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Longer Term Time Dynamics of Bit Error Rates

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ABSTRACT

In this paper an analysis is conducted to study the properties of indoor and outdoor wireless channel conditions over long time scales (several minutes). It shows that long term time dynamics exist in many different situations even when transmitters and receivers are stationary and the distance between them is only a few meters. We use software-defined radio (SDR) that implements radio communication functionalities in software. Transmissions have been achieved using the Universal Software Radio Peripheral (USRP), with the signal processing and time synchronization occurring in the GNU Radio environment on the LINUX (Ubuntu 14.04 LTS) platform. The work has been implemented in a typical school environment i.e., indoor conditions including a lab environment along with a hallway and outdoor conditions comprising a quadrangle environment. We used the benchmarking tool in the GNU Radio that defines and modifies modulation schemes, transmitter and receiver gains, operating frequencies, and other channel properties. Per-packet bit error rate is computed, visualized, and compared across multiple scenarios. We find a series of interesting time dynamics of the BER over several minutes that are not commonly studied in the literature.

Key Words: USRP, GNU Radio, modulation schemes, BER

1. INTRODUCTION

The world has witnessed a rapid transition from analog to digital. More functions of modern radio systems are implemented in software leading to innovative and inexpensive software radio architectures. Basically, software defined radio (SDR) [1] is used for high speed wireless communication systems with low hardware requirements and development costs. Due to its cost efficient feature, it is easily used by educational institutions, research hobbyists and research groups.

Software defined radio conducts all signal processing in software instead of hardware. Unlike conventional radios where signal is processed in the analog domain, in SDR signal is processed in the digital domain. The digitization is carried out by an analog to digital converter. Figure 1 shows the concept of SDR. The Figure shows the ADC process that is taking place taking place after the Front End (FE) circuit.

The FE is used to down convert the signal to a lower intermediate frequency (IF). The ADC will digitize the signal and pass it to the baseband processor for further processes like demodulation, channel coding etc. In a conventional radio all these processes are done in hardware.

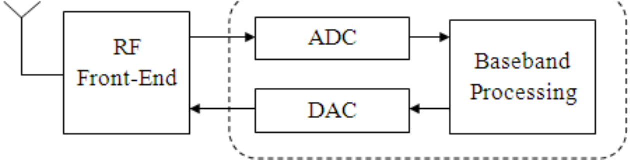


Figure 1: Software Defined Radio Block Diagram

2. BACKGROUND AND RELATED WORK

Before discussing the important BER measurements and observations, this section first discusses the hardware and software configurations. The section also discusses the limited amount of related work that has published results on these types of BER observations.

A. Universal Software Radio Peripheral (USRP)

The USRP [2] is a flexible device for implementing SDR developed by Matt Ettus of Ettus Research. We have used the USRP1, which consists of 2 main boards: the daughter board and the mother board. The mother board consists of the following.

- Four 12-bit analog to digital convertors with sampling rates of up to 64MS/s
- Four 14-bit digital to analog convertors with speeds up to 128 MS/s
- 2 digital up convertors (DUC) to up convert the baseband signal to 128 MS/s before translating them to the selected output frequency
- Programmable USB 2.0 controller for communication between the USRP and GNU Radio
- FPGA for implementing digital down conversion and high rate signal processing.

The daughter board acts as an RF front end of the SDR. There are four slots on the mother board which are used to connect the daughter boards with the mother board. Two of the four slots, labelled as TX_A and TX_B are meant for transmitter daughter boards and RX_A and RX_B are meant for receiver daughter boards.

The USRP will digitize the inflow data from the air interface and pass it to the GNU Radio through the USB interface. The GNU Radio will then further process the signal by demodulating and filtering until the signal is translated to a packet or a stream of data.

The USRP uses the GNU Radio framework for PHY layer processing on the PC. We describe GNU Radio next.

B. GNU Radio

GNU Radio is a free and open source software development toolkit that provides the signal processing blocks to implement software radios. It can be readily used with low cost external RF – hardware or without hardware in a simulation environment. GNU radio is licensed under the GNU general public license (GPL). All the code is copyrighted from the Free Software Foundation. The signal processing blocks are written in C ++ while Python is used as a scripting language to tie the blocks together to form a flow graph. This is shown in Figure 2. The Simplified Wrapper Interface Generator is used as interface compiler which allows the integration between C ++ and the Python language.

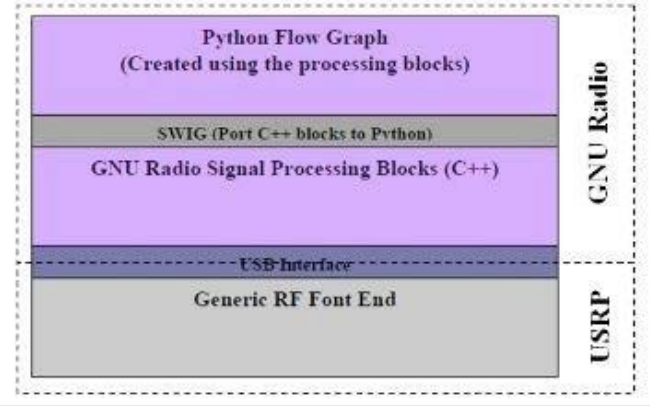


Figure 2: Components of GNU Radio

C. Universal Hardware Driver (UHD)

UHD is a hardware driver library for all USRP series radios and all types of daughter-boards. Conventionally, radio software uses different libraries for different USRP series and daughter-boards. Instead, UHD provides a consistent Application Program Interface (API). It is possible to use the UHD driver standalone or with other applications such as GNU Radio, LabVIEW and Simulink. UHD finds devices on a USRP system and instantiates a device object with desired parameters. It sets/gets radio properties (e.g. gain, amplitude, center frequency, sample rate, and time) and transmits samples by using standard Operating System (OS) read() and write() operations. To send and receive samples from/to the USRP, UHD creates a sending or receiving stream between the host computer and the FPGA in the USRP. UHD also supports control and management messages such as overflow, stream command error (Rx path) such as underflow, and sequence error (Tx path).

D. Related Work

There are few previous works that measured the BER over longer time scales. However, others have studied BER related to various aspects like co-operative transmission, varying frequency, signal to interference plus noise ratio (SINR) and also 2 X 2 MIMO.

Omar, et. al., [3] compared the BER between cooperative communication and single-input single-output by varying the following factors: distance between source and destination in fixed steps, and the transmit power of the source was progressively increased. Their primary objective was to determine how cooperative communication provides improved performance in terms of BER compared to a SISO topology.

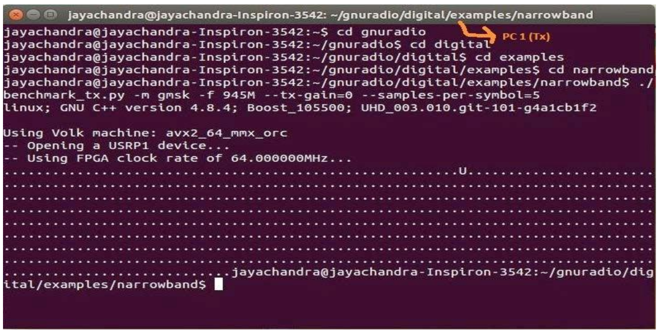
Soni, et. al., [4] provided performance analysis for open loop MIMO schemes for different modulation techniques. They used space time block coding using the USRP hardware. Their results show the constellations of signals received at frequencies 935 MHz and 1.9 GHz for different kind of modulation schemes i.e., 4-QAM, 16-QAM, 64-QAM. QAM modulation achieves lesser data errors due to greater distance between adjacent points in the I/Q plane by distributing the points more evenly. But their work was limited to QAM and space time block coding techniques.

Another experimental study by Hyungoo Yoon et. al., [5] provided a testbed for analyzing performance degradation of a MIMO-OFDM WLAN due to MPAN interferers by using USRP. Their scenario involved two WLAN transmitters and receivers respectively and used a WPAN transmitter as an interferer. They compared the constellation diagrams with and without interference and calculated BER at various SINR levels. They suggested their testbed can be used for assessing interference between various unlicensed devices by changing the software.

3. EXPERIMENTAL SETUP

Figures. 6, 7, and 8 show the experimental setup for measuring BER in SDR implementation utilizing GNU Radio and USRP. We have conducted several experiments in three different environments, and performance in terms of per packet bit error rate has been analyzed and reported in this paper. Two USRP radios and two laptops were used to run these experiments. The PC 1 with USRP A acts as the transmitter while PC 2 and USRP B acts as the receiver. Daughter boards used for these experiments are RFX900 which can cover frequencies from 750 MHz to 1050 MHz. The antenna used was a vertical antenna (VERT900). It allows an operation of frequencies ranging from 824 MHz to 960 MHz and 1710 MHz to 1990 MHz (dual band) with a gain of 3 dBi. For software part, the reconfigurable benchmark_tx.py and benchmark_rx.py in /gnuradio/gr-digital/examples/narrowband/ were used. We made considerable changes to GNU Radio Python code according to our requirements. The software sends a series of packets with known data within those packets. Then the results are compared with what is known to be the proper results. Figures. 3 and 4 show the commands to open and run the benchmark code for both transmitter and receiver, in the terminal window. Figures. 5 shows the output results after sending packets filled with the character 't'.

For all the scenarios, from transmitter we sent 2000 packets of the same data, each packet comprising of 11,960 bits.



```
jayachandra@jayachandra-Inspiron-3542:~$ cd gnuradio
jayachandra@jayachandra-Inspiron-3542:~/gnuradio$ cd digital
jayachandra@jayachandra-Inspiron-3542:~/gnuradio/digital$ cd examples
jayachandra@jayachandra-Inspiron-3542:~/gnuradio/digital/examples$ cd narrowband
jayachandra@jayachandra-Inspiron-3542:~/gnuradio/digital/examples/narrowband$ ./
benchmark_tx.py -m gmsk -f 945M --tx-gain=0 --samples-per-symbol=5
linux; GNU C++ version 4.8.4; Boost_105500; UHD_003.010.git-101-g4a1cb1f2

Using Volk machine: avx2_64_mmx_orc
-- Opening a USRP1 device...
-- Using FPGA clock rate of 64.000000MHz...
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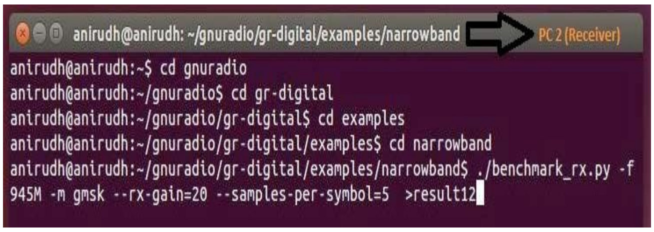
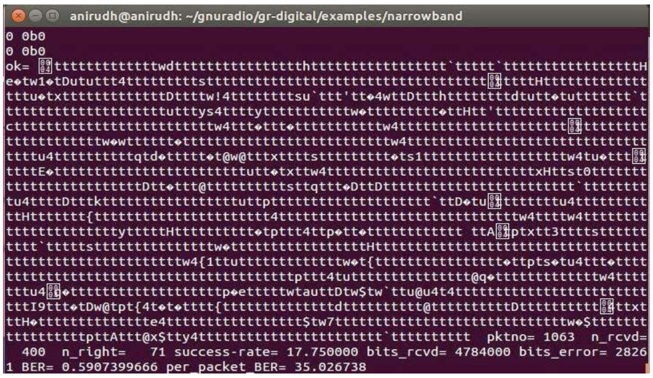
............................jayachandra@jayachandra-Inspiron-3542:~/gnuradio/dig
ital/examples/narrowband$ 
```

Figure 3: Transmitter Terminal Window



```
anirudh@anirudh:~$ cd gnuradio
anirudh@anirudh:~/gnuradio$ cd gr-digital
anirudh@anirudh:~/gnuradio/gr-digital$ cd examples
anirudh@anirudh:~/gnuradio/gr-digital/examples$ cd narrowband
anirudh@anirudh:~/gnuradio/gr-digital/examples/narrowband$ ./benchmark_rx.py -f
945M -m gmsk --rx-gain=20 --samples-per-symbol=5  >result12
```

Figure 4: Receiver Terminal Window



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ttttttttttpttAttt@x$tty4ttttttttttttttttttttt`tttttttttt  pktno= 1063  n_rcvd=
  400  n_right=   71 success-rate= 17.750000 bits_rcvd= 4784000 bits_error= 2826
1 BER= 0.5907399666 per_packet_BER= 35.026738
```

Figure 5: Receiver terminal window showing part of output

The three different environments where measurements were taken are as follows:

1. Lab environment (Closed Room)
2. Hallway with obstructions
3. Quadrangle environment

A. Lab Environment

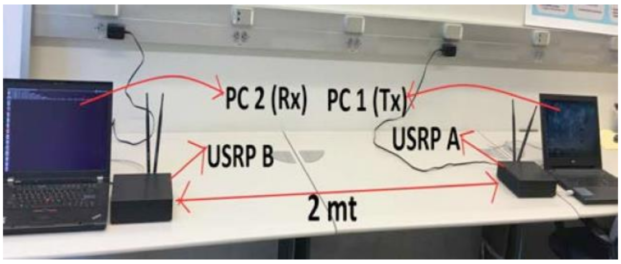


Figure 6: Lab environment setup

For the purpose of indoor channel propagation, the measurements were taken inside the laboratory with the radios separated at a distance of 2 meters. Various results are obtained using modulation schemes – BPSK, GMSK QPSK. The results and analysis of the modulation schemes are shown below.

B. Hallway with obstruction

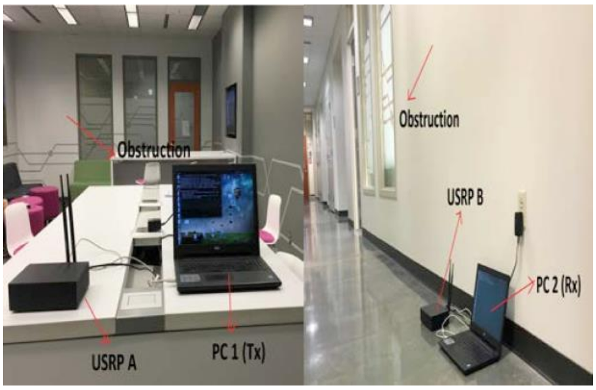
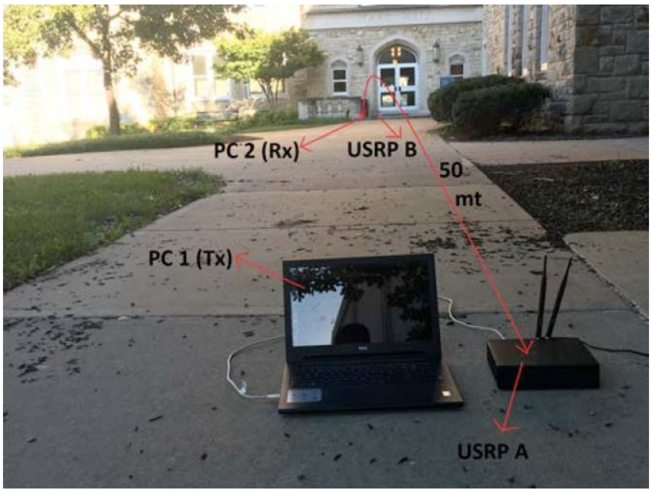


Figure 7: Hallway environment Setup

We have seen the performance of the modulation schemes in the indoor environment separated by a small distance. In this case we moved out of the lab and tested the radios using various factors and modulation schemes in the hallway where the radios are separated by 20 meters and in the presence of an obstruction, such as a wall. The plots and analysis are provided below.

C. Quadrangle environment

The most interesting part of our work is working in the outside environment. We placed the radios 50 m apart and tested for the results as we did for the first two cases. The environment which we tested was a quadrangle environment surrounded by buildings on the four sides where the radios were placed.



Figures 8: Quadrangle environment setup

4. RESULTS

We have worked on 3 modulation schemes in each of the environments as discussed above. Also, lab environment has plots with different gains for each of the modulation scheme.

To smooth variations in the plots, we applied a moving average window of size 50 (about 7 sec.), which helped us to determine the nature of each curve in a better way. Every plot displayed BER over several minutes of observations. Many cases showed obvious, slow variations of the BER.

A. Lab Environment

In Figures. 9, all of the BER curves have relatively low values except for bursts of errors in a few instances. BPSK has a lower BER when compared to other two modulation schemes. For QPSK we can see a long term trend of increased BER after 3 minutes and even a large burst of errors of around 50 packets at 1.5 minutes which caused the BER to be more. For GMSK no noticeable trends exist until 4 minutes, but a couple of high bursts of errors of around 50 packets indeed increased the BER.

Figures. 10 shows BPSK with different Rx-gains. The Rx- gain with 15 dB has no errors, whereas we can observe definite long term trends for gains of 5 and 10 dB. These long term trends in BER last several minutes. Also, there are periods of time where the Rx-gain of 10 dB had worse performance than 5 dB. For most of the time as gain increased we can observe a markedly improved reception of the sent data.

QPSK is shown with different Rx-gains in Figures. 11. The Rx-gain with 15 dB has no errors except a burst error in the beginning. For the other cases, we can clearly observe larger bursts of errors of around 50 packets, but at different points in time for gains 5 and 10 dB. Again there are obvious long terms trends in BER for gains of 5 and 10 dB.

Figure 12 shows GMSK with different Rx-gains. Values for BER are much higher than the previous two figures. Most of the time the Rx-gain with 10 dB is worse than 5 dB. Again we can see long term trends, especially for entire time for the 10 dB gain curve.

When comparing Figures. 10 through 12, all show long term swells in BER. The BER for GMSK was markedly worse. In all cases, 15 dB gain achieved zero or very close to zero BER. And QPSK was more susceptible to bursts of errors.

B. Hallway with wall as an obstruction

From Figures. 13, we can see the effects of longer bursts of errors. We can observe that some curves show less packets received due to packet losses. BPSK has low BER and received fewer packets when compared to QPSK and GMSK. QPSK encountered a couple of large bursts of errors of around 60 packets and a long term trend after 3.5 minutes of increased the BER. In contrast, GMSK has a series of varying peaks and also fewer packets were received when compared to QPSK.

C. *Quadrangle Environment*

Figure 14 was created from measurements in an outdoor quadrangle area. We can observe BPSK has a very low BER when compared to QPSK and GMSK. Here QPSK has a long term trend from 2 minutes to till the end with a few noticeable large bursts of errors in the beginning. For GMSK we lost more than half of the packets with moderate BER.

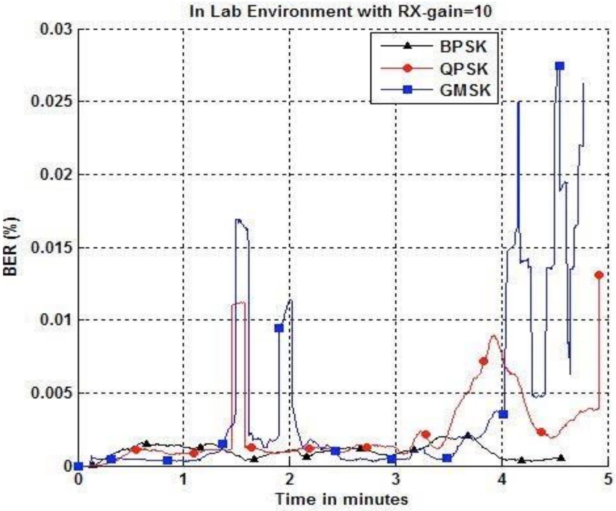


Figure 9: Lab environment

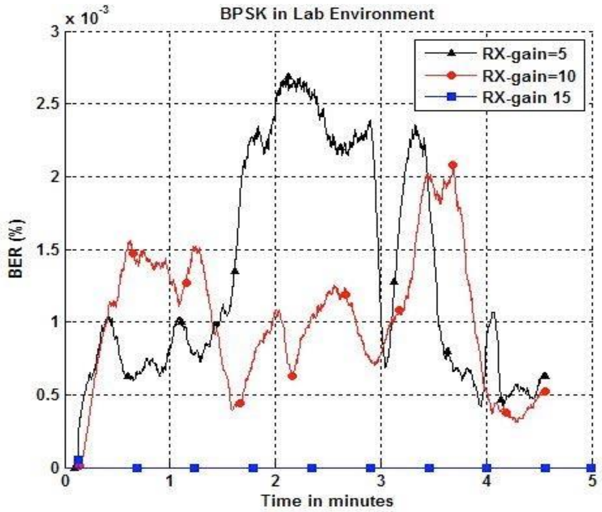
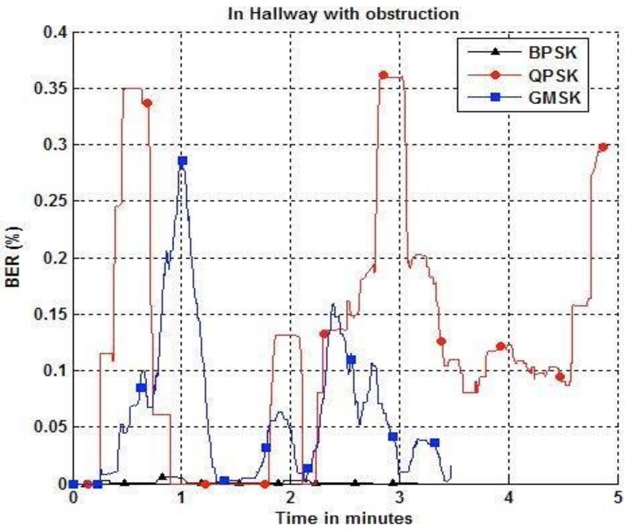


Figure 10: BPSK in lab environment



Figures 13. Hallway environment

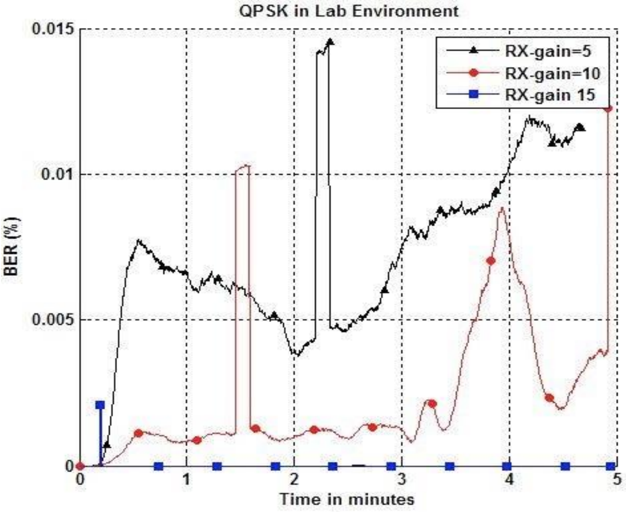


Figure 11: QPSK in lab environment

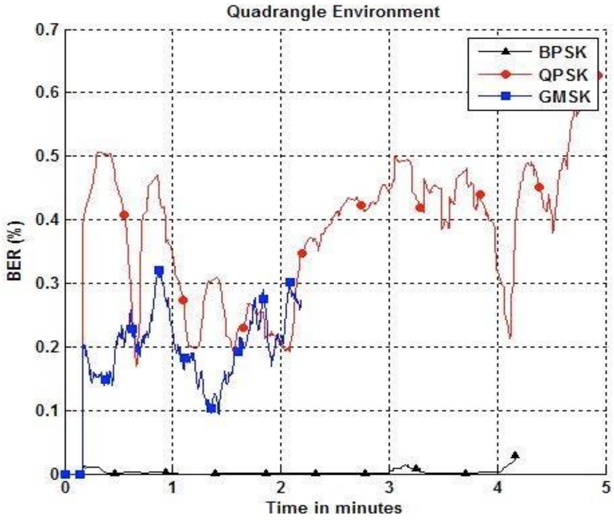


Figure 14: Quadrangle environment

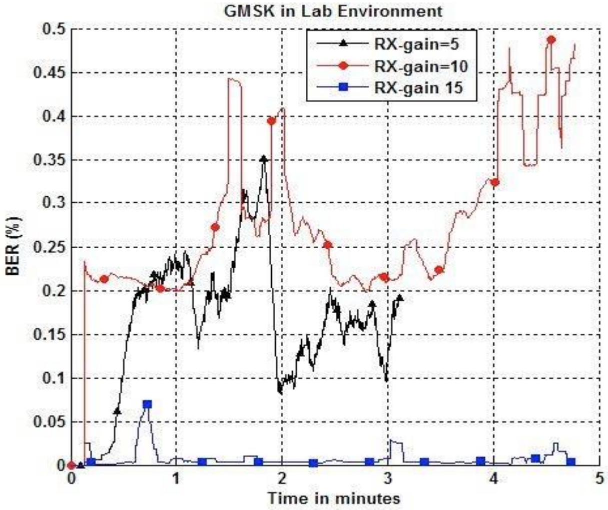


Figure 12: GMSK in lab environment

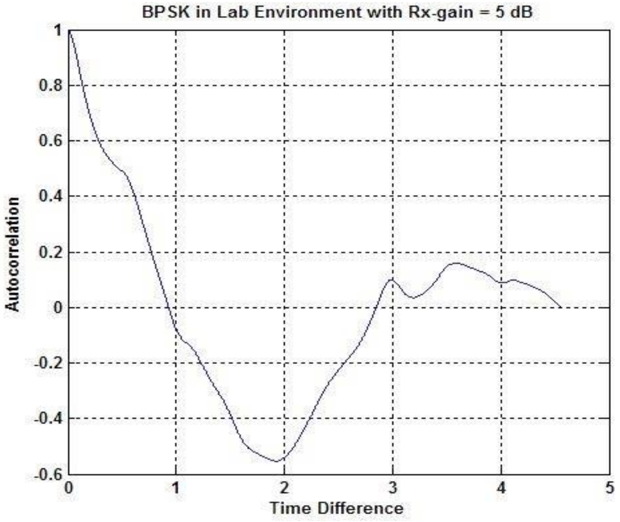


Figure 15: Autocorrelation

Table 1:. Data Statistics in each environment

Modulation Scheme	Environment	Tx-gain (dB)	Rx-gain (dB)	Avg. BER (%)	Filtered Std. Deviation (%)
BPSK	Lab	0	10	0.000031	0.002183
QPSK	Lab	0	10	0.00283	0.004791
GMSK	Lab	0	10	0.003694	0.005883
BPSK	Hallway	40	50	0.0008518	0.001517
QPSK	Hallway	40	50	0.1215	0.1058
GMSK	Hallway	40	50	0.061	0.06584
BPSK	Quadrangle	40	50	0.002105	0.003813
QPSK	Quadrangle	40	50	0.3742	0.1255
GMSK	Quadrangle	40	50	0.1873	0.07306

Figure 13 shows autocorrelation of filtered BPSK (moving average of 50 samples) in lab environment with Rx-gain 5 dB. It shows a significant positive correlation up to a full minute. It then shows a strong negative correlation for another 2 minutes. This clearly again demonstrates the long term correlation in BER that has already been seen earlier.

Table 1 gives details of each modulation scheme in the three environments which were discussed earlier. The table shows the average BER and standard deviation after filtering. To ensure reasonable reception quality of the data for hallway and quadrangle environments, we increased the Tx-gains and Rx-gains. The filtered average BER is lowest for BPSK in all the environments when compared to QPSK and GMSK. The filtered average BER for GMSK has a drastic difference in each environment. In some cases the standard deviations are quite large compared with the mean values.

5. CONCLUSION

Measurements were successfully obtained using software defined USRP radios for various environments, and several interesting results were obtained. We observed long term, slow variations in the BER in different environments for radios that were relatively close in distance and were not moving. Such results are not described by commonly used channel models for small-scale and large-scale fading. Further research is needed to obtain satisfactory explanations. There is a chance that hardware issues of the USRP had an influence, but otherwise we have seen BPSK to have less variations than GMSK and QPSK. And variations tend to be the same in different environments once TX and RX gains are adjusted.

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