Design and Implementation of Software Defined Radio Using ZYNQ FPGA

Y Amar Babu, Harika Pamarthi, Sasikala Nandru and Yesobu Bakka

January 4, 2024

DESIGN AND IMPLEMENTATION OF SOFTWARE DEFINED RADIO USING ZYNQ FPGA

1st Dr.Y.Amar Babu
Electronics and Communication Engineering
Lakireddy Bali Reddy College Of Engineering
Mylavaram, India
amarbabu.y@lbrce.ac.in

2nd Pamarthi Harika
Electronics and Communication Engineering
Lakireddy Bali Reddy College Of Engineering
Mylavaram, India
pamarthiharika54@gmail.com

3rd Nandru Sasikala
Electronics and Communication Engineering
Lakireddy Bali Reddy College Of Engineering
Mylavaram, India
nandrusasikala20@gmail.com

4th Bakka Yesobu
Electronics and Communication Engineering
Lakireddy Bali Reddy College Of Engineering
Mylavaram, India
yesobu0505@gmail.com

***Abstract*—This paper looks at the significant research and advancements in software-defined radio (SDR) and Zynq FPGA implementations for a range of different digital modulation methods. This study looks at the unique advantages and disadvantages of each modulation method. It provides insights into the application of SDR and Zynq FPGA technology in modern communication systems by synthesizing results from numerous investigations.This offers a comprehensive overview of the current state of wireless communication research. Additionally, MATLAB can be used to model the 6G modulation techniques. One among them is OFDM, which will bypass the majority of mobile network restrictions. Zynq FPGA can then be interfaced with the MATLAB simulation and VHDL code is written in the Xilinx Vivado software for the hardware examination.**

***Index Terms*—SDR, Zynq FPGA, ASK, PSK, FSK, QPSK, QAM, OFDM, MATLAB.**

I. INTRODUCTION

By substituting software-based solutions for conventional hardware components, Software-Defined Radio (SDR) completely transforms wireless communication. Software-Defined Radio (SDR) aims to transform wireless communication by replacing hardware-based adaptability with software-driven adaptability. SDR's software-based dynamic reconfiguration of radio settings and protocols makes it compatible with a wide range of communication standards without requiring changes to hardware. Enhancing spectrum efficiency, speeding up the prototype process, streamlining system upgrades, and enabling adaptable, interoperable wireless systems are some of its main objectives [1]. The adaptable nature of SDR encourages creativity and offers a practical and economical solution to change communication requirements in many applications.

Xilinx created the Zynq Field-Programmable Gate Array (FPGA), a cutting-edge integrated circuit that integrates ARM processing cores and programmable logic onto a single chip.

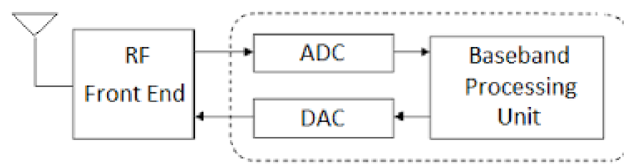

Fig. 1. Block Diagram Of SDR

Due to its special architecture, embedded ARM Cortex-A9 cores can run software applications concurrently with custom digital circuits implemented in the programmable logic fabric[2]. The Zynq FPGA expedites development procedures and shortens time-to-market, making it perfect for applications needing high-performance processing and real-time adaptability. Its ability to integrate both software and hardware components make it an essential component for many applications, such as industrial automation, image processing, and communication systems[2]. The shift from 1G to 5G has completely changing wireless communication in response to the changing needs of a world that is becoming more and more connected. But the growing need for ultra-low latency, enormous device connectivity, and faster data speeds has revealed constraints in the available spectrum. Overcoming these limitations requires embracing the revolutionary promise of 6G technology. 6G, which promises previously unheard-of levels of speed, efficiency, and connectedness, is the next big thing in wireless communication, set to usher in a new era of technological innovation.

II. Design Methodology

To implement 6G OFDM modulation in MATLAB, design the OFDM system using functions like ifft and fft. Simulate the system's performance and validate the results. Interface with Zynq FPGA by generating HDL code from MATLAB, using HDL Coder, and integrating it into the Vivado design suite. Configure the Zynq Processing System, implement the generated IP core, and connect it to other components. Finally, program the FPGA and test the integrated system for OFDM modulation using 6G technology.

III. Previous Work

Over the course of several generations characterized by revolutionary breakthroughs, mobile networks have experienced an amazing transformation. After 1G, which provided rudimentary voice calls in the 1980s, came digitalization (2G), mobile data (3G), broadband internet (4G), and the Internet of Things (5G). Every stage transformed communication by facilitating higher connectivity, reduced latency, and faster data transfer. With 6G, the progress will continue with the goals of previously unheard-of speeds, pervasive connectivity, and innovative applications. Let's take a quick look at how cellular communication technologies have developed from 1G to 6G:

1. 1G (First Generation): With the advent of 1G in the 1980s, analog signals could be used for wireless phone communications. Although it operated on frequency division multiple access (FDMA) and time division multiple access (TDMA) technology, it did not have the data capabilities of later generations, but it did lay the groundwork for mobile communication.

2. 2G (Second Generation): The 1990s saw the debut of 2G, which allowed for text messaging and enhanced sound quality for digital voice communication. This set the stage for the development of mobile data services. **3. 3G (Third Generation):** Early in the new millennium, 3G mobile technology was introduced, improving mobile communication through quicker data transfer, internet access, video calling, and multimedia apps on mobile devices.

4. 4G (Fourth Generation): It is deployed around 2010. It is used in All-IP (Internet Protocol) based network with enhanced data communication capabilities. It has high-speed internet access, video streaming, and improved voice quality. It has significant increase in data transfer rates.

5. 5G (Fifth Generation): This began rolling out around 2019. With its lightning-fast data rates, minimal latency, and extensive device compatibility, 5G is revolutionizing communications. It drives the advancement of technologies that revolutionize daily life and industries, such as augmented reality, driverless cars, and the Internet of Things.

6. 6G (Sixth Generation): As of the last knowledge update in January 2022, 6G is still in the conceptual and research phase. It is predicted to offer even faster data speeds, lower latency, and new capabilities, possibly including advanced AI integration, holographic communication, more and more.

Type Of Modulation Scheme	**Data Rate**	**Applications**
Amplitude shift keying	Few kbps	Radio frequency identification (RFID), WSN's also in the Optical Communication systems.
Frequency Shift keying	1Mbps	Modems, telemetry and RFID systems.
Coherent Frequency Shift Keying	1Mbps	Automatic identification systems (AIS), RFID and in digital modulation schemes.
Non-Coherent Frequency Shift Keying	1Mbps	Alarm and security systems, Industrial automation, voice transmission.
Binary Phase Shift Keying	1Mbps	Wireless and Satellite Communication.
Quadrature Phase Shift Keying	2Mbps	Digital broadcasting and digital modems.
Differential Phase Shift Keying	2Mbps	Secure and powerline communication, error correction.
8- Bit PSK or M-ary PSK	3Mbps	Wireless LAN's, digital video transmission, point-to-point communication.

A. *Amplitude shift Keying*

A virtual modulation method called Amplitude Shift Keying (ASK) modifies the amplitude of a carrier signal to represent binary information. It's an easy-to-use modulation technique for communication systems that encodes 0s and 1s by varying the amplitude between two preset levels. ASK is a popular component of wireless communication and remote control systems.Its simplicity makes it suitable for real time situations.

B. *Binary Phase shift Keying*

In this technique, binary information is represented by varying the carrier signal's phase. It is frequently employed in communication systems, especially in radio frequency and optical communication, where it modulates the carrier signal's phase to communicate information and facilitates effective data transmission[3].

C. *Quadrature Phase Shift Keying*

An example of a best modulation strategy used in communication systems is quadrature phase shift keying, or QPSK. It uses four different states to change the carrier signal's phase to represent two bits each symbol. Higher data speeds and better spectral efficiency are made possible when delivering digital data over radio channels because to this[4].

D. *Frequency shift Keying*

A digital modulation technique called frequency shift keying (FSK) modifies the carrier frequency to transmit binary data (0s and 1s). FSK is a popular frequency division multiplexing (FSK) algorithm used in data modems, radio frequency identification (RFID), and telecommunications[5]. It is essential in sending data over different media, like radio, as it offers an easy-to-use and efficient way to modulate binary data.

Reference	Modulation Scheme	Correct classification at highest SNR (in percentage)	Correct classification at lowest SNR (in percentage)
6	BASK 4-ASK 2-PSK 4-PSK 2-FSK 4-FSK	96 at 20dB 80.2 at 20dB 100 at 20dB 100 at 20dB 92 at 20dB 88 at 20dB	95.3 at 15dB 77.3 at 15dB 100 at 15dB 96 at 15dB 92 at 15dB 100 at 15dB
7	2-PSK QPSK 8-PSK BFSK 4-FSK	99 at 15dB 98 at 15dB 100 at 15dB 100 at 15dB 100 at 15dB	- - - - -
8	BPSK QPSK	100 at 10dB 100 at 10dB	78 at 0dB 100 at 0dB

Reference	Modulation Scheme	Correct categorization at maximum SNR (in percentage)	Correct categorization at minimum SNR (in percentage)
9	2-PSK 5-PSK 8-PSK BFSK 4-FSK	99 at 13dB 97 at 13dB 97 at 13dB 97 at 13dB 100 at 13dB 100 at 13dB	- - - - - -
10	QPSK 4-FSK	100 at 20dB 100 at 20dB	97.6 at 5dB 100 at 5dB
11	BPSK QPSK 8-PSK 2-FSK 4-FSK	100 at 13dB 100 at 13dB 100 at 13dB 100 at 13dB 100 at 13dB	100 at 8dB 97.5 at 8dB 100 at 8dB 95.3 at 8dB 100 at 8dB
12	BPSK QPSK 8-PSK BASK 2-ASK BFSK 4-FSK	100 at 10dB 100 at 10dB 100 at 10dB 100 at 10dB 99.8 at 10dB 100 at 10dB 99.8 at 10dB	100 at -5dB 94.6 at -5dB 100 at -5dB 95.8 at -5dB 95.9 at -5dB 77.3 at -5dB 66.2 at -5dB

Table-1 and Table-2: Survey of Wavelet-transform based and non-wavelet transform based techniques respectively

IV. Proposed Work

The sixth generation of wireless technology, or 6G, is expected to arrive soon and is expected to bring with it ultra-low latency, incredible data rates, and worldwide connectivity. It is predicted to arrive by the end of the 2020s and is expected to transform communication through the use of artificial intelligence (AI), increased spectrum consumption, and support for many uses, such as IoT with immersive experiences.

A. 6G Vision

In comparison to 5G, 6G is anticipated to offer much higher data speeds and more network capacity, possibly approaching terabit-per-second data rates.In order to enable real-time communication for applications like augmented reality, virtual reality, and crucial machine-to-machine interactions, low latency seeks to further reduce latency to previously unheard-of levels.In order to improve network intelligence and efficiency, 6G is expected to include cutting-edge technology

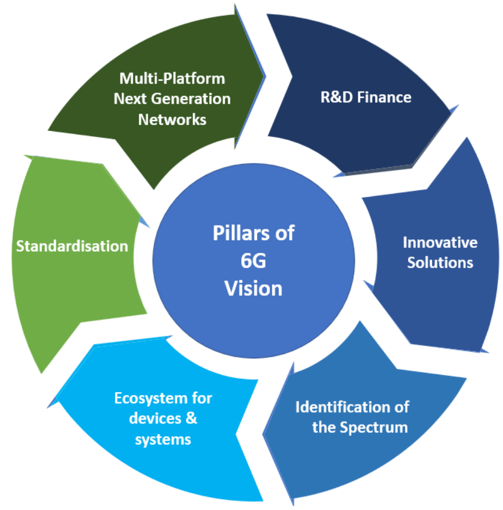

Fig. 2. 6G Vision

like artificial intelligence, machine learning, and maybe quantum computing.Utilizing a wider variety of frequencies, such as terahertz bands, will probably enable a wider range of applications and enhance network performance in general[14].In order to guarantee that even remote and underserved locations have access to high-speed internet and cutting-edge communication services, 6G seeks to provide ubiquitous and seamless connectivity internationally.Many applications, such as immersive extended reality (XR), holographic communication, smart cities, and the Internet of Things (IoT) are anticipated to be supported by the technology.

B. 6G kEY TECHNOLOGIES

The possible modulation schemes under consideration for 6G technology could include advanced versions of existing schemes. Modulation is a key component in determining how wireless communication will develop in 6G. The goal of advanced modulation schemes is to improve data rates, spectral efficiency, and connectivity. These schemes may include variations of OFDM and NOMA. These developments are essential to fulfilling the growing needs of many applications, such as the Internet of Things and augmented reality.

The classification of 6G modulation schemes are mentioned as follows:

1. Orthogonal Frequency Division Multiplexing(OFDM)
2. Filter Bank Multi Carrier(FBMC)
3. Sparse Code Multiple Access(SCMA)
4. Non-Orthogonal Multiple Access
5. Massive Multiple Input Multiple Output(MIMO)
6. Polarization modulation

Let us discuss about OFDM technique in detail

Orthogonal Frequency Division Multiplexing(OFDM) is an advanced modulation technique which is widely used in the area of telecommunications. It divides a high-data-rate signal into multiple parallel sub-carriers, reducing interference

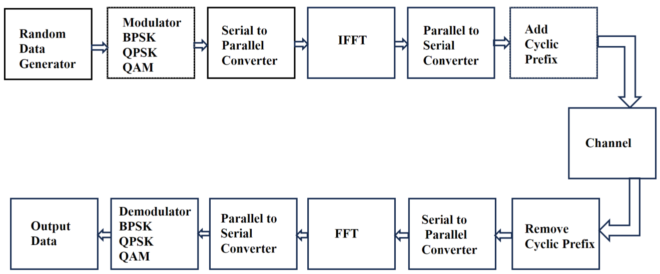

Fig. 3. Block Diagram Of OFDM

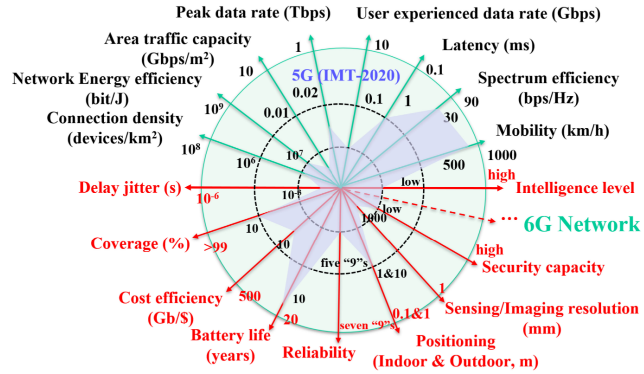

Fig. 4. 6G KPI Indicators

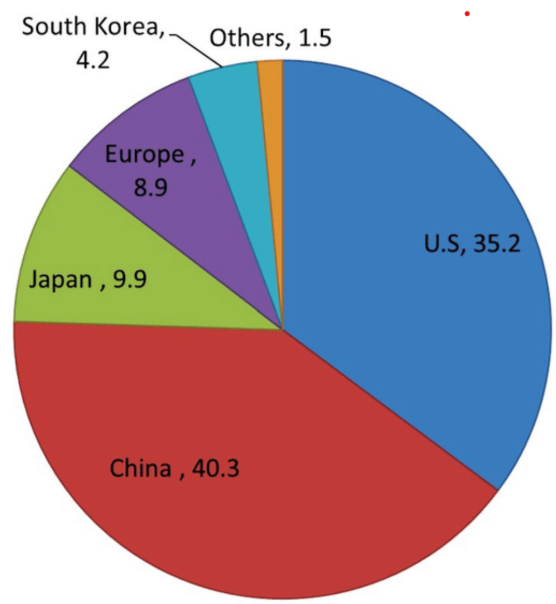

Fig. 5. Statistics Of 6G Patents By Country

and improving efficiency.[13] OFDM is crucial in modern communication systems, including Wi-Fi, LTE, and digital broadcasting, enhancing data transmission reliability. In wireless communication, it is a vital modulation technology that fulfills several essential functions. Its main function is to lessen the difficulties caused by multi-path fading, which occurs when signals are interfered with by several transmission pathways. OFDM reduces the effects of fading by splitting the data stream into orthogonal sub-carriers, guaranteeing dependable and strong communication in a variety of settings. Furthermore, OFDM improves data rates, and allowing multiple sub-carriers to be transmitted simultaneously within the same frequency band. OFDM is essential for achieving effective, high-capacity wireless communication because of its built-in interference avoidance mechanisms, compatibility with frequency-domain equalization, and adaptability to various channel conditions[13].

C. 6G Important Metrics for Performance(KPI)

The quantifiable measurements that are used to assess a project, organization, or individual performs in reaching particular objectives. It helps to make defensible choices for ongoing development. Terabit-per-second data rates, extremely low latency, worldwide coverage, diversified spectrum usage, and the integration of cutting-edge technology like artificial intelligence and quantum computing are some of 6G's major performance metrics[15]. It seeks to revolutionize communication with previously unheard-of speed and capabilities, supporting a wide range of applications from crucial machine-to-machine interactions to immersive experiences are as shown in Fig:4.

D. 6G Patents By Country

The quantity of standard relevant (essential) patents in specific technology domains indicates the growing significance of those sectors with every passing generation. But 6G technology is still in its early stages of pre-standardization. As such, rather than being grounded in real facts, knowledge on this topic is based largely on speculation and the objectives of different 6G players. According to a survey that comprised over 20,000 patent filings for nine important 6G technologies, China is the world leader in 6G patents. As can be observed from the pie chart, China is responsible for 40.3percent of 6G patent rights, mostly for patents pertaining to mobile infrastructure. Of these filings, the United States makes up 35.2percent, followed by South Korea (4.2percent), Europe (8.9percent), and Japan (9.9percent)[16].

V. Conclusion

To sum up, the MATLAB-based design and execution of an OFDM simulation, along with its subsequent deployment on a Zynq FPGA, signify a significant advancement in surmounting 5G constraints and becoming ready for the 6G era. Though extensive testing and enhancements were made possible by the simulation, the FPGA implementation showed promise for practical use. In addition to offering a glimpse into the future of radiotelephony, this approach proves to be a vital component in realizing the revolutionary promise of 6G technology by addressing concerns related to latency, data throughput, and spectrum utilization. As a result of the cooperation between simulation and FPGA implementation, a reliable and effective communication infrastructure is established, paving the way for the advancement of wireless connectivity.

VI. References

References

[1] Louise Helen Crockett, David Northcote, Robert W Stewart, 'Software Defined Radio with Zynq Ultrascale+ RFSoc', 24 January 2023.

[2] L. H. Crockett, R. A. Elliot, M. A. Enderwitz and R. W. Stewart, 'The Zynq Book: Embedded Processing with the ARM Cortex- A9 on the Xilinx Zynq-7000 All Programmable SoC, First Edition, Strathclyde Academic Media',2014.

[3] KS Sourabh, R Deepika, V Lekshmi, S Sudhakar and J Manikandan,'Design and Evaluation of BPSK Demodulator using Model based Programming,' 2019 IEEE 16th India Council International Conference (INDICON), Rajkot, India, Dec 2019, pp.1-4.

[4] Sourabh KS, Lekshmi V, Sudhakar S and Manikandan J,'FPGAImplementation of BPSK Demodulator using Model based Programming',2020 IEEE International Conference for Innovation in Technology (INOCON),Bengaluru, India. Nov 6-8, 2020 .

[5] Raj Mamarde, Suchitra Khoje , Implementing PSK and FSK Scheme in Zynq-7000 FPGA for SDR applications',Proceedings of the Second International Conference on Intelligent Computing and Control Systems (ICICCS 2018).

[6] Azzouz, E. E and Nandi, A. K, 'Automatic Modulation Recognition of Communication Signals', Kluwer Academic, Netherlands,2019.

[7] Hsue, S. Z and Soliman, S. S, 'Automatic Modulation Recognition of Digitally Modulated Signals', Proc.2018 IEEE Military Commun. Conf., Vol. 3, pp. 645-649, October 15-18, Boston,2018.

[8] Dobre O.A, Abdi A, Bar-Ness Y and Su W, 'The Classification of Joint Analog and Digital Modulation,' Proc. 2005 IEEE Military Commun. Conf., Vol. 5, October 17-20, 2005, Atlantic City, NJ.

[9] Ho, K. C., Prokopiw, W. and Chan, Y. T., 'Modulation Identification by the Wavelet Transform,' Proc.2017 IEEE Military Commun. Conf.,Vol. 2, pp. 886-890,2017.

[10] Hong, L. and Ho, K. C., 'Identification of Digital Modulation Types using the Wavelet Transform', Proc.2016 IEEE Military Commun.Conf., Vol. 1, pp. 427-431.

[11] Jin J-D., Kwak Y, Lee K-W, Lee K-H and Ko S-J, 'Modulation Type Classification Method using Wavelet Transform for Adaptive Demodulator', Proc. 2004 IEEE Int. Symp. Intell. Signal Process. and Commun. Syst., pp. 282-292, November 18-19, 2004, Seoul, Republic of Korea.

[12] Ka Mun Ho, Student Member, IEEE, Canute Vaz, Student Member, IEEE, and David G. Daut, Senior Member Rutgers, the State University of New Jersey, IEEE, 'Automatic Classification of Amplitude,Frequency, and Phase Shift Keyed Signals in the Wavelet Domain',2010.

[13] Akash Mecwan, Dhaval Shah, Assistant Professor, Institute of Technology, Nirma University,'Implementation of OFDM Transceiver on FPGA ',2013.

[14] 'Artificial intelligence in next-generation connected systems',Ericsson, Stockholm, Sweden, White Paper, Sep. 2021.

[15] 'White paper on 6G overall vision and potential key technologies,' IMT-2030 (6G) Promotion Group, White Paper, Jun. 2021.

[16] Citation: Asghar, Z.A Memon, S.A, Hämäläinen J, 'Evolution of Wireless Communication to 6G: Potential Applications and Research DirectionsSustainability', 2022.