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Software Defined Radio: USRP N210 with GNU Radio

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Abstract*: Driven by the increasing interest from the research community, this paper presents the current role of software defined radio (SDR) in academic and commercial applications which is helpful for the researchers, professors as well as students working in the area of signal processing and wireless communication. The authors mainly focus on universal software radio peripheral (USRP) N210 which is employed as hardware and GNU Radio as software to implement SDR for various applications that help the researchers to test and analyze various proposed techniques for different systems. Furthermore, this paper presents the implementation of basic analog/digital modulation techniques, and recent research works carried out by using SDR. This paper also presents several limitations and current usage of SDR in commercial and academic applications.

Keywords* : *GNU Radio, Hardware Radio, Software Defined Radio, USRP.

NOMENCLATURE

ACM Adaptive coded modulation
ADC Analog to digital converter
CVSD Continuously Variable Slope Delta
DSBSC Double-sideband suppressed-carrier
DM Delta modulation
DVB Digital video broadcasting
FSK Frequency shift keying
FM Frequency modulation
FMCW Frequency modulated continues wave
GMSK Gaussian minimum shift keying
GNU Radio A humorous recursive acronym meaning 'GNU's not Unix
GSM Global system for mobile
OSI Open system interconnection
PCCC Parallel concatenated convolutional codes
PSK Phase-shift keying
PLL Phase locked loop
SWIG Simplified wrapper and interface generator
TDMA Time-division multiple access
USRP Universal software radio peripheral
UHD USRP hardware driver
VCO Voltage controlled oscillator
WiMAX Worldwide interoperability for microwave access

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I. INTRODUCTION

A radio is a device to transfer the information from one point to another point where the information may be analog or digital that includes wired or wireless communication [1]. Mostly, hardware radios were used till 1990 which have many disadvantages such as cost, complexity, reliability, reconfiguration, etc. Moreover, hardware radios can handle one or two waveforms and also not possible to communicate two groups of people with different types of hardware radios. In order to avoid these challenges, Mr Joseph Mitola introduced a term, *Software Radio* in 1991 while reducing the complexity, cost, etc [2]. This software radio incorporates non- digital signal processing (DSP) hardware segments like radio frequency (RF) distribution, RF conversion, power handling and anti aliasing filters etc. However, this shift towards software particularly in large scale telesystems applications due to the enhanced performance and consistently decreasing costs of emerging technologies.

The ideal case of software radio is *software defined radio* in which ADC/DAC are placed next to the antenna [3]. It is possible to upgrade an air interface protocol, frequency band and functionality of the system by the use of software. The reason behind this SDR is how a radio waveform can be reprogrammed or reconfigured flexibly through changing software and without modifying the hardware such that using a common platform. SDR capabilities and services are presented [4]. As the generation is being changed, the utilization of SDR is becoming very essential.

The software defined radio (SDR) is more advantageous to radio equipment manufacturers, system integrators, radio service providers and end users due to the following features and capabilities of SDR.

– The implementation of most of the radio products is possible using the common SDR platform. Hence, the new radio applications can be developed easily with less manufacturing cost.

– SDR permits the execution of completely reprogrammable and reconfigurable wide range of communications systems, with high performance by reducing size, power consumption and obsolescence.

– Software can be reused and new capabilities/features can be included to the existing infrastructure.

– An attractive solution is developed that makes software upgrades of base stations than the costly replacement of base stations.

– SDR provides a duplex data transmission in which a two way communication is possible.

– SDR is more beneficial for space and military applications.

Daniel et al., presented the most recent research initiatives on programmable networks, modern network architectures and their research issues. Maintaining the security in software defined networks is a challenging task. To the best of authors' knowledge, most of the survey papers discussed about the software defined networks. In our contribution, we present not only our experiment results but also a detailed literature survey on software defined radio specifically that employed USRP and GNU Radio.

II. SOFTWARE DEFINED RADIO TESTBENCH - GNU RADIO AND USRP

As shown in Figure 1, in which high frequency (RF) signal is received by one of the smart antennas of USRP N210 hardware and it is converted to medium frequency and then to low frequency. Hardware is connected to PC through Gigabit Ethernet cable where necessary baseband signal processing can be carried out in the transmitter (Tx) path. In the receiver path, low frequency signal is transmitted from PC to USRP and then in to the air.

2.1 GNU Radio

GNU Radio is an open source free software specifically designed to communicate with USRP by interacting with the USRP hardware driver (UHD). UHD Sink block which acts as USRP receiver and its reconfigurable parameters are shown in Figures 2 (a) and (b), respectively. Due to its open source license, developers can share their processing codes and make them available in the GNU Radio installation. Since many signal processing codes have already been developed and tested, complex waveforms can be created very quickly. This makes it easy to reconfigure our application and tune it during real-time execution. Figure 3 depicts the architecture of GNU Radio, where all the applications using signal processing blocks are developed in C++ and the connection among them is developed in Python. Any application can be developed as per user requirement by just connecting these signal processing blocks available in its library.

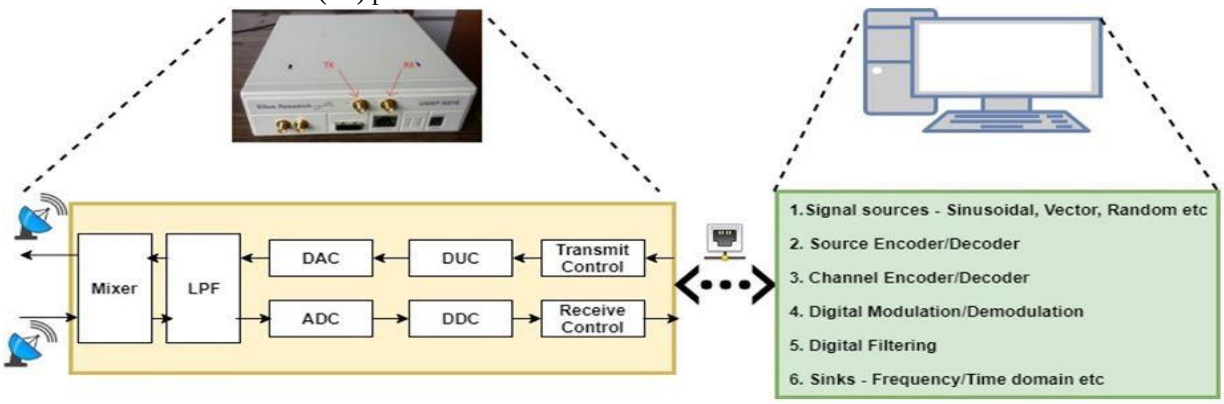

Fig. 1 Block diagram of SDR.

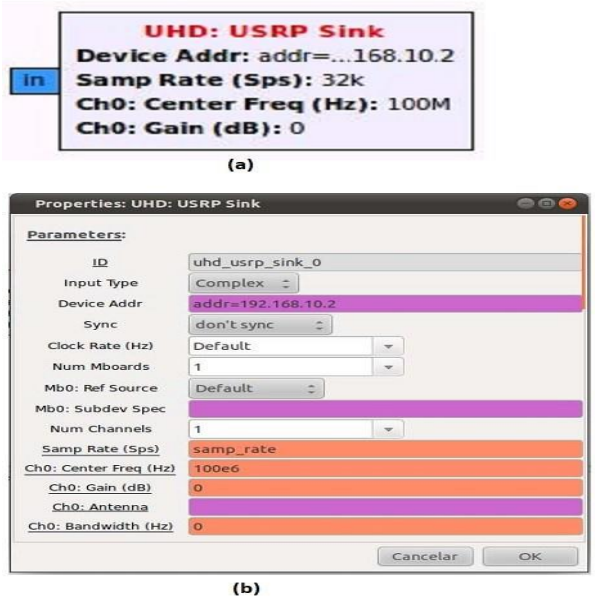

Fig. 2 (a) UHD Sink block (b) UHD Sink parameters.

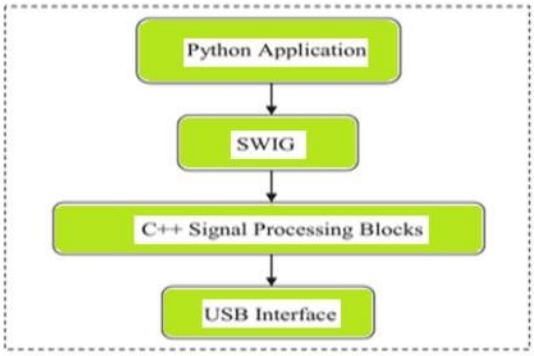

Fig. 3 Block diagram of GNU Radio architecture.

2.2 Universal Software Radio Peripheral (USRP) N210

The popular hardware platform to implement SDR is Universal software radio peripheral (USRP) which consists of transmit/receive antennas, Voltage-controlled oscillator (VCO), low noise amplifier, Phase-locked loop (PLL), mixer, low pass filter,

ADC/DAC, DDC/DUC, transmit/receive control and FPGAs. The USRP X Series boards are high end boards, USRP Network series (N series) boards are most popular, USRP Bus Series boards are single circuit boards and USRP Embedded series are for low level applications. Depends on the user application, particular board can be used.

III. RESULTS AND DISCUSSION

In this section the implementation of analog and digital modulation techniques using SDR is presented separately.

3.1 Analog Modulation Techniques

Amplitude modulated waveform can be generated by using the GNU flow graph shown in Figure 4 which consists of Signal source, Multiply Constant and sink blocks. The multiply const block controls the modulation index k_a value. We can observe the properties of the message signal $m(t)$ and modulation waveform $1+k_a m(t)$ by changing the modulation index and the signal frequency.

The GNU Radio is developed to provide practical exposure in the area of communication systems concepts such as various signals generation, applying basic signal operations (filtering, modulation, coding and multiplexing techniques) and to observe the output in frequency domain , time domain, etc. We can also perform different experiments such as generating and receiving of AM, Double-sideband suppressed-carrier (DSBSC), singlesideband suppressed-carrier (SSBSC) signals, Frequency modulation (FM) and Phase modulation. In addition, Gandhiraj et al., demonstrated SDR with USRP1 and GNU Radio by implementing Community Radio Schemes and

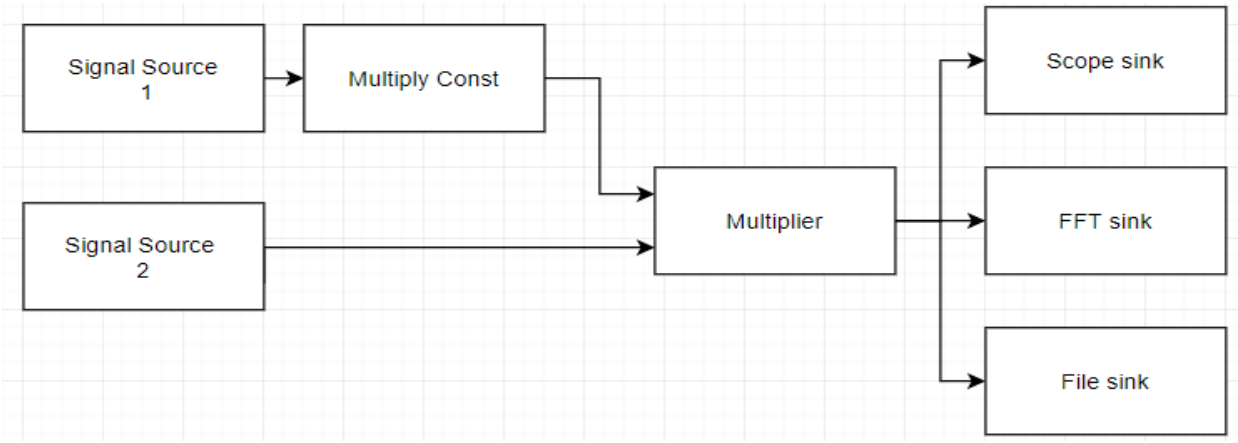

Fig. 4 GNU Radio flow graph to generate AM signal.

Radio Data System (RDS) and Simple DVB and OFDM data. In general, weather surveillance radar uses pulse-radar type which may consume more power to generate pulse, therefore Aditya et al., designed a Frequency Modulated - Continuous Wave (FMCW) radar using software-defined radar that resulted in cost and complexity reduction. Vahideh et al., proposed a new indoor positioning system using frequency modulation (FM) broadcast and this FM signals are generated easily by employing SDR.

3.2 Digital Modulation Techniques

Recently, most of the communication is carrying out in digital in which data is transmitted and received as binary bits (either 1 or 0) due to its advantages than analog communication. Delta modulation (DM) has more advantages such as low cost, low noise, lower bandwidth consumption etc rather than analog-to-digital modulation techniques. Furthermore, computational analysis of a Gaussian Minimum Shift Keying (GMSK) transceiver, demonstration of a differential Chaos Shift Keying communication system is also presented.

Sruthi et al., designed a low cost and low complexity digital transceiver employing RTL-SDR and Stefan et al., implemented modulator/demodulator
arts of a digital video broadcasting (DVB) - T2 transceiver. Alexander et al., demonstrated the practical approach on basic digital communication by implementing a transmitter and receiver with structure and waveform synthesis, multicarrier modulation, duplex communications and spectrum sensing techniques which can be very useful for beginners working in communication area. The recent version of DM, Continuously Variable Slope Delta (CVSD) modulation is described and implemented.

Siva et al., presented the design of WiMAX physical layer with forward error correction (FEC) coding, concatenated coding, continuously variable slope delta (CVSD) vocoder and energy detection spectrum sensing techniques using software defined radio (SDR) testbed by employing USRP N210 and GNU Radio. The impact of coding techniques such as convolutional code, Reed Muller (RM) and Reed Muller Golay (RMG) codes on transmitted signal using a GNU schematic is analyzed and it is concluded that the RMG coder is preferable for WiMAX physical layer, since the transmission of data with RMG codes result in less BER compared to that obtained using other coders. The BER performance of WiMAX system is further improved by employing Concatenated Coding in which convolutional code is incorporated as an outer code and Reed Muller coder as inner code. Figure 5 presents the encoding-decoding block diagram of the concatenated coding system for BER analysis using USRP source and sink. The concatenated OFDM signal is transmitted using TX/RX antenna of USRP N210 RF front end and received by RX2 antenna of other USRP N210 hardware over air in the lab environment.

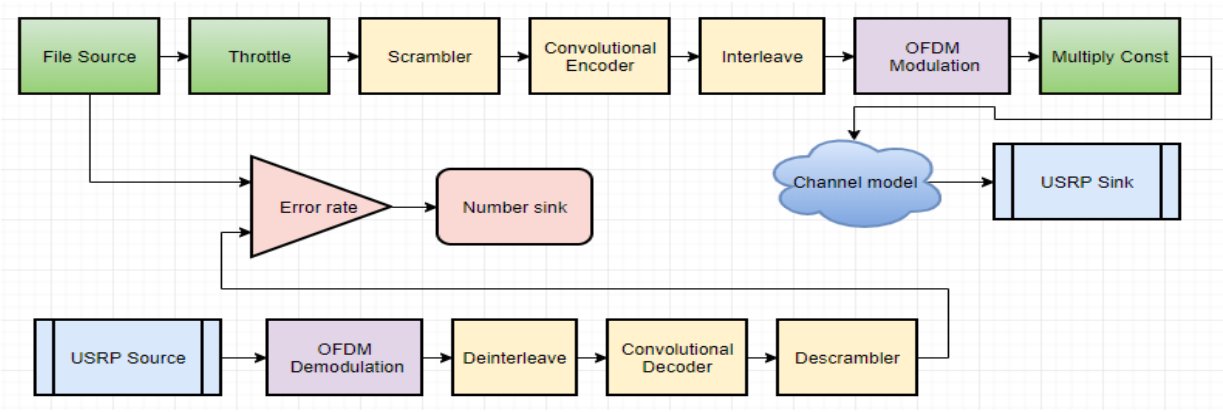

Fig. 5 GNU Schematic for OFDM transmission and reception over SRP source and sink for BER analysis.

The implementation of an energy detection spectrum sensing for FEC based WiMAX PHY using software defined radio testbed is presented. The transmitted OFDM signal, shown in Figure 6, is received by the USRP. The same experiment is carried out for FM and AM frequencies (103.45 MHz and 710 KHz).

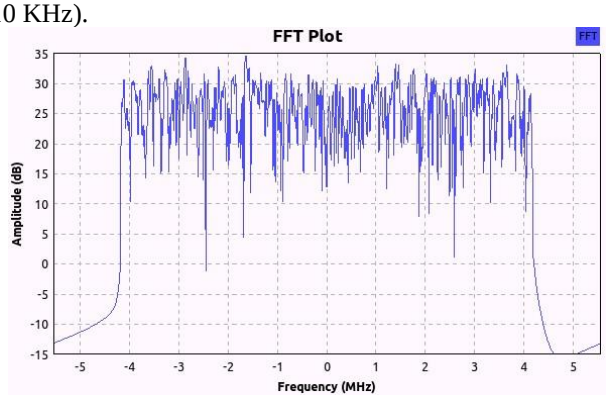

Fig. 6 Transmitted Coded-OFDM signal.

Coding & modulation techniques will be allotted as per the channel conditions, since received signal has more or less error probabilities. The performance enhancements of WiMAX PHY are analyzed in terms of BER and throughput for SISO and MIMO systems using the WiMAX simulator with the combination of MIMOOFDM and ACM techniques. The impact of high PAPR on OFDM based WiMAX system using software defined radio testbed is presented. In this work, the PAPR and out-of-band distortion are analyzed for WiMAX system by employing Channel coding, Rail clipping, Phase modulation, Sample and Hold and Threshold methods and experimental tests are performed for practical proof. The conventional OFDM symbol generated using SDR testbed without employing any PAPR reduction technique are presented.

Vonmalm et al., tested various wireless communication applications such as MAC protocol, physical functions, data transfer using SDR. Rondeau et al., designed filterbanks in GNU Radio for performing signal detection, collection, and analysis operations that are of increasing interest to the DSA and CR communities. Recent, broadcast systems are being integrated with hierarchical modulation (HM) and scalable video coding (SVC) to avoid poor channel conditions by improving the performance. Schertz et al., analyzed HM system using SDR in terms of peak signal to noise ratio (PSNR) and bit error rate (BER) and achieved better performance. Hashem et al., designed an enhanced OpenBTS based on software that allows users to make calls with out interfering existing telecommunication providers' networks that resulted a low cost and improved sensitivity. An open source LTE receiver, Orthogonal Frequency Division Multiplexing (OFDM) receiver and subsurface radar are implemented using SDR, respectively. Some more recent works carried out by using SDR are presented in Tables 1.

Table 1 Recent works carried out by employing SDR.

Year	Overview	Reference
2017	Reviewed the detailed literature of software-defined acoustic modems (SDAMs) and tested a NILUS MK 2 sensor nodes	[5]
2017	Designed and validated a ultrasonic intra-body area networks using software defined testbed	[6]
2017	Presented latency measurements of portable GFDM software implementation	[7]
2017	Implemented an Advanced Television Systems Committee (ATSC) 3.0 modulator using SDR	[8]

2017	Designed Convergence of Multiple Radio Access Technologies (CONTACT) architecture	[9], [10], [11]
2017	Implemented a low cost Unmanned Aerial Vehicles (UAVs) to sustain GPS spoofing attack or WiFi attack and suggested solutions to them	[12]
2017	Analyzed SDR-based radar architectures	[13]
2018	Designed a SDR based system for radio signal's detection and classification from civilian drones	[14]
2019	Presented a new transceiver architecture based HPDSM	[15]
2019	Presented the challenges and scope of IoT using Cognitive Radio Network and Software-Defined Network	[16]

IV. LIMITATIONS IN SDR

– Two tone Inter Modulation Distortion (IMD)
– The design of architecture depends on the limitations of ADC/DAC performance
– Complexity in using the software
– There are technology limits on achievable RF performances
– overall radio reliability is defined by software reliability
– Higher initial costs
– Current SDR hardwares consume more power

V. CONCLUSIONS

I have presented the current and future applications of software defined radio (SDR) due to the increasing interest towards wireless communication from research community. This paper demonstrated the SDR platform with USRP hardware and GNU Radio software by presenting their features. Further, basic analog communication systems such that Amplitude modulation is implemented and presented results for different modulation index values by showing the demonstration of GNU Radio signal processing blocks. Then, basic digital communication methods and the recent works carried out by employing SDR are presented. The paper is concluded by presenting some limitations of SDR.

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