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Implementation of Wireless Channel Receiver based on Universal Software Radio Platform

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Abstract

This paper addresses the design and implementation of the wireless channel receiver (WCR), which uses direct-sequence spread spectrum (DSSS) and code complementary keying (CCK) demodulation methods based on the universal software radio peripheral (USRP). National Instruments (NI) USRP 2921 and LabVIEW are used as the system setup hardware and software components, respectively. This cost efficient WCR test bed consist of a dual band vertical antenna, USRP 2921, and a computer. LabVIEW program has considered to design the DSSS/CCK receiver functionality. Wi-Fi channels are limited resources and effected by many factors. Circumstantial measurements are required to determine more information about these Wi-Fi channels. Though, measurements of the WCR are critical. The spectrum of 2427 and 2447 MHz band with the proposed WCR is measured. The experimental results demonstrate that the proposed WCR is capable of detecting the IEEE 802.11b Wi-Fi signals within these bands, and spectrum in this band is observed.

Key words: DSSS, CCK, IEEE 802.11b, USRP, LabVIEW, receiver

1. Introduction

The demand of data has induced a dramatically extension in wireless local area networks (WLANs) capacity and applications in the last two decades [1]. There are various WLAN standards that have different requirements driven by IEEE to provide wireless users with different capacities in terms of data rate and accessibility [2]. In addition this, Wi-Fi wireless networks with IEEE 802.11 standards have increased the popularity in recent years. So Wi-Fi spectrum monitoring techniques has become valuable to management the user traffic or specify the Wi-Fi channel. Thus modifying hardware components cost-effectively has evolved critical. Software defined radio (SDR) implementations provides the flexibility and cost efficiency. Designing the spectrum monitoring with the universal software radio peripheral (USRP) is the most popular SDR tool [3].

The first few widely presented amendments to IEEE 802.11 [1] WLAN specifications, called IEEE 802.11a, IEEE 802.11b, and IEEE 802.11g, featured relatively low spectral efficiencies and data rates. Extended rate protocol (ERP) direct-sequence spread spectrum (DSSS)/code complementary keying (CCK) ERP-DSSS/CCK is used by IEEE 802.11b [12] and this physical layer uses DSSS technology with CCK modulation. This standard provides 1 Mbps and 2 Mbps data rates with DSSS technology and 5.5 Mbps and 11 Mbps data rates with CCK modulation. Many SDR based systems have been developed to monitor for wireless channel characterization [4], [5]. The hierarchical SDR controlled wireless sensor network platform proposed in [6]. In this platform, wireless sensors communicate with a USRP 2. The USRP2s is the cluster head to provide data

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gathering using the least interfered channels due to their capability in channel sensing and waveform selection. In [7], the technique of a bidirectional transceiver that operates on the USRP platform is implemented compliant with the IEEE 802.11b standard for the 1 Mbps specification on MATLAB. This approach presents a novel implementation methodology at the USRP hardware driver and building up the protocol stack. The WLAN channel sounder has been implemented for IEEE 802.11b in [8]. This WLAN channel sounder uses a novel measurement system to analyze the IEEE 802.11b spectrum and channel measurements.

In this paper, we present the SDR based wireless channel receiver and monitoring tool with National Instruments (NI) 2291 USRP [9] device and LabVIEW [10] for IEEE 802.11b signals. For real-time monitoring physical layer frames, NI USRP is measured 2432-2447 MHz spectrum band. A LabVIEW virtual instrument (VI) for wireless channel receiver is developed to achieve this task. For analyzing captured IEEE 802.11b signals, a LabVIEW GUI is developed to provide user friendly access to the SDR implementation. The remainder of this paper is structured as follows. First, Section 2 provides the mathematical model to design for the IEEE 802.11b channel receiver. Then, Section 3 introduces of the wireless channel receiver setup. The experimental results of the spectrum monitoring are explained in section IV. Lastly, a brief conclusion is presented.

2. Wireless Channel Receiver Design

The IEEE 802.11 b transmission frames consist of long or short preamble encoded by differential BPSK (DBPSK) and data payload of different size [4]. These frames are spread out with a Barker code. After the desired threshold level is determined by a carrier sense mechanism, two types of correlator are used in the DSSS receiver to provide chip-synchronization. The first of them correlates the received signal with the known Barker code. The receiver processes sliding version of received signal to compute the deterministic correlation value of the overlapping part with Barker code [11]. The obtaining signal presents repetitive peaks anytime the barker code align with the received samples. These peaks generally are used to down-sample the received samples to the default symbol rate. The second one performs correlation Barker spread out with DSSS preamble to determine the proper timing synchronization of the received signal. When *r(n)* is the received signal, the cross correlation is written as in [12],

$$d(n) = \left| \sum_{k=0}^{L_b} r(k) b(n-k) \right|^2 \tag{1}$$

where, *b(k)* is Barker code, L_b is the length of this code. This correlation operation is integrated over a fixed period of time. Then locally correlated code is delayed half of a chip period and this process repeats until a synchronization has been declared. When the synchronization is declared, it means that a maximum value of one chip occurs. This value is provided as a timing synchronization of a DSSS frame. Then the carrier and phase synchronization steps, signal detection and timing synchronization is introduced. The received signal under the additive noise *w(t)* with carrier frequency and phase offsets is defined with;

$$r(n) = s(n)e^{(j2\pi\Delta f n+\theta)} + w(n) \tag{2}$$

where Δf is frequency offset and ϑ is the phase offset. The carrier frequency offset is recognizable but shall be ignored because the samples are differentially encoded BPSK. The phase estimation provides the phase error between the received and the expected signals. The Barker matched filter is used to demodulate the data at two mandatory rates. The known Barker code are correlated with the received data. Then, the data bits are computed based on the highest correlation value. The received data is demodulated using a CCK correlator [13]. After the frame header is demodulated, the phase of the last bit of the header is determined and used as a phase reference for the higher rate part of the received packet. When the data samples are decoded, the obtaining bit sequence is de-scrambled. When the beginning of frame is determined, the other information is extracted in the same way. Finally, the cyclic redundancy check (CRC) process is applied to confirm that the obtained data is corrected. If data payload is modulated with the DSSS, the receiver demodulates it the DSSS receiver chain. Otherwise, the wireless channel receiver demodulates the data payload CCK receiver chain.

3. Wireless Channel Receiver Setup

The wireless channel receiver setup includes hardware and software components. The hardware components are an antenna, daughterboard of USRP 2, motherboard USRP2, of a Gigabit Ethernet NIC card and a computer as shown in Figure 1. The software components are the operating system, NI USRP2 hardware driver and NI LabVIEW. The USRP2 board holds and transmits the data samples through Ethernet cable to the PC via LabVIEW USRP2 driver. LabVIEW software is implemented to provide the carrier detection, barker match filter, time synchronization, auto-correlation and frame error statistics with the 802.11b wireless channel receiver requirements.

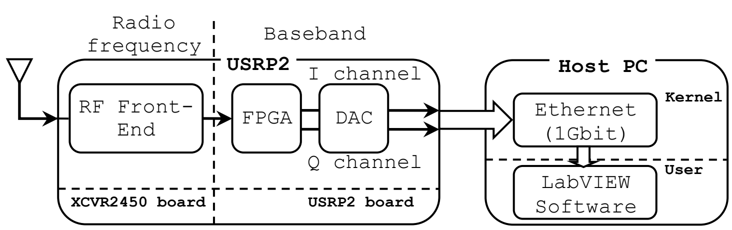


Figure 1. Hardware and software structures of the wireless channel receiver

To change wireless channel receiver system using a LabVIEW, a VI is build the user interface in LabVIEW. This VI determines USRP2 device IP address, active antenna, sampling rate, antenna gain, number of samples, 802.11 channel number and carrier sense detection threshold for manipulating parameters in the wireless channel receiver model and indicators to display details of the spectrum, signal constellation and power indicator diagram. Figure 2 shows the GUI of the main.vi of the proposed receiver on LabVIEW. Its program bocks are implemented according to basic receiver functions. The following is a summary of each blocks duty.

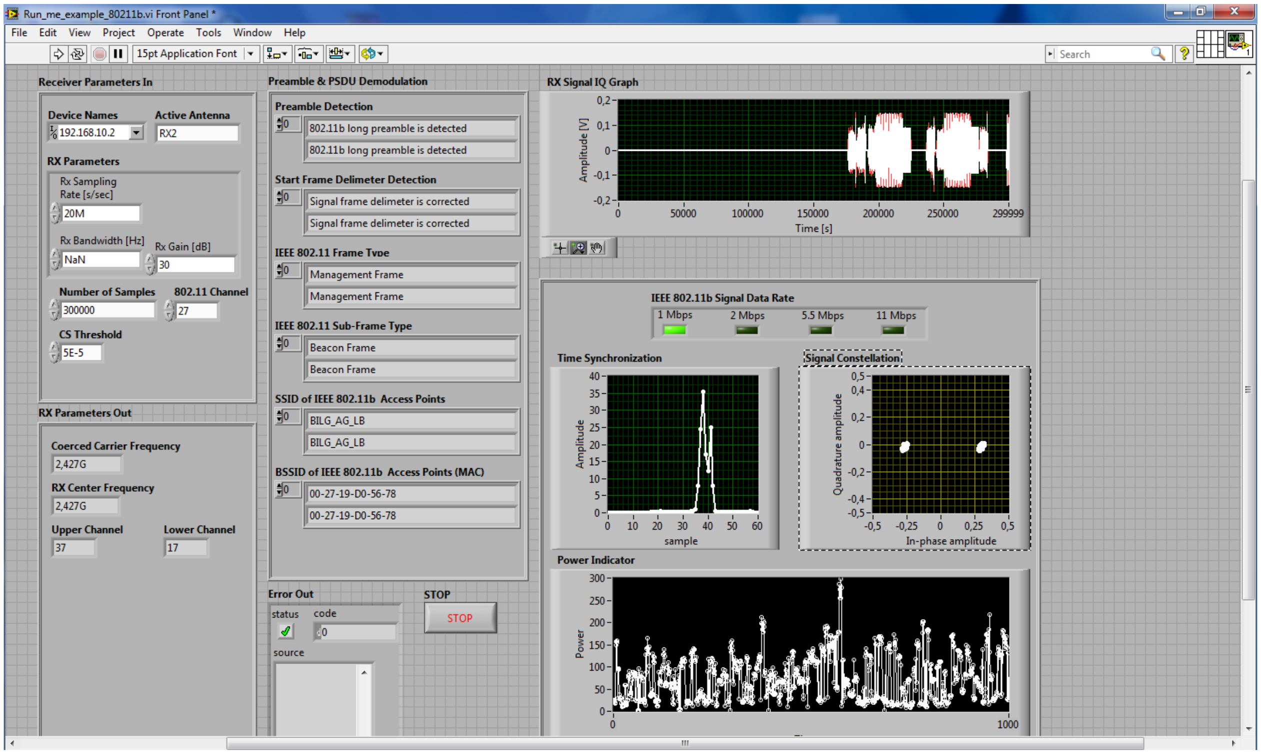


Figure 2. LabVIEW front panel of wireless channel receiver

Carrier Detection Block operates low pass filter based on a data samples from receiver chain. The output of filter is shown as;

$$y_{i+1} = cy_i + (1 - c)p_i \tag{3}$$

where *y* is the low-pass filter output, *p* is the received sample's power, and *c* is a constant number. RX Filter Block receives the output of the carrier detection block as input and confirms signal detection when the threshold is achieved related with the two consecutive samples. Rake Block uses rough timing index determined by RX Filter block to determine correlation between known barker sequences and re-sample received signal. It implements barker matched filter as shown in Figure 3. Burst RX Block implements correlation between Barker spread out and known DSSS preamble and declares the synchronization over the received signal. Figure 4 shows the block diagram of the burst RX signal.

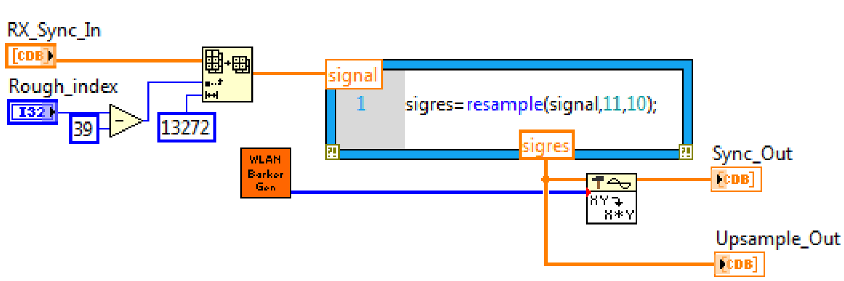


Figure 3. LabVIEW rake function block

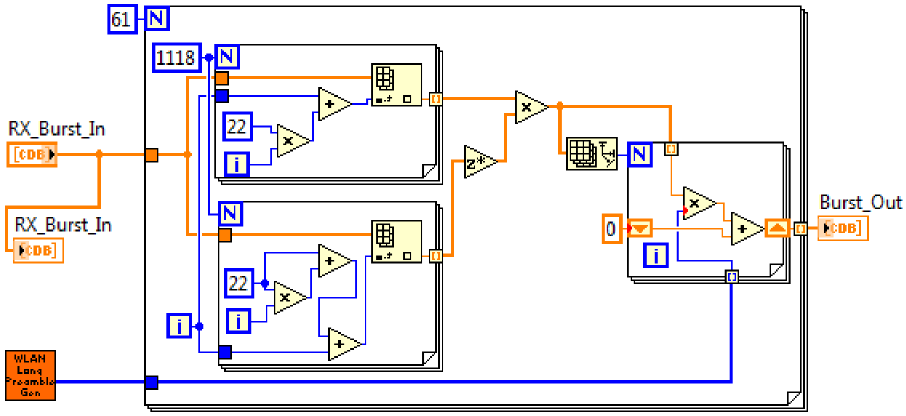


Figure 4. LabVIEW burst RX function block diagram

Phase Offset Block estimates phase offset of received DSSS/CCK signal. To determine the phase offset, the block uses the synchronization samples within desired period and searches peak of the samples. Once the peak is found, angle of this peak's value is used for phase offset. This block also finds the timing index for timing synchronization. Time Synchronization Block uses the timing index to locate the first sample of DSSS preamble and down-sample the signal to the symbol rate of 1 Mbps. Time synchronization of DSSS signal with LabVIEW is depicted in Figure 5. Phase Correction Block corrects the down-sampled signal using phase offset estimation stated as in Eq.(2). BPSK Demodulation Block demodulates the input signal modulated using BPSK. The block only uses 0 and 1 to map constellation points. De-Scrambler Block de-scrambles of the digital signal input. This output is decoded using the generator polynomial $G(x) = z^{-7}+z^{-4}+1$. PLCP Determination Block determines bit sequence of PLCP preamble and PLCP header. In details, PLCP consists of synchronization bits and SFD, PLCP header consists of signal, service, length and CRC information. Each of these fields can be determined in this block. CCITT CRC-16 Block computes CCITT CRC-16 frame check sequence (FCS). In the ERP-DSSS signal, the signal, service, and length fields consist of 32 bits is protected with a CCITT CRC-16 FCS by the polynomial $x^{16}+x^{12}+x^{6}+1$. CCK Rake Block: implements carrier frequency synchronization and rake combination for 1.375 Msps. CCK Demodulation Block: implements CCK demodulation. The CCK demodulation is implemented with a correlator to correlate the 64 CCK complex code word as shown in Figure 6

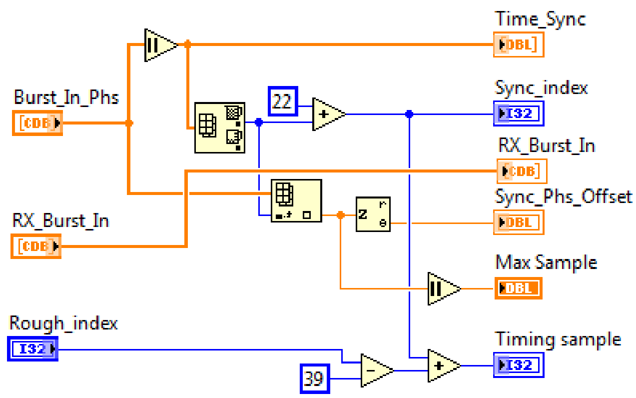


Figure 5. LabVIEW the time synchronization function block diagram

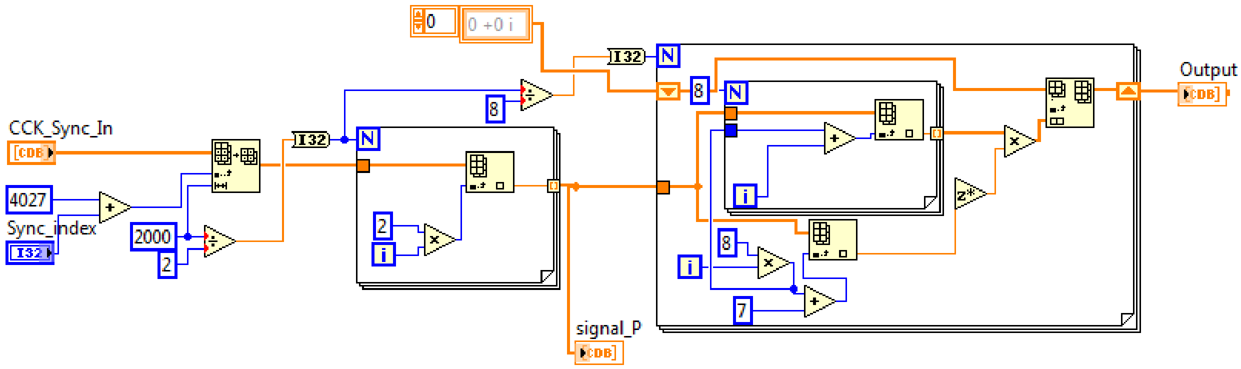


Figure 6. LabVIEW CCK rake function block diagram

After the PLCP bit sequence is determined and CRC computation is done, receiver implements data field demodulation in the PSDU according to signal field in the PLCP header. Signal field has four different data rates 1, 2, 5.5, and 11 Mbps. In this system, the four data rates are assigned to 1, 2, 4, and 8 binary number in the PLCP determination block, respectively. This block says to data rate to PSDU demodulation sub-block in the receiver.

4. Experiment Results

In this paper, IEEE 802.11b transmissions within the frequency range 2417-2457 MHz, with the center frequency of 2427 MHz and 2447 MHz are captured using two different NI USRP 2291. The wireless channel receiver experimental setup inside wireless communication and information system laboratory, which is established in the Umuttepe campus of Kocaeli University, is depicted in Figure 7. The dipole antenna is a 2.4 and 5 GHz dual band vertical antenna. The antennas are plugged to USRP2 by a SMA connection port. The two USRP2 are connected to the ethernet port of host computers through cable. At least three Wi-Fi users are forced to generate data traffic and uncontrolled users may be connected to access point. The spectrum of Wi-Fi channels are processed to LabVIEW GUI to get real-time monitoring, measured and saved.

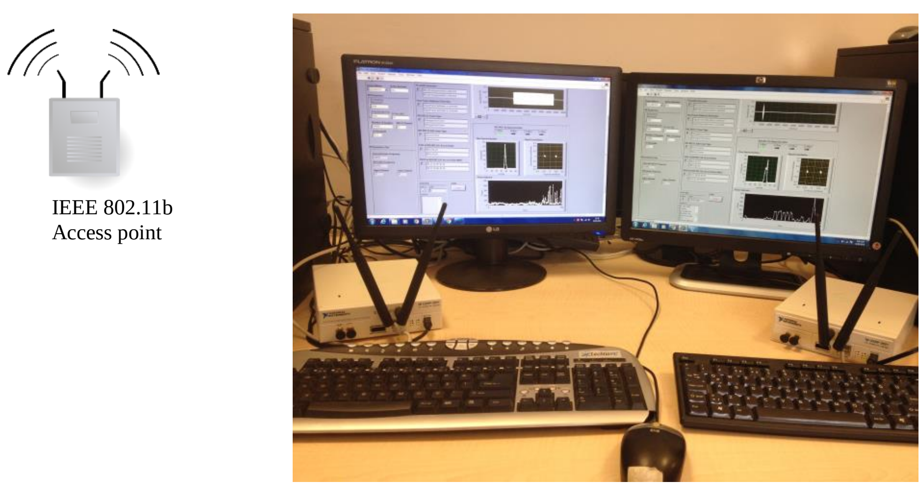


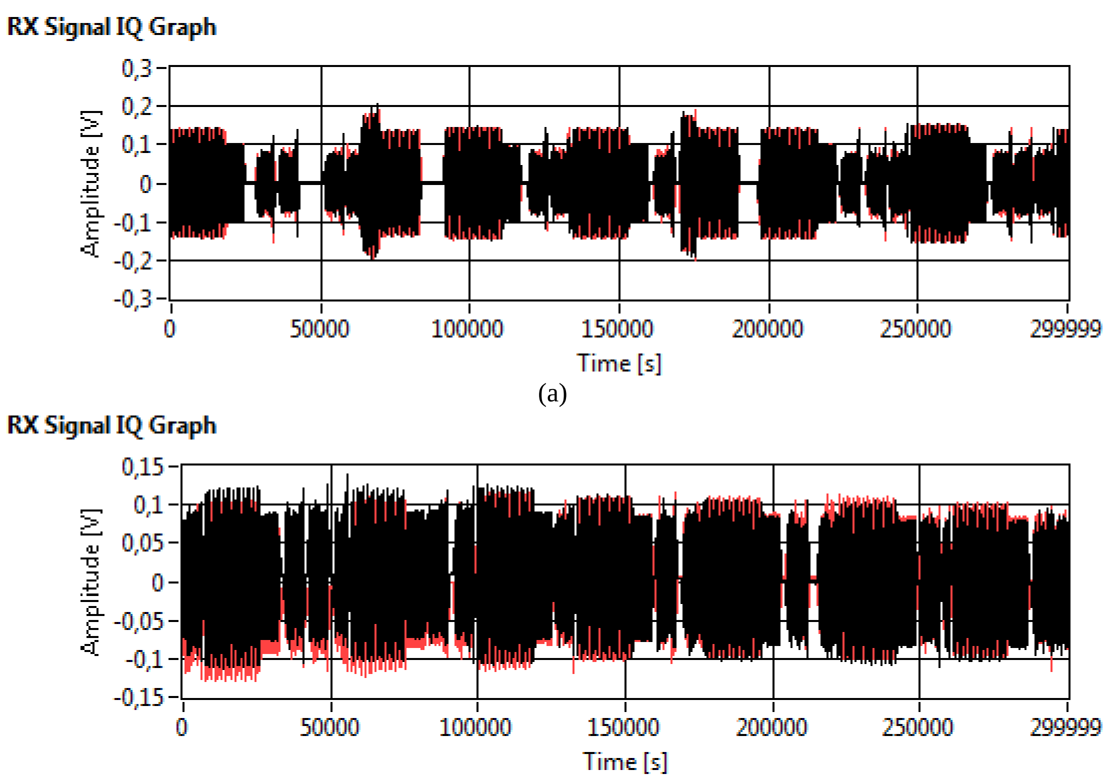
Figure 7. Setup inside WINS Lab. IEEE 802.11b frames are captured using NI USRP and LabVIEW software

The NI USRP device connected to PCs are configured with the IP addresses 192.168.10.2. The USRP devices have the following specifications and parameters as show in Table 1.

Table 1. NI USRP parameters used with wireless channel receiver

Parameters	PC 1	PC 2
Active antennas	RX1	RX2
RX sampling rate	20 M	
RX antenna gain	30 dB	
Number of samples	100000	
Channel of spectrum	4	8
Carrier detection threshold	5e-5	

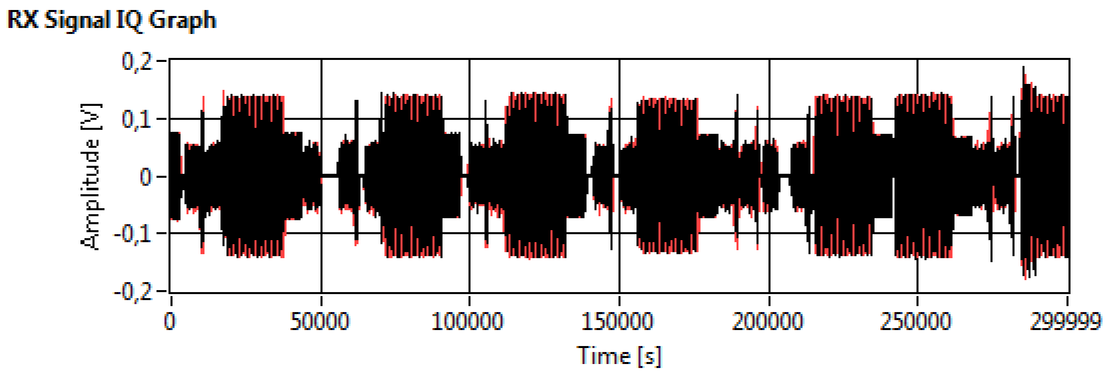
The experiments are run to evaluate the performance in uncontrolled wireless environments for identical scenarios. The 4th and 8th Wi-Fi channels are used to capture IEEE 802.11b frames. Figure 8 depicts the received amplitude peak to peak value versus time samples plot for the 4th channel measurement (20MHz-2427 MHz). It has been determined that six and seven IEEE 802.11b preamble with the 1 Mbps data rate DSSS modulation in Figure 8(a) and 8(b), respectively. In order to show details of the spectrum, 8th channel band is plotted in Figure 9. This channel is showed with IEEE 802.11b preamble and CCK modulated payload determined LabVIEW GUI of the system in Figure 9(b).



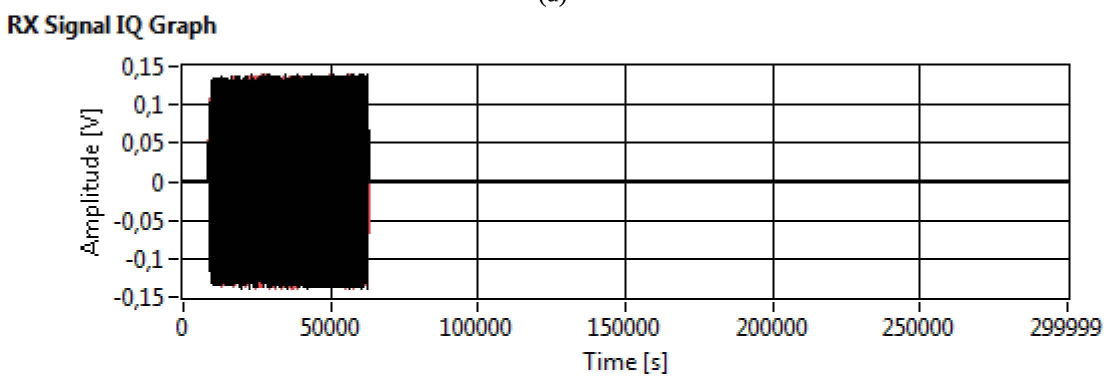
(a)

(b)

Figure 8. (a) (b) Amplitude spectrum of I and Q channels for 20MHz-2427MHz for different samples



(a)



(b)

Figure 9. (a) (b) Amplitude spectrum of I and Q channels for 20MHz-2447MHz for different samples

The variations in the amplitude of the received frames timing synchronization peaks are plotted in Figure 10. These results can be used as the power indicator to determine the received signal strength indicator (RSSI). This indicator shows the 0 and 300 as the minimum and maximum value, respectively. The cause of these variations is considered the environment static. The wireless channel receiver captures the IEEE 802.11 frames using two channel estimation methods. Figure 11(a) shows the totally 1000 received 802.11b frames based on the MAC address of the PC or wireless router in the network. These frames are captured in the 4th and 8th channels in 2.4 GHz. This is because, the wireless access point transmits packets in this channels for this network.

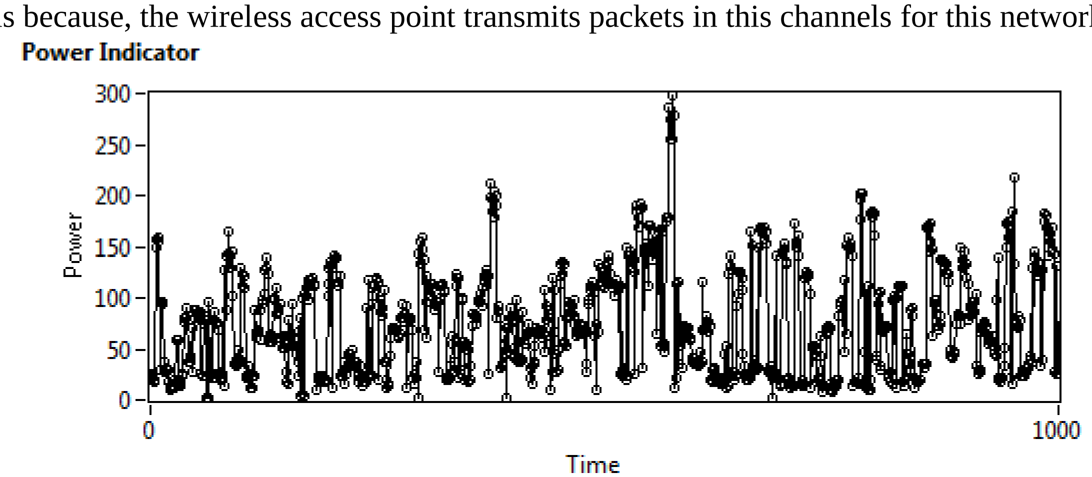
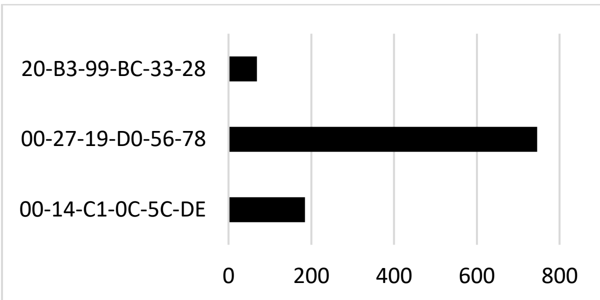
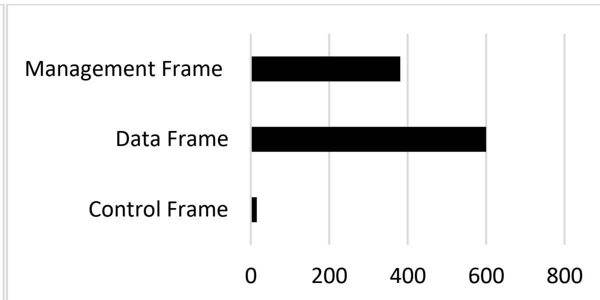


Figure 10. IEEE 802.11b frames second correlator output's peak values

Three wireless devices are found during frame capturing progress as shown in Figure 11(a). These device's MAC addresses are also corrected with the software wireless sniffer setup in a PC. As seen the results, one of these devices constitutes the 74% overall throughput within in this channel. The wireless device whose MAC is 20-28 generated only 69 IEEE 802.11b frames. Figure 11(b) and (c) show number of IEEE 802.11 frame and sub frame types for all captured frames. While the most captured frame type is data frame with the 60%, the most sub frame types QoS data and beacon frames with 60% and 36%, respectively.



(a)



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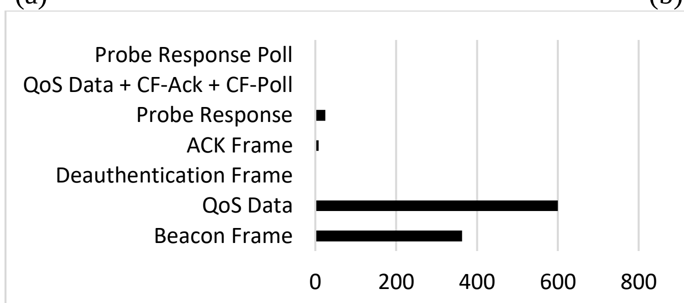

(c)

Figure 11. Experimental test scenario in the laboratory

Conclusions

The wireless channel receiver based on NI USRP compliant with IEEE 802.11b signals has been presented. The receiver blocks implementation on the LabVIEW with the USRP hardware driver. The program blocks are programmed to realize a basic receiver model that provides the IEEE 802.11 frame type and data modulation information. The spectrum of 2417 MHz-2457MHz band has been monitored and captured. The proposed receiver has user friendly GUI to determine receiver parameters and show relative information about captured frames. The receiver ensures the continuous reception of data samples.

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