,.\begin{bmatrix} x_1 \\ -x^*{}_2 \end{bmatrix} + n_1 \tag{1}$$

$$\boldsymbol{r_2} = [\, h_{21} \quad h_{22}] \,.\begin{bmatrix} x_2 \\ x^*{}_1 \end{bmatrix} + n_2 \tag{2}$$

Where, $\boldsymbol{r_1}$, $\boldsymbol{r_2}$ are the received signals at the respective antenna port 1 and 2, $h_{11}$, $h_{12,}$ $h_{21}$, & $h_{22}$ are the uncorrelated path channel through which signal travels and STBC requires each of these channels to reach the receiver. The analysis above shows, the signal received in each antenna is weighted according to channel path, such that the combination of all the antennas result in MRC between these signals, this provides received signal redundancy and results in, higher chance of being able to use most of the received copies to correctly decode the received symbol and recover the original signal. The low complexity along with the full diversity gave Alamouti great advantages as compared with the high order STBC codes.

## III. MAXIMAL RATIO COMBINING (MRC)

MRC is a linear receiver decoding structure which combines and weight the various signal replicas received for decoding. MIMO system uses various linear receivers decoding structures [8]-[14], among which, MRC receiver has good performance and less complexity as compared. As copies of the received signal experienced an uncorrelated fading at the receiver, the probability that all these copies fade simultaneously is considerably reduced with respect to the probability that a single copy experiences a fading. Symbols recovery using MRC receiver combines all the received signals, weight and decode the transmitted symbol. Signal at receiving antenna port 1 and 2 (i.e. $\boldsymbol{R_{x1}}$ & $\boldsymbol{R_{x2}}$) will be in the form of (1) and (2) above. This weigh and combine the signal copies according to channel path and combining the two antennas results in maximal ratio between these signals therefore, decoded symbols will be in the form:

$$\boldsymbol{x_1} = \frac{h^*{}_{11}\, y_1 + \; h^*{}_{22}\, y_2}{|h_{11}|^2 + \; |h_{22}|^2}, \qquad \boldsymbol{x_2} = \frac{h^*{}_{21}\, y_2 + \; h^*{}_{12}\, y_2}{|h_{21}|^2 + \; |h_{22}|^2}$$

## IV. MIMO SYSTEM MODEL

The testBED requires software toolkit and USRP hardware components to model the real-world wireless communication system, this prototype requires a number of USRP devices to be configured as transmitter and receiver. In this regard, LabVIEW software component together with USRP NI-2922 hardware radios are utilized. The software toolkits uses user-friendly graphical user interface (GUI) with a distinctive number of panels for system design, implementation, this provides an avenue for system parameters definition, signal flow monitoring, and error detection and correction, as compared with another software environment. The complete testBED setup with the antenna configuration is shown in Fig. 1, this uses a list of additional software components and hardware peripherals as summarized in Table 1.

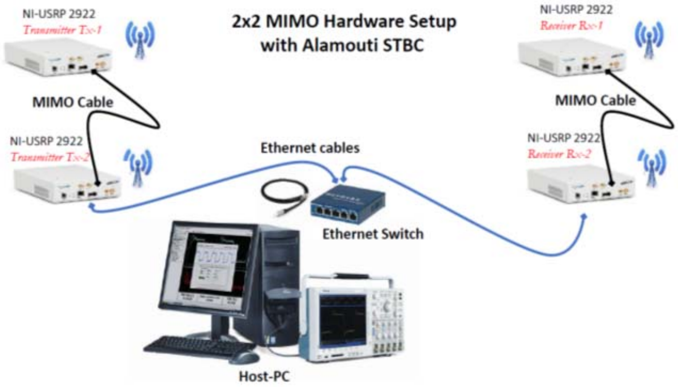


Fig. 1. Complete testBED architecture.

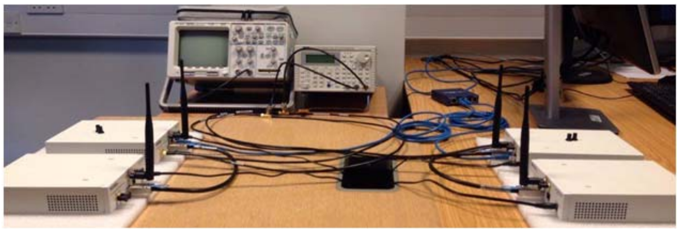


Fig. 2. Physical arrangement of USRP radio testBED.

TABLE I. 2X2 MIMO SOFTWARE/HARDWARE COMPONENTS

| S/N | 2 × 2 MIMO testBED | | |
|---|---|---|---|
| | ***Hardware Component*** | ***Qty.*** | ***Software Component*** |
| 1 | Host PC | 1 | NI LabVIEW Version 2016 |
| 2 | Ethernet cables | 3 | NI-USRP hardware driver |
| 3 | Ethernet Switch | 1 | NI LabVIEW Mod. Toolkit |
| 4 | MIMO cables) | 2 | |
| 5 | SMA-to SMA | 4 | |
| 6 | NI-USRP 2922 rad. | 4 | |
| 7 | VERT2450 Antenna | 4 | |
| 8 | External ref. Source | 1 | |

### *A. 2x2 MIMO TestBED Architecture*

This complete hardware testBED setup consist of a Host PC with gigabit Ethernet port, a 5-port Ethernet Switch (*NETGEAR GS105 ProSafe)*, and a pair of NI-2922 SDR configured as transmitters and receiver. USRP NI-2922 radio is a single channel, full-duplex SDR with tuneable center frequency of 400MHz - 4.4GHz and a MIMO expansion slot. As plug-and-play radio, it motherboard consists of single transmitting port and two receiving port, this performs the analogue-to-digital (ADC) and digital-to-analogue (DAC) conversion, as well as sample rate decimation/interpolation and interfacing. The hardware was selected due to its full-duplexing capabilities and the tuneable carrier frequency. As shown in Fig. 1 above, the first radio transceiver *Tx-2* is directly connected to the switch using Ethernet cable and the other radio transceiver *Tx-1* is connected to the first using the MIMO cable to configure the transmitter. Similar procedure is repeated with the other pair of the radio *Rx-1* and *Rx-2* to configure as a receiver. The hardware setup provides the 2x2 real-time MIMO system using USRP radios. A data (as packets) are transmitted, received, processed and decode the original signal, the BER is calculated and displayed via the software window (LabVIEW front Panel).

The LabVIEW software component provides an essential tool for testBED configuration, especially when the USRP radio requires MIMO cables to synchronize its pairs at the transmitter and receiver. The software platform is divided into two basic environments; the LabVIEW front panel and the block diagram. The front panel contains the system parameter setup, real time waveforms (time domain) display, individual channel and combined channel signal constellation display using the respective modulation schemes shown in Fig. 2, input and output bit stream together with the respective BER. On the other hand, block diagram consists of a number of LabVIEW communications blocks for implementing signal generation, hardware transmission-reception and received signal processing (Fig. 3). Transceiver up-conversion and down-conversion are automatically realistic via the USRPs units, as the platforms through which transmit and receive signals are configured over-the-air (wireless channel).

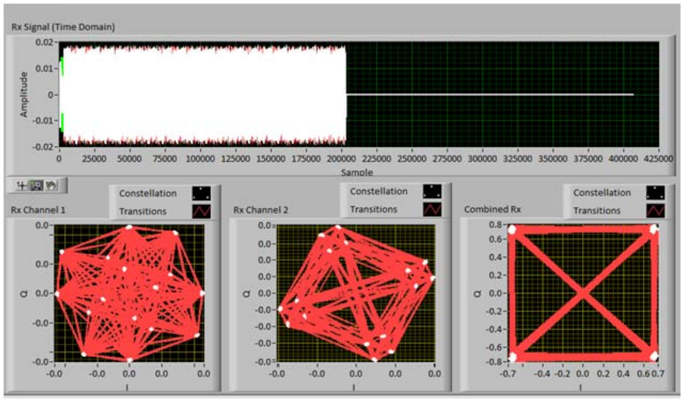
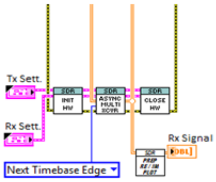


Fig. 3. LabVIEW front panel of the received signal waveforms.

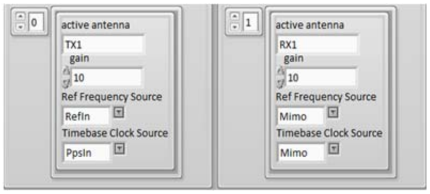
### *B. USRPs Hardware Synchronization*

For 2x2 MIMO transmissions, these multiple devices need to be synchronized, this configure the USRP radio start trigger time and clock module. The parameters that made USRP radios synchronization possible are the reference input source (*REF-IN*) and the timebase clock source of pulse per second input (*PPS-IN*), these are usually obtained internally or externally from a source to the radio. USRP pair (master-slaves) at either end must be synchronized with MIMO cable as shown in Fig. 4(d). In this way, one device serving as the Master set its clock internally or externally while the other device is driven using MIMO cable as a slave as shown in Fig. 4(d). This uses the timing imposed by the Master device and hence, synchronizes the pair of radio at the transmitter or receiver for two antennas transmission or reception.

The hardware specification shows the possibility of real-time prototyping with or without external reference source. The multiple USRP radios hardware at the transmission/reception processing are synchronized via the external source of 10MHz with the reference frequency set to *RefIn & PPSIn*, respectively as shown in Fig. 4(c). The testBED run 2x2 MIMO real-time with space Time Block Coding (Alamouti) using LabVIEW.



(a) Hardware timestamp selection



0
active antenna
TX1
gain
10
Ref Frequency Source
RefIn
Timebase Clock Source
PpsIn

1
active antenna
RX1
gain
10
Ref Frequency Source
Mimo
Timebase Clock Source
Mimo

(b) Hardware RefIn & PPSIn source selection

(c) External Freq. source generation

(d) MIMO cable hardware synchronization

Fig. 4. USRPs Hardware synchronization settings with external source.

As default, each device used its own internal clock individually, thus, received signal decoding was not successful, the testBED requires all USRPs devices both at the transmitter and receiver to be synchronized all together hence, requires centralization of reference clock source. Using above detail, transmitter and receiver synchronization were successful via 10MHz central external reference source (*TG1010A Programmable 10MHz FUNCTIONAL GENERATOR*) and external reference source of 1PPS from Arbitrary Functional Generator (*AFG1022 Tekronix*) as shown in Fig. 4(c). This defined the external source used for *RefIN* and *PPS* clocks applied to testBED for transmission and reception, respectively.

## C. TestBED Parameters

The software/hardware parameter setting that defines the testBED setup utilized is summarized in Table 2. These parameters mostly same value at both transmitter and receiver, furthermore, the parameters are selected, considering the USRP devices and/or the Host-PC limitations due to underflows or overflows e.g. the carrier frequency of 2.411GHz, External reference source of 10MHz for both the transmitter and receiver pairs, are within the range of the USRP devices specified in the NI-USRP catalogue whereas start triggered time, *IQ* sampling rate, number of symbol per packet etc. where chosen to prevent the system underflows or overflows.

For the said 2x2 MIMO testBED, the *I/Q* Sampling Rate of 1M (sample/second) for both the transmitter and receiver pairs baseband *I/Q* signal samples was chosen. The Symbol Rate, *Tx* Oversample Factor, and *Rx* Oversample Factor values were also chosen so that the *I/Q* Sampling Rate is an even multiple of the desired Symbol Rate and finally, an even-valued Oversample Factor that corresponds to the multiple was also chosen to ensure the relationship between the *I/Q* Sampling Rate, Symbol Rate, and Oversample Factor parameters is numerically expressed as:

$$\frac{I}{Q} Sampling\ Rate\ =\ Symbol\ Rate\ \times\ Oversample\ Factor \tag{3}$$

In order to present system performance numerical results obtained (i.e. BER) in an over-the-air (channel) transmission, the testBED software component offers a window for defining the values of the gain in which the respective BER is computed and displayed. The obtained BER result with the respective modulation schemes (QPSK, 16-QAM, and 64-QAM) was presented and analyzed below.

TABLE II. TESTBED SOFTWARE/HARDWARE PARAMETER SETTING

| S/N | **USRP-2922 testBED Parameter** | | |
|---|---|---|---|
| | Parameters | Transmitter | Receiver |
| | IQ Sampling rate (Sample/s) | 1M | 1M |
| | Carrier Frequency (Hz) | 2.411G | 2.411G |
| | Start Triggered Time (s) | 2 | 2 |
| | Fractional Seconds | 2mS | 0 |
| | Active Antenna | TX1 | RX1 |
| | Ref. Freq. Source (MHz) | 10 | 10 |
| | Time base Clock source | 1PPS | 1PPS |
| | Symbol Rate | 100k | 100k |
| | Oversample Factor | 10 | 10 |
| | Modulation Scheme | QPSK, QAM | QPSK, QAM |

## D. TestBED Capacity Prediction

The capacity of MIMO channel is simply, the data rate that can be achieved over a given bandwidth (BW) and at a particular SNR with diminishing BER [10], [22]. As the testBED transceiver radios are fixed, it is assumed that the channels remain same with no further interference, it is necessary to estimate, stores and processes the channel matrix using pilots. The most adopted scheme, however, is the codebook precorders as detailed in [22].

At the transmitter, a number of pilots were appending using training sequence (codebook) which is known to both the transmitter and receiver. Pilots are usually placed in specific time-frequency positions of symbols for channel estimate by comparing the received pilots with the transmitted ones. This also compares the transmitted symbols to that of the receive ones via different MIMO transmission paths. In order to evaluate the real-time system capacity, it is necessary to acquire, store and process the received channel matrix for empirical Cumulative Distribution Function (CDF) analysis using Matlab as the stored channel coefficients are usually complex with real and imaginary parts. Since the training sequence used are known to both, transmitter and receiver, the received signals from the transmitted vector (1) and (2) above will be in the form:

$$\begin{bmatrix} r_1 \\ r_2 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \cdot \begin{bmatrix} \boldsymbol{v}_1 \\ \boldsymbol{v}_2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix}$$

$$\boldsymbol{r_1} = h_{11} * \boldsymbol{v}_1 + \quad h_{12} * \boldsymbol{v}_2 + n_1 \tag{4}$$

$$\boldsymbol{r_2} = h_{21} * \boldsymbol{v}_1 + \quad h_{22} * \boldsymbol{v}_2 + n_2 \tag{5}$$

$$\boldsymbol{r_i} = \boldsymbol{H_{ij}}\ \boldsymbol{W} + \boldsymbol{n_i} \tag{6}$$

Where, $\boldsymbol{H}_k \in \mathbb{C}^{2\times 2}$ is the $2\ \times 2$ wireless channel matrix from receiver back to the transmitter mathematically represented as $\boldsymbol{H}_{ij} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix}$ with h as the channel parameters stored.

$\boldsymbol{W} = [v_1 \;\; v_2\;]_{2\times 1} \quad \boldsymbol{W} \in \mathbb{C}^{R_x}$ are training sequence chosen from the codebook containing set of unitary precoders that defines the MIMO configuration. Note that, the transmitted signals $\boldsymbol{W} = [v_1 \;\; v_2\;]$ are the training sequence (summarized below in Table 3.) used for channel estimated, evaluating the ratio received signal and its corresponding pilot $\boldsymbol{r_1}/\boldsymbol{v}_1$, $\boldsymbol{r_1}/\boldsymbol{v}_2$, $\boldsymbol{r_2}/\boldsymbol{v}_1$ and $\boldsymbol{r_2}/\boldsymbol{v}_2$ at the received signal directly give raised to instantaneous channel parameters $h_{1\,1}$, $h_{1\,2}$, $h_{2\,1}$, $h_{2\,2}$ as the estimated channel matrix. These matrices exploit the MIMO diversity boosting the system throughput.

TABLE III. CODEBOOK MATRICES SPECIFIED IN

| ***Codebook Index*** | **Number of layers** | |
|---|---|---|
| | 1 | 2 |
| 0 | $\frac{1}{\sqrt{2}}\begin{bmatrix}1\\1\end{bmatrix}$ | $\frac{1}{\sqrt{2}}\begin{bmatrix}1 & 0\\0 & 1\end{bmatrix}$ |
| 1 | $\frac{1}{\sqrt{2}}\begin{bmatrix}1\\-1\end{bmatrix}$ | $\frac{1}{\sqrt{2}}\begin{bmatrix}1 & 1\\1 & -1\end{bmatrix}$ |
| 2 | $\frac{1}{\sqrt{2}}\begin{bmatrix}1\\j\end{bmatrix}$ | $\frac{1}{\sqrt{2}}\begin{bmatrix}1 & 1\\1 & -j\end{bmatrix}$ |
| 3 | $\frac{1}{\sqrt{2}}\begin{bmatrix}1\\-j\end{bmatrix}$ | - |

CDF usually quantify the capacity of MIMO channel in terms of a curve, this basically gives a probability that the system capacity is above a certain threshold. Using the over-the-air transmission channel matrix stored from the testBED, the capacity curve was computed using particular SNR by multiplying the estimated channel matrix stored while the throughput will then be directly related to transmission bandwidth. System performance can enhance be further by appropriate selection of the precoding matrix that maximized the SNR. The result obtained is shown in Fig. 14, this verified MIMO techniques by exploiting the diversity of the channel to improve capacity consequently the system throughput.

## *E. BER computation*

Over-the-air transmission bit streams are received and stored in a vector array by means of indexing Fig. 5. BER computation typically applies a number of LabVIEW blocks to sequentially calculate and display the BER in real-time, in this way, the software window compare the number of transmitted bits to that of incorrectly received ones via iteration. The iteration processes stored the bits at the respective indexes, which is use to compare each bit independently between stored arrays.


trigger found? ●
BER 0.0198
input bit stream 0: 1 1 1 1 1 1 1 0 1 0 0 0 1 0 1 1 0 0 0 1 1 1 0 1 0 1 1 0
output bit stream 0: 1 1 1 1 1 1 1 0 1 0 0 0 1 0 1 1 0 0 0 1 1 1 0 1 0 1 1 0

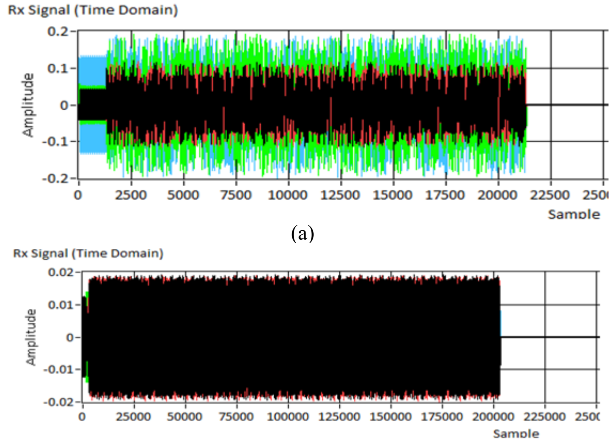
Fig. 5. LabVIEW front panel of the Input/output bit stream & BER.

In another word, indexing allowed comparison of *Tx* bit in position *i* with *Rx* bit in position *i*. In the case of equal bits, the comparator outputted a *FALSE* value, transformed into a digital '0' showing no any bit in error otherwise, if the discrepancy is noted between these compared bits, a comparator display a *TRUE* value, which is transformed into a digital '1' thus represent the system bit error. The sum module block then receives the binary digital array and summed all the number of bits in error to obtain the total number of error bits whereas the transmitted bits size array module delivered the number of transmitted bits, from the number of symbol per packet set via the link parameters. Finally, the number of bits in errors as compared with and a number of transmitted bits calculate the system instantaneous BER.

## V. RESULT AND ANALYSIS

Real time 2x2 MIMO testBED was successful, implementing Alamouti diversity, the testBED runs a number of modulation (QPSK, 16-QAM, and 64-QAM) monitored and displayed its results in real-time. Displayed results include time domain waveform, received signal (channel 1) constellation, received signal (channel-2) constellation, combined channels received signal constellation and the system BER. System performances were evaluated based on the displayed BER obtained with these modulations and their corresponding constellation plots and the received signal channel matrix data.

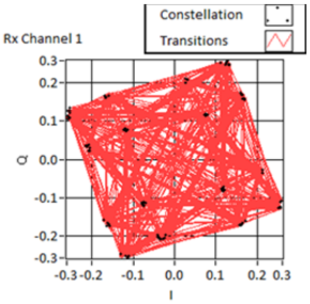
The propagation channel was considered stationary in the measurement campaign. The real-time measurement results were obtained using the defined parameters detailed in Table 2. System performance evaluation was obtained by monitoring and recording the real-time results display in software window (front panel) together with the received signal waveforms, constellations, and the corresponding BER.



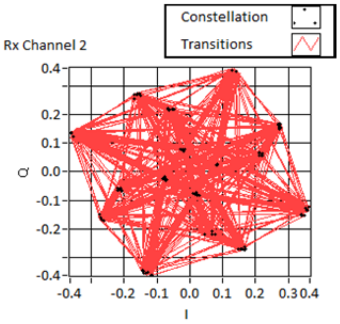
(a)

(b)

Fig. 6. (a) Time domain waveform with fewer samples; (b) Time domain waveform with more samples.



(a)



(b)

Fig. 7. (a) Channel 1 constellation; (b ) Channel 2 constellation.

### *A. QPSK Constellation Results*

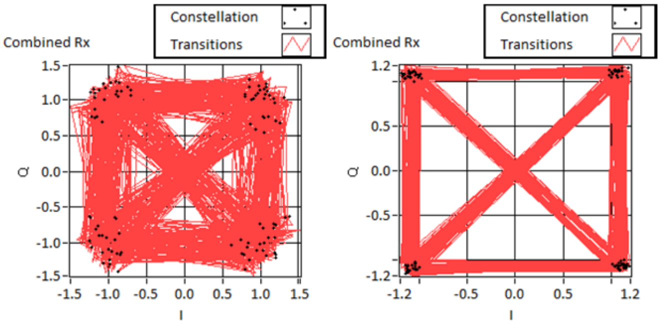


Fig. 8. QPSK Combined channels received signal constellation with fewer samples.

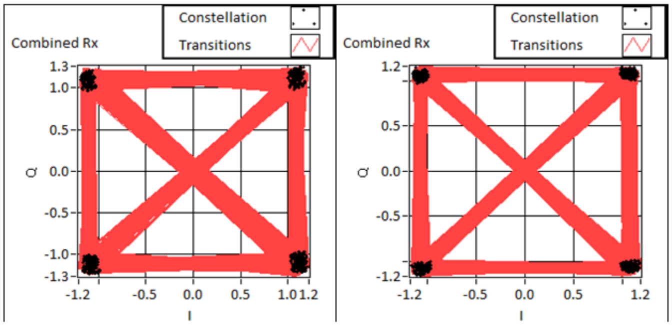


Fig. 9. QPSK Combined channels signal constellation with more samples.

### *B. 16-QAM Constellation Results*

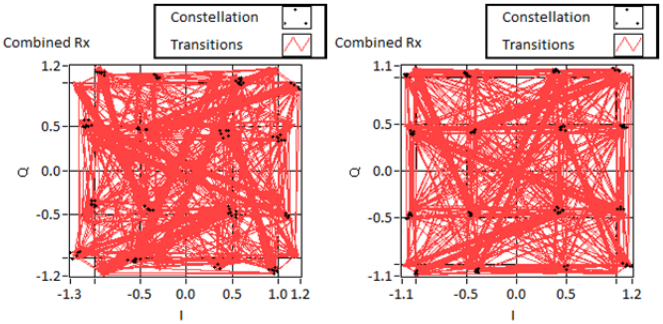


Fig. 10. 16-QAM Combined channels received signal constellation with fewer samples.

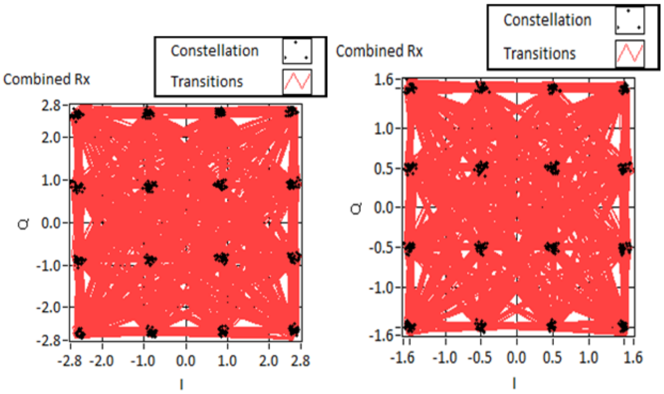


Fig. 11. 16-QAM Combined channels received signal constellation with more samples.

### *C. 64-QAM Constellation Results*

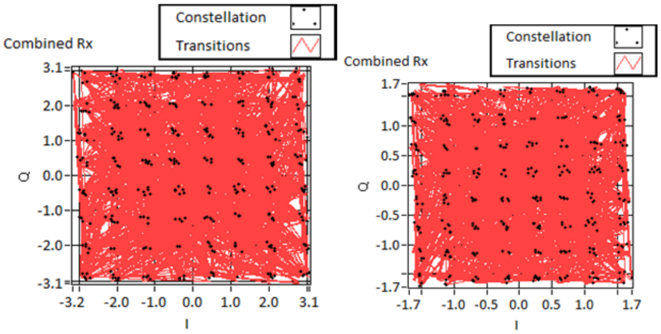


Fig. 12. 16-QAM Combined channels received signal constellation with fewer samples.

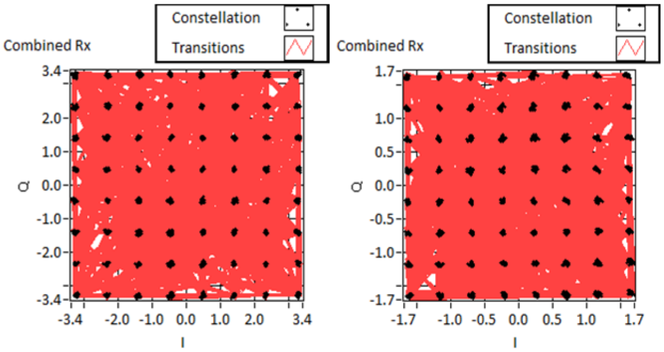


Fig. 13. Combined channels received signal constellation with more samples per packet.

Fig. 6(a) and 6(b) show the receive signal time domain samples of both antennas Rx1 and Rx2 using specified (Symbol per Packet) link parameters, increasing the transmission data, in turn, improve the resolution of the displayed results and hence the corresponding BER display with the respective modulations. Fig. 7(a) and 7(b) shows individual receiving channel (Rx1 and Rx2) constellation plot with the corresponding IQ signal samples display.

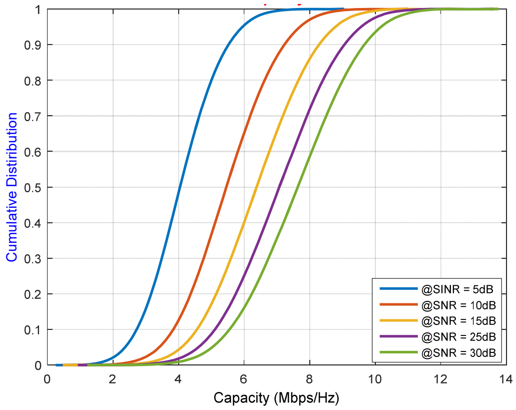


Fig. 14. MIMO (theoretical) capacity prediction at various SNR.

Fig. 8 to 13 shows the successful reconstruction of combined receive signal with specified modulation. Table 4 summarized the respective BER obtained during over-the-air transmission using these modulation schemes. The system performance BER results are all within the threshold limit of wireless system standards. This show successful implementation of 2×2 MIMO testBED with NI USRP-2922 radios in real-time.

TABLE IV. TESTBED REAL-TIME BER PERFORMANCE EVALUATION

| NI USRP 2922 2×2 MIMO testBED BER @2.411GHz | | | |
|---|---|---|---|
| | Modulation Scheme | | |
| Iter. | QPSK | 16-QAM | 64-QAM |
| 3 | 1.32445 x $10^{-6}$ | 1.11356 x $10^{-5}$ | 1.10264 x $10^{-4}$ |
| 5 | 1.27655 x $10^{-7}$ | 1.45338 x $10^{-6}$ | 1.43523 x $10^{-4}$ |
| 8 | 1.24435 x $10^{-7}$ | 1.25454 x $10^{-6}$ | 1.68445 x $10^{-5}$ |

System performance with lower modulation QPSK scheme provide good BER as compared respectively with higher order 16-QAM and 64-QAM as expected, as shown in combined received signal constellation. Good performance with lower order modulation is because of wider spaces between the symbol mapping adjacent constellation points compared with higher order modulation shown in Fig. 10, 12 and 14, respectively, this distributes the points more evenly in I/Q plane.

As detailed in [23] using Shannon Capacity theorem, capacity of a wireless channel is simply, the data rate that can be achieved over a given BW and at a particular SNR with diminishing BER thus, system capacity with the realistic CDF analyzed from the stored channel matrix conversely indicate a very high probability at different SNR values, although its throughput depends on actual transmission bandwidth. Theoretically, 5dB SNR shows over 90% probability that the system capacity is greater than 4bps/Hz. Similarly, with 15dB SNR, there is a 90% probability that the capacity is greater than 8bps/Hz. Finally, taking a strict threshold assessment of 99%, above capacities are reduced to 7.2 bps/Hz and 9.6 bps/Hz, respectively. In this way, the capacity of MIMO system improves considerably with increases in the MIMO antenna configuration.

## VI. CONCLUSION

In this paper, USRP NI-2922 hardware radios with LabVIEW software were used to successfully implement real-time MIMO testBED demonstrate the real-world scenario, the system assessment is based only on the wireless channel characteristics to evaluation system performance. The system exploits spatial diversity using relevant modulation schemes and over-the-air transmission to evaluate MIMO performances in real-time. Although the system depicts Single-User-MIMO scenario, combined signal constellations reconstruction with these modulation schemes shows the successful implementation of MIMO testBED system using hardware radio. The testBED shows significant improvement in term of BER with all the values obtained beyond the threshold, this reduces considerably with modulation order as expected). System performances can be improve as the number of transmitting and/or receiving antennas increases which require additional hardware radios. Furthermore, extension from Single-User to Multiple-Users scenario can further demonstrate improvement in spectral efficiency for bandwidth utilization.

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