

Software Defined Radio Design for OFDM Based Spectrum Exchange Information Using Arduino UNO and X-Bee

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Abstract – A cost expenditure of software defined radio software has limiting the development of cognitive radio in third countries. Moreover, a complexity of signal processing library in a SDR platform has contributed to the hard implementation in real applications. In this works, the development of SDR platform with low cost expenditure is proposed. Arduino UNO and X Bee uses for the OFDM based spectrum exchange information. In a case of spectrum sensing scenario, the objective of the local spectrum sensing is to detect the PU's signal detection. The performance of SN ability to sense the PU's signal is crucial. It was shown that from the previous works as the detected power is quantized into information bit is simulated. In order to implemented the spectrum exchange information during sensing, Arduino UNO and X Bee is implemented to sense the presence of PU activity channels of wifi terminals based on the energy of the signals. The detected power (RSSI) of wifi terminals is exchanged into an OFDM subcarrier tone signal such as orthogonal sub-channel that being equally divided from the licensed band. The results shows that using proposed software defined radio (SDR) based on Arduino and X Bee, the cognitive radio spectrum sensing is applied. The received power from the PU's channels such as wifi networks can be detected as well. The system could received and exchanged into OFDM-based subcarrier information bits.

Keywords: *Software Defined Radio, OFDM-Based, Spectrum Sensing, Cognitive Radio, Arduino UNO, X-Bee*

I. INTRODUCTION

One of the main components of cognitive radio (CR) is spectrum sensing, by sensing it adapting to the environment. Spectrum sensing techniques is featuring detection and signal specific aspect detection scheme. Sensing method should decide whether is depending of SNR, minimal sensing time or scanning of spectral bandwidth. While many other characteristics have also been discussed as possible additional capabilities, this more restricted definition and consider physical (PHY) and medium access control (MAC) functions that are linked to spectrum sensing. However, spectrum sensing perform poorly when the communication channel experiences fading and shadowing. Through the CR concepts, software radio is developed to fulfil the gap of complexity hardware and cost effective.

However, most of the researchers are assumes that the spectrum sensing performance is theoretically. In software radio [1], analog to digital converter (ADC) process is directly done after the antenna. ADC will digitize the electromagnetic wave captured by the antenna and pass it to the baseband processor for further process; demodulation, channel coding, source coding and etc. Nowadays, the software radio is widely implemented by using FPGA and any language software processing blocks such as C++, C#, Python, etc.

II. PROPOSED SOFTWARE DESIGN ARCHITECTURE

At this stage, X-Bee sensing nodes will digitize inflow data from the PU transmitter and passing it into software radio through X-Bee shield interface. The Ssoftware radio passed the magnitude square of the received signal strength from the Wifi antenna and translated into a piece of packets or stream data as digitation results format. Figure 1 describes proposed software radio component architecture based on X-Bee and Arduino UNO.

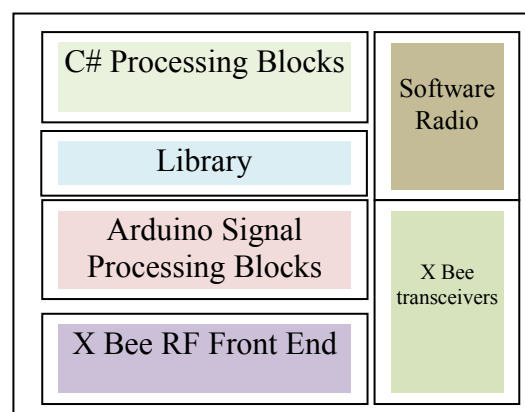


Figure 1: Proposed of SDR - X Bee Node for Cognitive Radio Components

In this work, a software radio platform based on X-Bee and Arduino UNO is developed as shown in Figure 2. The aim's of this platform is to maintain the signal processing block in digital domain which reduced cost of complexity SDR platform. The digitation works is done by arduino UNO device using ADC block module. ADC then sampled and quantized the magnitude square signal and pass it into baseband processing which are written using C#. The magnitude square signal then digitized into FFT bins for further processing.

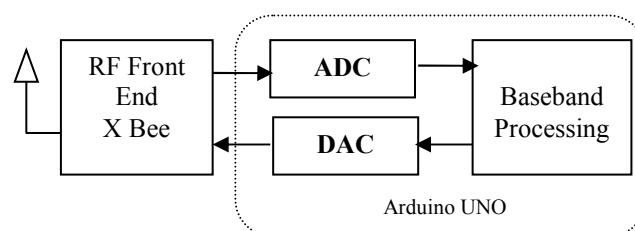


Figure 2: X Bee Arduino Software Radio Diagram

In this proposed SDR architecture, the SDR X-Bee Sensing Nodes (X_{SN}) consist of two main boards, the first X-Bee and the shield, second is Arduino UNO. For 16 MHz Arduino, the clock is set to $16 \text{ MHz}/128 = 125 \text{ kHz}$. By conversion in AVR that takes 13 ADC clocks thus $128 \text{ kHz}/13 = 9615 \text{ Hz}$ is the maximum sampling rate of Arduino UNO. A software radio spectrum sensing is developed using C# (dot Net frameworks) which consist of signal processing blocks library and communicator library in Arduino UNO.

III. THE SPECTRUM SENSING MECHANISM

A calculation radio frequency energy in the channels to determine the magnitude square of the FFT output. The received signal $x(t)$ is sampled in a time window then passes through an FFT device to get the spectrum band of $x(f)$. In this mechanism, the energy signal of power spectral density is assumed as received signal strength indication (RSSI).

Sensing information exchange mechanism has been explored in several studies. The previous work done by [2, 3] proposed a cooperative spectrum sensing scheme using a single orthogonal subcarrier that could combat bandwidth limitation on reporting channel by quantizing the detected power level into an OFDM tone signal structure to transmit the sensing node (SN) data to the MN. This stage is called local spectrum sensing process by SN. Channel access, calculation complexity, delay and synchronization problems rise during the contention period in the reporting channel.

In [4] proposed the cooperative networking without common control channel, this method aimed to reduce the complexity function using M orthogonal sub-channel that being equally divided from the licensed band. However, the dwelling time between the pair is increased the delay and idle time makes sensing process inefficient.

Moreover, the studies assumed that the spectrum exchange information during sensing process is fully simulation stages. The experimentation in spectrum information exchange is an interesting topic for further investigation. Most of the CR research does not consider the implementation of the spectrum exchange information in real environment. However, the spectrum exchange information implementation of the primary user (PUs) and SNs heavily influence the documentation of the local observation database performance in real-time application.

IV. OFDM BASED SPECTRUM EXCHANGE INFORMATION USING ARDUINO AND X-BEE

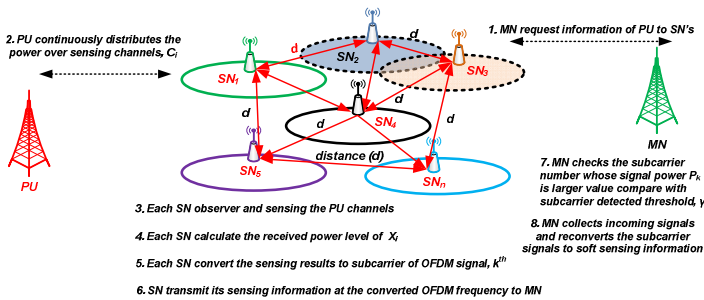


Figure 3: OFDM based Cooperative Spectrum Sensing Information Exchange Method for Conventional CRN

Figure 3 describing the network topology. First, the master node (MN) from secondary wireless networks (*secWN*) requests the sensing information to the surrounding X-Bee sensing nodes (X_{SN}). This request contains the subcarrier number of a frequency spectrum called C_i to be observed by sensing nodes. The MN sends this information request through the common control channel (CCC). Each X_{SN} then received the information and observed the power level

in C_i . Assume, one of the users in primary wireless network, called PU, uses subcarrier C_i for its transmission. The power level of P_{PU} for this transmission is observable by one or more X_{SN} in *secWN*. X_{SN} then sense and calculate the suggested a new subcarrier for MN, symbolized as k [2].

The X Bee SN will observe the energy power of the P_{PU} only in physical (PHY) layer through the sensing channels. For i^{th} number of X_{SN} , the observation of spectrum sensing is decided using the following hypothesis, given as

$$Z_i(t) = \begin{cases} w_i(n) & H_0 \\ A_i \cdot s_i(n) + w_i(n) & H_1 \end{cases} \quad (1)$$

Where $Z_i(t)$ is the received signal at the i^{th} X_{SN} and $s_i(n)$ is the received transmission signal of the PU, $w_i(n)$ is the Gaussian noise and $A_i(n)$ is the channel gain of the sensing channel between the PU and the i^{th} X_{SN} 's.

Then, the energy detector, maps the received signal to the transmitter by time-averaging the power of the received signals [5]. The statistical hypotheses for the individual X_{SN} node utilizing the energy detector is given by [6]

$$z(y)|H_0: x = \frac{1}{IN} \sum_{n=0}^{N_i-1} |w_i[n]|^2 \quad (2)$$

$$z(y)|H_1: x = \frac{1}{IN} \sum_{n=0}^{N_i-1} |A_i s_i[n] + w_i[n]|^2 \quad (3)$$

Where i is the X_{SN} index: I , the total number of X_{SN} s, x_i is the statistical testing of i^{th} X-Bee sensing nodes, and x is the statistical test of the cooperative sensing at MN. $w_i[n]$ is defined as Gaussian white noise of the n^{th} samples with mean $\mu=0$ and variance $\sigma_w^2 = 1$; $A_i[n]$ is the received signal amplitude when the X_{SN} 's transmits a signal $s_i[n]$ with channel gain A_i ; with $E[s[n]]=0$ and $E[|A_i s[n]|^2] = \sigma_s^2$ representing signals power; and N , the total number of sampling signals.

At this stage, a number of subcarriers that able to sense and detect the presence of licensed user are assigned. An X_{SN} computes the energy levels by using energy detector. It is then compared to a pre-determined threshold value. Each received signals are sampled in time window using FFT mechanism to measure the power spectral density. The magnitude of the measured power is defined as the detected received signal parameter based on timing average [1]. The magnitude of the power received by the X_{SN} is then converted into the subcarrier number of OFDM signals, known as spectrum information exchange.

Assume that the requested information of C_i is received by the X_{SN} . There is a single user of primary wireless network of PU observable and transmitting at subcarrier C_i in the same channel. The power level of PU transmission in C_i is denoted by P_{PU} , where:

$$P_{PU}(dB) = 10 \log_{10} P_{Signal} \quad (4)$$

P_{PU} signal is the maximum allowable signal power of PU in decibel (dB) for this frequency spectrum. It is corresponding from the use of primary user power level by [7].

The power level of P_{PU} is observable by X_{SN} . In a single X_{SN} , the received P_{PU} suffered from the noise and path loss [8-12]. The distance of primary transmitter (PU) to X Bee sensing nodes is considering path loss factor. Moreover, the distance from the primary transmitter to the individual

sensing can be obtained by [13]

$$L_{pu} = 20 \log_{10} \left\{ \frac{\lambda}{4\pi d_0} \right\} - 10n \log_{10} \left\{ \frac{d_0}{d_{pu}} \right\} \quad (5)$$

The detected primary signal power then exchanged into subcarrier number of OFDM know as quantisation power process. The conventional quantisation mapping of the spectrum exchange information at i^{th} SN given by [14]

$$k(i) = \left\lfloor P_{R(SN)}(i) * \frac{N_c}{\alpha} \right\rfloor \quad (6)$$

The received power $P_{R(SN)}(i)$ in the i^{th} X_{SN} is converted into k subcarriers number of OFDM signal separated by a width of α . Where k_i denotes the subcarrier index, $P_{R(SN)}(i)$ denotes the quantisation of the received power at each SN normalized by the noise level as shown in Figure 4. The N_c denoted the number of OFDM signal subcarriers and α denotes the parameter controlling the subcarrier's width. Where $P_{R(SN)}(i)$ is the received detection power at i^{th} conventional X-Bee SN's.

$$\begin{aligned} &P_{R(XSN)}(i) \\ &= P_{PU}(dBm) - 20\log_{10} \left\{ \frac{(4\pi^2 * ((d_0(i) - d_{PU}(i)) * 2))}{\lambda} \right\} \\ &+ \sum_{i=1}^I \left(P_T(SN_i)(i) \right. \\ &\left. - 20\log_{10} \left\{ \frac{(4\pi^2 * ((d_0(i) - d_{SN}(i)) * 2))}{\lambda} \right\} \right) + N_i(0, \sigma)(i) \end{aligned} \quad (7)$$

And k is assumed is the function of power quantisation at the frequency carrier. Where $P_{R(XSN)}(i)$ is the received power; λ is the wavelength, $d_{SN}(i)$ is the radius distance between PU and SDR X-Bee SN's module; $P_{PU} dBm$ is the power transmit of primary transmitter; $N(t)(i)$ is the additive white noise with noise and variance. The $P_{R(XSN)}$ path loss is derived from the free-space path loss as stated in [15, 16]. As stated by [17], the use of free-space path loss model is sufficient to measure the interference based on distance.

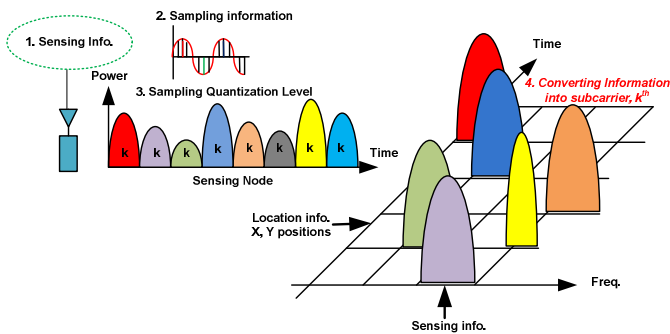


Figure 4: Spectrum Information Exchange Mechanism within Local X_{SN} nodes.

V. EXPERIMENTAL SETUP

A comprehensive comparative analysis study could be represent the simulation and implementation in the real environment is needed. This work describe the spectrum information exchange technique development for cognitive radio networks using Arduino UNO and X Bee.

Figure 5 shows the experimental setup for the experimental study of SDR for implementation of spectrum exchange information utilizing Arduino and X-Bee SN's. The experiments have been conducted by measured the energy signal in terms of RSSI and

reported in this paper. Three existing wifi stations act as PU has been installed within the building which is distributed into three levels of floor building. The types of wifi stations uses type 802.11 b/g which provide higher bandwidth and consist of 13 channels.

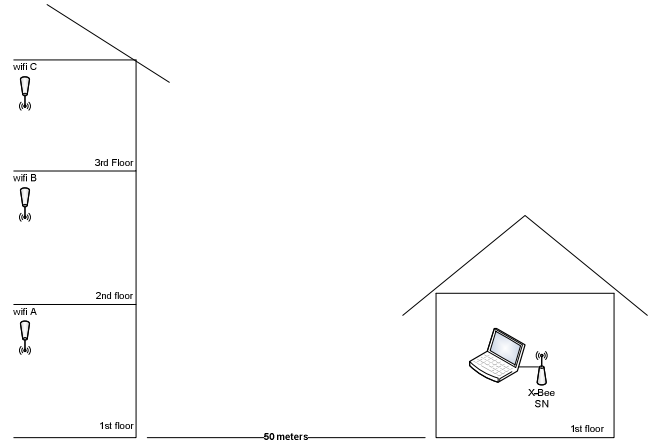


Figure 5: SDR Spectrum sensing topology for OFDM spectrum exchange information using Arduino and X-Bee

The module attached with Arduino UNO, X-Bee RN-XV which cover 2,4 GHz and X-Bee Shield. In this experiment the obstacle factors such as roof, tile and concrete block are ignored. The height of building is around 20 meters and the distance of SDR X-Bee SN's module and wifi stations around 50 meters. The height and distance are calculated by using free space path-loss formula which is compiled in the signal library blocks on the Arduino UNO. In other building, one Laptop and SDR X-Bee SN's module installed to scan and detect the presence of wifi channel stations.

The sensing result is aimed to detect the RSSI level ($P_{R(XSN)}$) as radiated energy power of wifi stations. The RSSI value is done in the intermediate frequency (IF) before baseband amplifier in zero-IF systems. The output of the RSSI is a DC analog level which could be sampled by an internal ADC in the Arduino UNO. By the internal processor bus the available resulting codes of samples is provided. At this works, limitation of the scope is involved the PU activity channel which represents by wifi stations and sensing node activity which represent by X Bee SN's Arduino boards.

The detection of energy signal each channels on the wifi stations are measured and sensed by SDR X-Bee SN's module. The results are presenting two distinct values such as RSSI value and subcarrier OFDM value or k . Moreover, the RSSI value is converted or exchanged into subcarrier number of OFDM tone signal by using 512 FFT bins by library of signal processing block that compiled into Arduino UNO blocks. The RSSI value each channels and subcarrier number then presented into GUI module as shown in Figure 6. It's nature, and could shown the channel for each wifi station that can be detected. Therefore, multiple channel from multiple wifi station could be and detected presented in the software radio analysis based on the received signal strength (RSSI). This mechanism also presented how each wifi stations are uses their channel to broadcast the bandwidth. Therefore, interference could be detected if one or two wifi stations are uses the same channel number within neighbouring areas.

Figure 7 describes GUI software radio module which is designed for OFDM based spectrum exchange information.

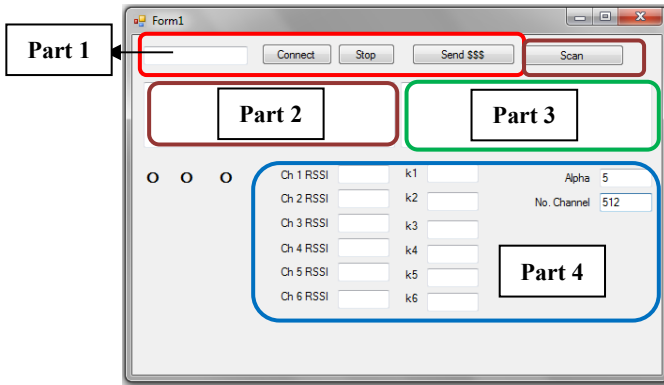


Figure 6: The GUI SDR X-Bee SN’s module design for OFDM based spectrum exchange information

The GUI comprises of four parts, the first part is represented the connection setup among SDR X-Bee SN’s module and personal computer (PC) or Laptop. The process is determine which port that used in the communication setup. The second part is sensing process, at this stage, the sensing mechanism is done by SDR X-Bee SN’s module and the results are shows in part three. While sensing, the RSSI and exchange information into subcarrier number is displayed in part four. Within this step, the subcarrier width parameter (*alpha*) and number of channels are setup manually.

VI. RESULTS AND DISCUSSION

Figure 7 and Figure 8 describes the sensing detection results using SDR X-Bee SN’s module. As shown in the GUI display, COM4 is used after connection setup is ready. Thus, the sensing mechanism is running and detected four wifi stations which is displayed their own MAC address and channel that are uses. *Teknik Industri* wifi, *BAP_FTI* wifi, *AulaFTII* wifi and *LAB TE* wifi are detected by the SDR X-Bee SN’s Module. Moreover, the channels that are uses are displayed well which presence the RSSI values (in dBm). Thus, the subcarrier exchange information of the RSSI value is displayed by *k* subcarrier symbols. Alpha and number of channels are set manually which given by 5 and 11 channels.

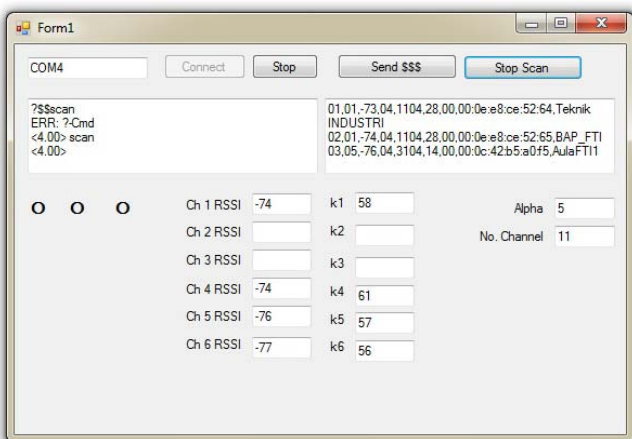


Figure 7: The GUI dispalyed of OFDM-based Spectrum Exchange Information utilizing Arduino UNO and X-Bee for CRN with alpha is 5 and number of channel is 11.

There are two RSSI values has the same value on channel 1 at the wifi *Teknik Industri* and wifi *BAP_FTI* on channel 4. The condition due to nearest placed of wifi position perhaps uses the same channel. However, the subcarrier exchange is different which are point to *k* = 58 for *Teknik Industri* wifi and *k* = 61 for *BAP_FTI*

wifi. In other hand, the distance is influenced the RSSI value exchange information into subcarrier number of OFDM tone signal. The nearest position to SDR X-Bee module is less more than the farthest away.

Figure 8 shows of channel 5 that detected from *LAB TE* wifi and channel 6 is detected from *AULAFTII* wifi. However, the results of spectrum exchange information is almost the same. This condition due to the distance of both wifi station is almost the same to the SDR X-Bee SN’s module.

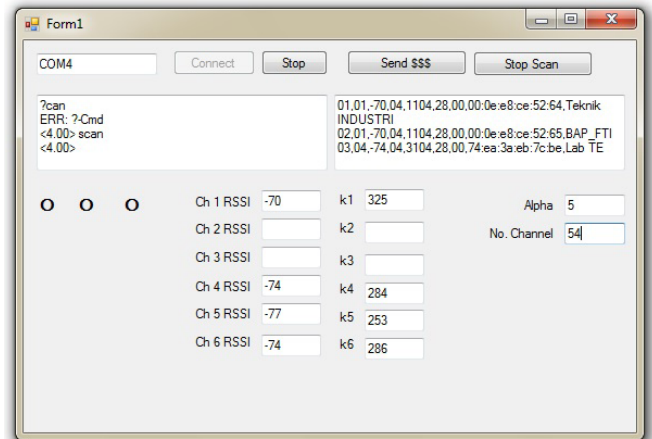


Figure 8: The GUI dispalyed of OFDM-based Spectrum Exchange Information utilizing Arduino UNO and X-Bee for CRN with alpha is 5 and number of channel is 54.

The measurement shows that the designed of SDR based on Arduino UNO and X-Bee is performed well. The RSSI value and exchange information are displayed and given the true values.

VII. CONCLUSION

The designed of SDR X-Bee sensing node for spectrum sensing and information exchange has been presented. The performance of hardware and software module is performed well. The SDR X-Bee Module could detected the presence of wifi channels and energy signal as well. The GUI design is able to conduct the results of SDR X-Bee module perfectly. For the future development, multiple SDR X-Bee node and mobility of nodes are needed to further developing in order to investigated the performance in mobility environment.

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