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Design and Development of Reconfigurable Wi-Fi MAC Layer for Wireless Personal Area Networks (WPAN)

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Abstract: Wi-Fi is an acronym for wireless fidelity has a wide range of users in the present day scenario. Wi-Fi is a Wireless Personal Area Network (WPAN) and also a Local Area Network (LAN) has become a default feature in almost all the gadgets, Palmtops, Laptops, Mini-computers, Consumer electronics, etc., supports for wireless access, high speed data transfer. In this paper, Wi-Fi MAC layer, the sub layer of data link layer in the ISO model is designed using the IEEE802.11 standards. The Wi-Fi MAC Transmitter and Receiver are designed using a HDL, targeted to a reconfigurable hardware device like FPGA and the design is then verified.

Keywords: Wi-Fi, MAC Layer, IEEE 802.11.

I. INTRODUCTION

In the present day the use of Personal Area Networks (PAN) is very prominent. A PAN is a small area comprising of few meters radius in which the user can communicate with another user or a server using his gadget or a personal computer or a laptop or any other device[1]. Now a days the PANs are wireless as the name Wireless Personal Area Network (WPAN)[2]. These WPAN comprises of Bluetooth, IrDA (Infrared Data Association), ZigBee and Wi-Fi. The key advantage of the WPAN is it requires less or no infrastructure for the communication with the other devices i.e., it can be connected directly or plugged in. Hence WPANs are inexpensive, low cost, ease of installation, flexibility, maintenance, use only low power devices and high performance, reliable data transfer.

A. Bluetooth

Bluetooth is a WPAN technology standard used for the data exchange over short range, maintained by Bluetooth Special Interest Group. It uses radio waves in short wavelength UHF, ISM 2.4-2.485GHz band. It uses a Frequency Hoping Spread Spectrum (FHSS) radio technology, Gaussian Phase Shift Keying (GPSK) modulation scheme[3]. It has advanced up to the version 4.0 by enhanced speeds and throughput. The version 1.2 supported the speed of 1Mbps later in the version 2.0 it was improved to 3Mbps and the throughput is 80Kbps. The version 3.0 and 4.0 supports up to 24Mbps. The main drawback of Bluetooth is it can be used only for indoor communication or only for few meters.

B. ZigBee

ZigBee is a wireless mesh network standardized in 2003 later revised in 2006 for data exchange up to few tens of meters. It is used for low data rate transmission, reliable data exchange, long battery life and low power device. ZigBee hardware consists of both analog and digital circuits. It also uses 2.4 Ghz unlicensed band radio technology with 16 channels of 5MHz each and Binary Phase Shift Keying (BPSK) for modulation[4]. The main drawback is ZigBee supports only up to 250 Kbps raw data speed.

C. Wi-Fi

Wi-Fi is designed according to the IEEE 802.11 Standards with various data speeds, which are supported by the protocol version standards[6,15].
The 802.11 standard operates in two modes:

- AdHoc mode
- Infrastructure Mode

In Adhoc mode the access point communicate with the other device directly such as an access point which may be a handheld device, PDA, or a server. In this there is no connection to a WLAN or a server or any network which enables the user to work independently through a Wi-Fi device or a Wi-Fi hotspot[7]. The key advantage of adhoc network is it does not require any pre existing infrastructure and also it is decentralized. The information is exchanged in a peer to peer manner and the intermediate nodes which are similar to access points pass on the information to other nodes. In infrastructure mode there is a need for the existing infrastructure such as Station (STA), Access Point (AP), Basic Set Service (BSS), and Distributed System (DS) which are connected in a wireless star. Initially when two access points need to communicate with each other, there will be two sets of BSS. In each BSS there are several stations and an access point. The station connects to the access point, access points are further connected to a distributed system. In this the station transfers the data to the access point and then it transmits to the distributed system from there to access point and to station of the other BSS[8].

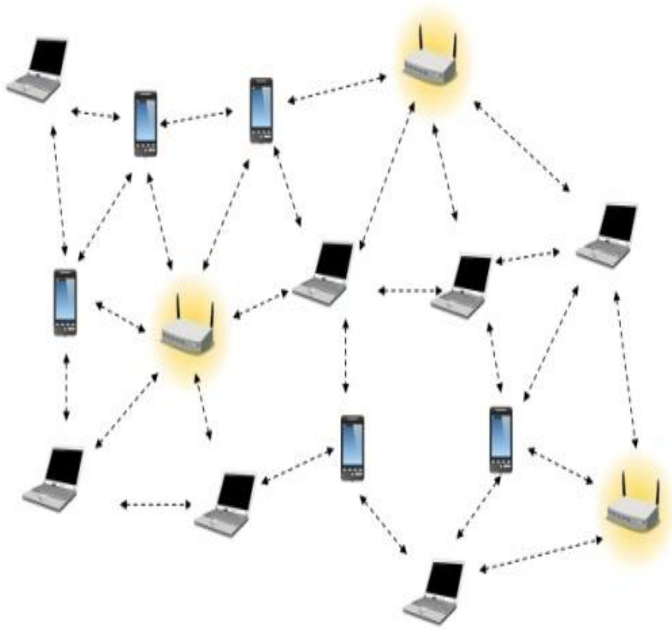

Figure1. Example of Adhoc Network.

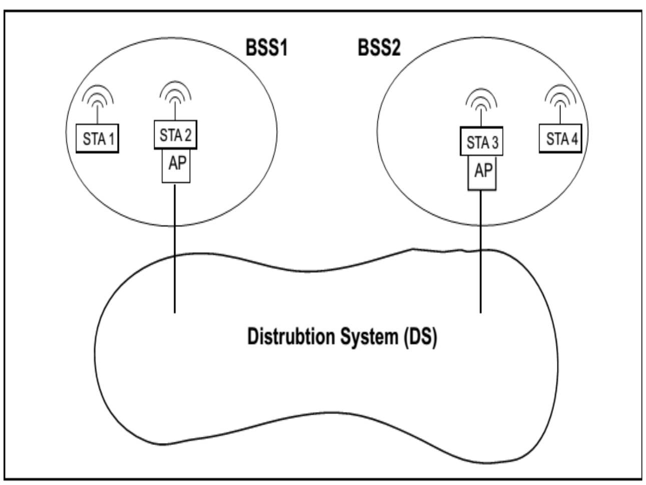

Figure2: Example of Infrastructure Mode

II. MAC LAYER

MAC is an acronym for Medium Access Control layer is a part of the Data Link layer in the OSI reference model. The Data Link Layer consists of Logical Link Layer and MAC layer, hence MAC layer is also known as subzero layer of Data link layer[9]. There are two different mechanisms specified in the MAC layer:

- Distribution Coordination Function (DCF)
- Point Coordination Function (PCF)

In real-time applications DCF is a contention scheme, whereas PCF is a contention free or a polling scheme. The MAC layer and physical layer standards are defined by IEEE 802.11 protocols and standards. In real-time DCF is more prominent and widely used because of its contention scheme. The MAC layer is the intermediate layer of Data Link Layer and Physical Layer[10]. As there is a large demand for real-time applications major concern of the MAC layer is to offer the best QoS, an important parameter of any communication protocol along with the fair access control for the shared medium, provide reliable data exchange and efficient data transmission.

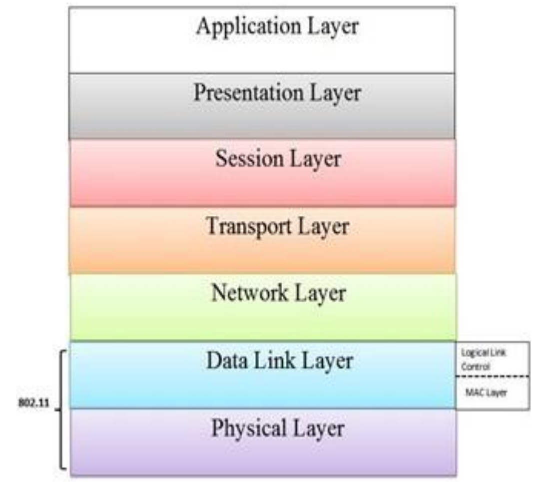

Figure3: OSI Reference Model.

DCF is the basic access mechanism for the contention based services in IEEE 802.11 MAC layer. It uses Carrier Sense Multiple Access (CSMA) with Collision Avoidance, CSMA-CA protocol as the contended services must be provided to the stations and access points. During the high load condition in the contended services the delay is more; hence it can be accessed for asynchronous data transmission [10,11,12].

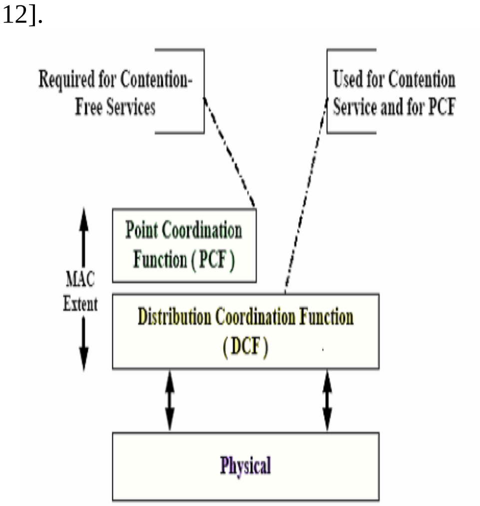

Figure4: Architecture of MAC Frame Format

The MAC layer goal is to provide the Reliable data transfer packets using the Data frames Control Frames, Management Frames to the Physical Layer. The MAC Layer functions are as follows:

- Generation of MAC Frames.
- 32-Bit CRC for Payload Data.
- FIFO Buffer for Receiver.

- Bit to Byte Parallelization of data.

MAC architecture performs functions like:

- Assembling the data into frames while transmission
- Dissemble frame, detect error and address recognition during reception of data.

III. DESIGN OF MAC LAYER

The MAC frame format in the figure-5 is the IEEE 802.11 Protocol and standard, it is designed along with the MAC transmitter and receiver on the hardware. The design supports all the versions of IEEE 802.11 such as 802.11a/b/g/n/ac, each has its own significance as in the table-1.

Table-1: IEEE 802.11 Specifications[11]

Standard	Frequency Band	Bandwidth	Maximum Data Rate
802.11	2.4 GHz	20 MHz	2 Mbits/s
802.11b	2.4 GHz	20 MHz	11Mbits/s
802.11a	5 GHz	20 MHz	54Mbits/s
802.11g	2.4 GHz	20 MHz	542Mbits/s
802.11n	2.4 GHz , 5 GHz	20 MHz, 40 MHz	600Mbits/s
802.11ac	5 GHz	40 MHz, 80 MHz, 160 MHz	6.93Gbits/s

In this all the fields are contained in the packets except for some fields like payload. The payload data cannot be taken at the fullest because of the resource constraints.
There are 4 address fields each of 6bytes for

1. Source address
2. Destination address
3. Receiver node address
4. Transmitter node address

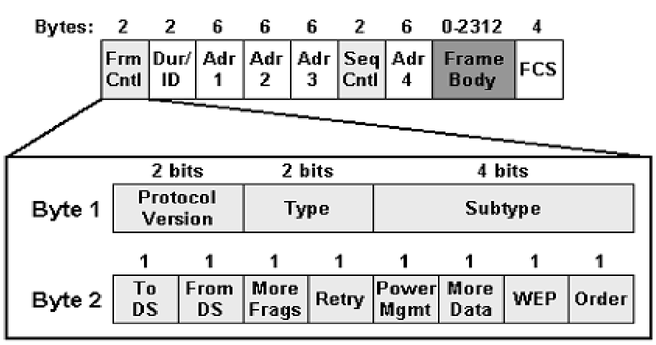

Figure5: MAC Frame format

The Frame control has 2bytes or 16 bits[12] in which

- Bit 15-14: Protocol version
- Bit 13-12: Type
- Bit 11-8: Subtype
- Bit 7: To DS, 1=the distribution system
- Bit 6: From DS, 1= exit distribution system
- Bit 5: More Frag, 1=more fragment frames to follow, 0=Last frame
- Bit 4: Retry, 1= retransmit the data
- Bit 3: Power Management. 1 = station in power save mode, 0 = active mode
- Bit 2: More Data. 1 = additional frames for destination address
- Bit 1: WEP, 1 = data processed with WEP algorithm. 0 = no WEP
- Bit 0: Order 1 = frames must be ordered

The Duration ID is of 2 bytes or 16bits (15–0) for data frames = duration of frame. For Control Frames the associated identity of the transmitting station. FCS is of 4Bytes or 32bits (31 – 0) Frame Check Sequence which is a 32 bit CRC[15].

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Frame Control	Duration ID	Address1 (source)	Address2 (destination)	Address3 (rx node)	Sequence Control	Address4 (tx node)	Data	FCS
2	2	6	6	6	2	6	0 - 2,312	4

Figure6: MAC Frame Control

In the MAC layer transmitter design the input data is chosen randomly and the data is sent for coding serially. In coding the data is encoded and kept secured for the further processing. Then the Serial to parallel converts the data from bit to byte manner and one of the functions of the MAC layer is done. As soon as the data is parallelized it is sent to the signal processing Filters. The signal processing is done by the IFFT using the radix 8 architecture. Here the data is up converted to the RF Frequencies as the low frequency signal requires a setup or infrastructure to transmit. Hence the up converter converts the signal to RF frequencies and is passed to RF front-end, RF front-end to the channel.

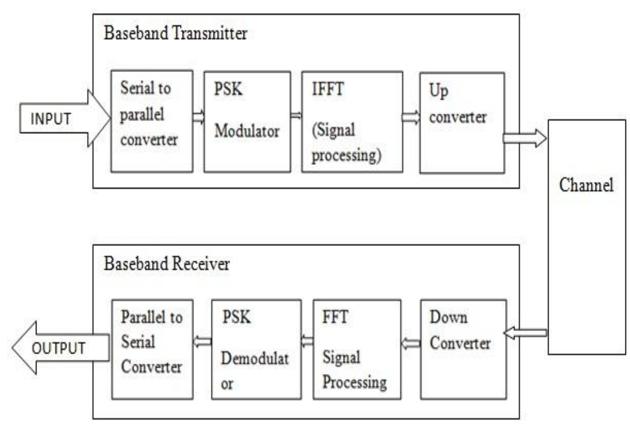

Figure7: Wi-Fi MAC hardware Architecture

From channel it is then passed through the RF and then down converted to the original frequency. The signals are then processed for the signal processing using FFT. The data is then converted to serial data using a parallel to serial converter. This data is then decoded and the given data is transmitted. In this the frames are generated randomly so that the generalized frame format can get all the data, control and management frames and also supports for the reliable transmission. The frames are iterated up to 32 times so that all the frames are transmitted according to the payload.

IV. SIMULATION

The Hardware is implemented using Verilog hardware description language[16,17,18] using Xilinx 13.2 system edition and the design is then verified on the xilinx Spartan-6 xc6slx45 development board. Figure-8 is the top module of the design that is implemented on the development board. 'In' represents the input data that is randomly chosen and the Load1 and Load2 are random data that are to be iterated using Iter(4:0).

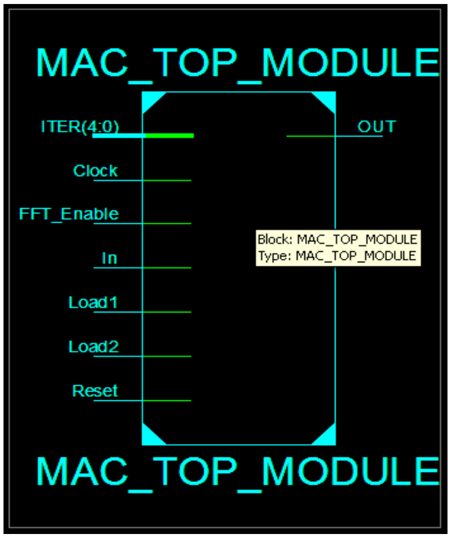

Figure8: Top module of MAC Layer.

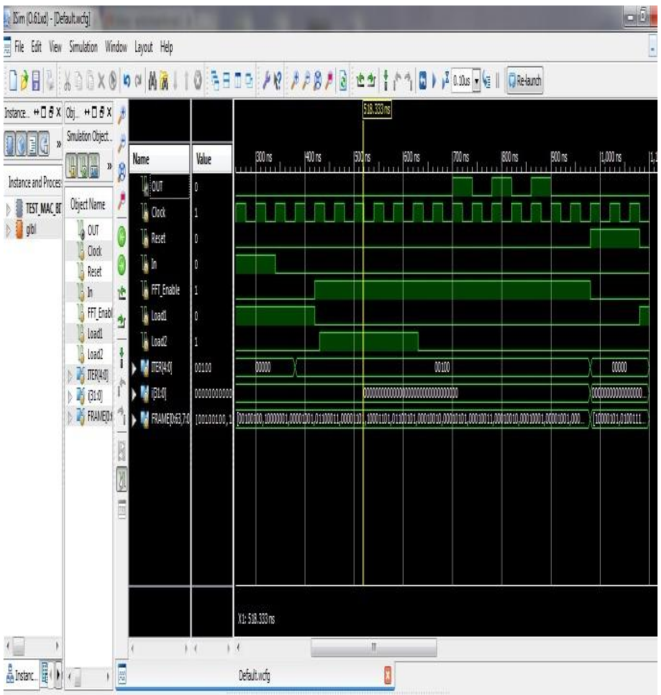

Figure9: Top module.

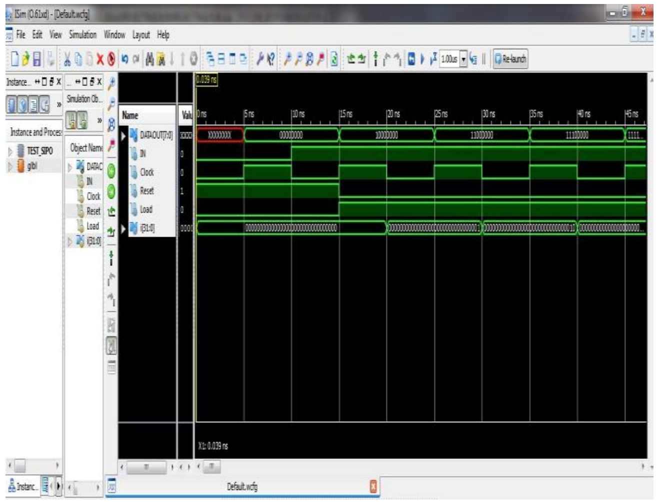

Figure10: Serial to Parallel conversion.

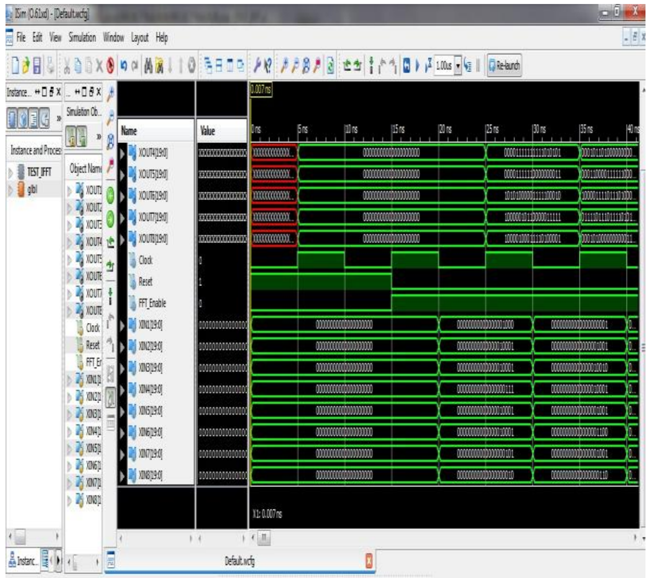

Figure11: IFFT

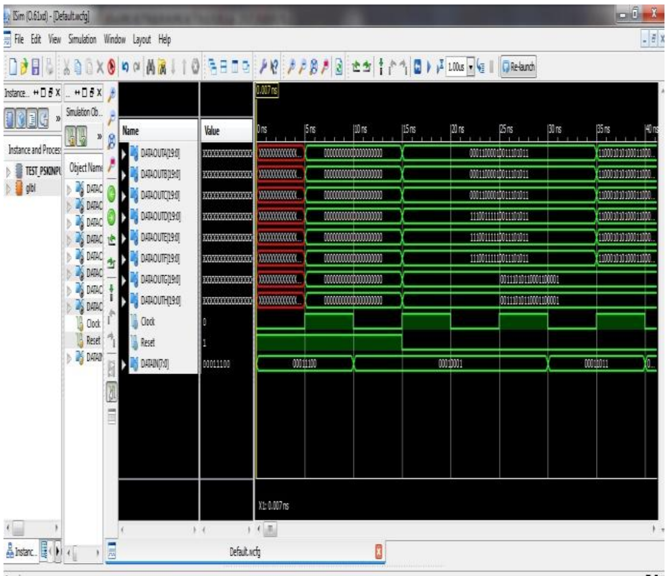

Figure12: PSK Modulator.

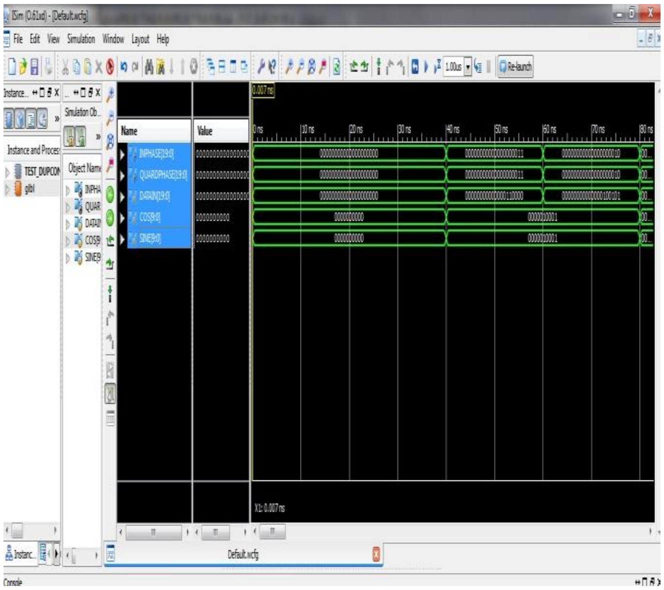

Figure13: Up converter.

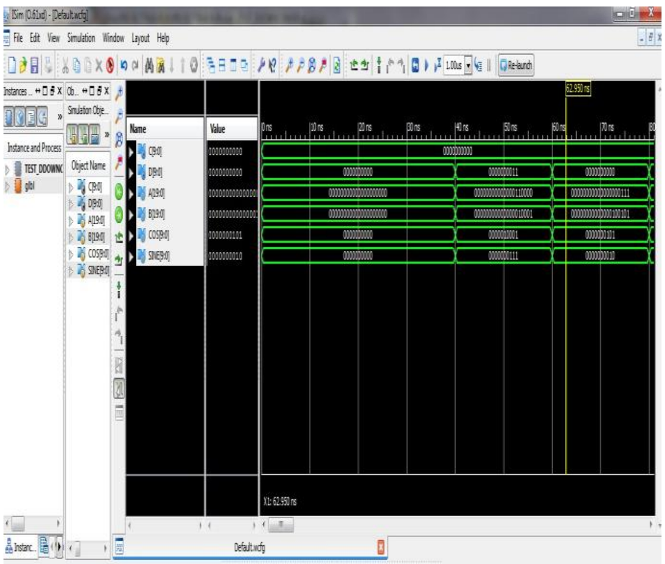

Figure14: Down convertor.

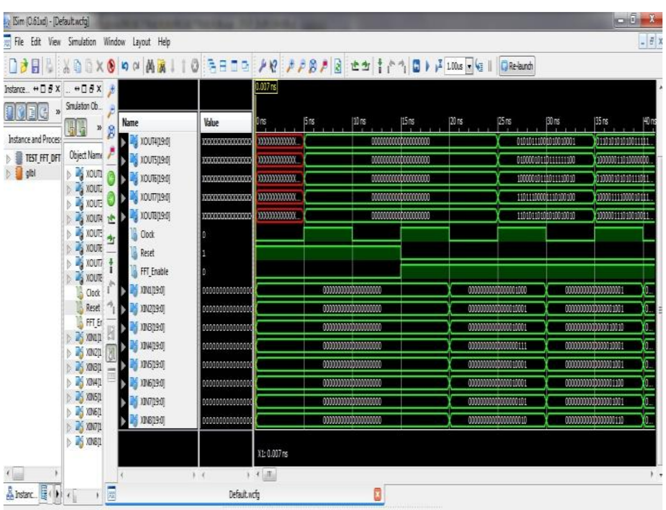

Figure15: FFT.

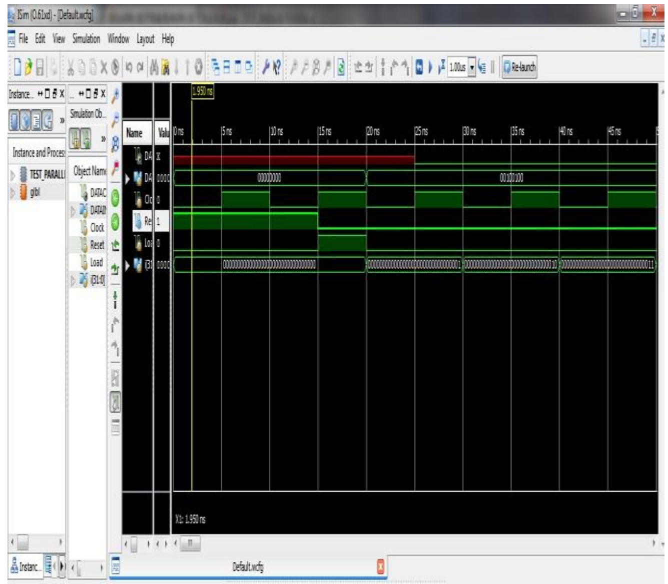

Figure16: Parallel to Serial.

V. CONCLUSION

The modules of the Wi-Fi MAC layer architecture are implemented on the Xilinx FPGA which supports all the protocol versions of the IEEE802.11 standards. This is designed for a single user, can also be used for multi user, if polling and CSMA-CA are implemented along with this design, for which the high end hardware is required. This paper describes about the architecture of the Wi-Fi MAC layer transmitter and receiver with all its modules.

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