Building Cognitive Radios in MATLAB Simulink – A Step Towards Future Wireless Technology

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***Abstract – Cognitive Radio (CR)* is a future radio technology that is aware of its environment, internal state and can change its operating behavior (transmitter parameters) accordingly. It is intended to coexist with primary users (PUs) for using the underutilized spectrum without any harmful interference. Its key domains are sensing, cognition and adaptation.**

This paper presents a detailed survey of coexistence techniques used in IEEE 802 wireless network standards family to reduce the interference between different types of networks. It also presents a prototype system for designing and testing cognitive radios built on top of software defined radio in a MATLAB/- Simulink and interfaced with a universal software radio peripheral-2 (USRP2) main-board and RFX2400 daughter board from Ettus Research LLC. The philosophy behind the prototype is to sense, predict and adjust the operating parameters to achieve the desired objectives. The PUs detection (sensing) is performed using the statistical (non-parametric) spectrum estimation techniques, which are more useful in a noisy environment. Regression-based statistical time-series modeling & analysis are carried for PU's channel behavior prediction for spectrum decisions. Software-defined radio is used for reconfigurability to adjust the operating parameters of the cognitive radios.

Keywords – cognitive radio; software defined radio; coexistence; spectrum sensing; spectrum estimation; spectrum prediction; time series analysis; autoregressive model; USRP2; MATLAB/- Simulink.

I. Introduction

The traditional static spectrum allocation strategies cause temporal and geographical holes of the spectrum usage in licensed bands. The spectrum occupancy: completely free, partially free and fully occupied, is known as *white*, *grey* and *black* holes in spectrum usage [1][2]. The different spectrum occupancy studies have shown that the radio spectrum (i.e. 3KHz - 300GHz) is inefficiently used today [3]. FCC spectrum policy task force permits unlicensed devices to make opportunistic or dynamic use of spectrum occupied by existing services. Cognitive radio has a potential to improve spectrum occupancy by opportunistically identifying and exploiting the available spectrum resources without causing a harmful interference. The cognitive radio is considered as a future radio technology that should be aware of its surrounding environment and internal state and can make decisions about its radio operating behavior (transmitter parameters) to achieve the predefined objectives. According to FCC (Doc. Nr. 03-322) the cognitive radio system may be deployed in network-centric, distributed, ad-hoc and mesh architectures. It serves the needs of both licensed and unlicensed applications. The cognitive radio's control mechanism uses inputs such as environmental, spectral and channel conditions to make changes in its radio operating behavior for predefined objectives.

For re-configurability a cognitive radio looks naturally a software-defined radio. The "software-defined radio" and "cognitive radio" terms were coined by Joseph Mitola [4][5], but have become their own field of research. In an introduction of reconfigurable logic and the coining of the term software-defined radio (SDR), the dominant implementation architecture used for RF Front-Ends (FEs) was the super-heterodyne architecture. An SDR system provides software control for a variety of modulation methods, filtering, wideband or narrowband operations, spread spectrum techniques and waveform requirements etc. The frequency bands are still constrained at the RF Front-Ends. An SDR allows an implementation of signal processing functionality in software instead of dedicated hardware circuitry.

The worldwide regulatory and standardization activities are working for cognitive radios. IEEE DSYSPAN Standards Committee is divided into six 1900.x working groups (WGs), to address the issues related to the deployment of next generation radio systems and spectrum management. Each WG is responsible to formulate standards for different aspects of a cognitive radio [6]. ETSI - reconfigurable radio systems (RRS) TC also created four WGs; for system aspects, radio equipment architecture, cognitive management & control and public safety respectively [7]. The cognitive radio should be capable of using bands assigned to unlicensed users and utilizing the licensed part of a radio spectrum without harmful interference.

This paper is a further extension of our previous work of software-defined radios [8]. It presents a detailed survey of coexistence mechanisms used in IEEE 802 wireless standard family and also presents an experimental prototype system for cognitive radio built on top of software-defined radio in MATLAB/- Simulink and interfaced with Universal Software Radio Peripheral-2 (USRP2) main-board and RFX2400 daughter board from Ettus Research LLC. MATLAB has a rich family of toolboxes that allows building a sophisticated cognitive radio on top of SDR.

The rest of the paper is organized as follows; Section II presents a detailed survey of coexistence mechanism used in IEEE 802 wireless standard family. This is followed by a prototype system design in Section III. The prototype system development is spread over three sections for simplicity from Section IV to Section VI. Spectrum estimation techniques are used for primary user´s detection and identification in Section IV. The advanced statistical time series modeling and analysis are carried to predict (forecast) a future environmental behavior of primary users in Section V. An efficient spectrum management and adaptation is accomplished in Section VI using a reconfigurability of software defined radio to build a cognitive radio. The Section VII wraps up everything to draw a conclusion and future directions.

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II. Background and Related Work

Interference is not an inherent property of a spectrum but a property of device [3]. It may categorized as: an *acceptable* that does not impact the receiver performance; a *harmful* that causes a signal quality on the receiver side to be unacceptable for a current modulation/coding of the link; *destructive* that disables a victim from decoding the received signal using any available modulation. Coexistence is an ability of a system to perform a task without a harmful interference, in a shared environment where other systems have an ability to perform their tasks. It may achieved by numerous methods such as coordinating time sharing, geographic separation, frequency separation, transmission power control, etc. The deployment of coexistence methods has typically been a static, cognitive radio would have a dynamic deployment that should be implemented in real time by a radio device or network [9].

The IEEE 802 wireless family contains different types of access networks namely: wireless personal area network (IEEE-802.15.x), wireless local area network (IEEE-802.11), wireless metropolitan area network (IEEE-802.16), and wireless regional area networks (IEEE-P802.22). IEEE Std.-P802.19 addresses coexistence between unlicensed wireless networks. The following sub-sections present a detailed survey of coexistence mechanisms used to reduce interference between different types of 802 wireless networks sharing the same spectrum by avoiding a harmful interference.

A. Wireless PAN (IEEE 802.15)

An IEEE Std.802.15.1-2005 (Bluetooth) uses an adaptive frequency-hopping (AFH) mechanism for coexistence between wireless technologies sharing the 2.4GHz RF spectrum. AFH is based on channel classification, an interference-free channel is classified as "good" channel, and an interference laden is classified as "bad" channel. The *received signal strength indication (RSSI)*, *packet error rate (PER)* and *carrier sensing schemes* may be used separately or jointly as channel classification method. The channel is likely to suffer from interference if RSSI is high and an error is detected, it should be considered as "bad" channel. A vendor specific packet error threshold can also be declared for channel classification. A packet may deem in-error if an access code correlate fails, header-error-check (HEC) fails or, the cyclic-redundancy-check (CRC) fails for a payload bearing packet. In carrier sensing an interfered channel may identified upon detection of IEEE 802.11b PHY layer signal. The IEEE Std. 802.15.2-2003 addresses coexistence mechanisms that can be used to facilitate coexistence of Bluetooth and WLAN (IEEE-Std.802.11b) [10].

Similarly, IEEE Std. 802.15.4-2006 (i.e. ZigBee) provides: channel assessment (CCA); dynamic channel selection; link quality indicator (LQI), received energy detection (ED); transmit power control etc. techniques for coexistence.

B. Wireless LAN (IEEE 802.11)

A carrier sense multiple access/clear channel assessment (CSMA/CCA) ensures that no two wireless devices transmit simultaneously on a same channel. A network allocation vector (NAV) is a timer that shows the radio resource is occupied (reserved) and it is stored in RTS (request to send) and CTS (clear to send) messages. The network allocation vector is used for (CSMA/CCA) [11].

The spectrum management services in 802.11h amendment: *dynamic frequency selection (DFS)* and a *transmit power control (TPC)* are used for coexistence in 5GHz band in Europe. In DFS a device uses a radar interference detection function in order to detect radar signals with a level above the *interference detection threshold* to avoid a co-channel operation and its takes a responsibility for selecting a next channel after a radar signal is detected (ETSI EN 301 893). *TPC* is used to adapt a transmission power based on regulatory requirements to reduce interference with satellite services in the 5 GHz band. The STA determines a *regulatory maximum transmit power* for a channel by a minimum of regulatory maximum transmit power received in a country element from an access point (AP) in its basic service set.

C. Wireless MAN (IEEE 802.16)

An IEEE Std. 802.16-2009 specifies a dynamic frequency selection (DFS) for regulatory compliance mechanism. It facilitates the detection and avoidance of interference and the prevention of harmful interference into other users including specific spectrum users identified by regulation. A WiMAX OFDM systems may use: *subcarrier nulling* in which a transmitter does not send data on subcarriers that need to be avoided; *side-lobes suppressing* of subcarrier; and *peak-to-average power ratio (PAPR) reduction*, for coexistence mechanism [12]. Std.802.16h-2010 amendment specifying a coexistence control channel (CXCC) mechanism to enable coexistence among license-exempt systems and to facilitate the coexistence of such systems with primary users. CXCC is a logical channel composed of a periodic sequence of time slots. It is used for sensing, synchronization, cumulated interference measurement and broadcast of coordinated coexistence related information. It also specified three coexistence mechanisms: *MAC frame synchronization*, including Tx and Rx intervals; *dynamic channel selection (DCS)* and *adaptive channel selection (ACS)* for finding less interfered or less used frequency and separation of remaining interference in time domain by using coexistence frame & coordinated scheduling.

D. Wireless RAN (IEEE 802.22)

An IEEE P802.22/D8-2010 is aimed to use cognitive radio techniques (TVWS: TV white spaces) to allow broadband access; haring of geographically unused spectrum in VHF and UHF (54-862MHz) TV bands. It uses TV channels 5–13 in the VHF band and 14–51 in the UHF band for fixed broadband access systems. It uses geo-location/database and spectrum sensing methods for spectral awareness. A spectrum sensing function (SSF) of spectrum manager (SM) at PHY layer senses a spectrum for: analog or digital television, and licensed wireless microphones. The SM at base station (BS) controls uses of and access to spectra resources for the entire cell. Std.802.22.1-2010 presents a self-coexistence mechanism based on coexistence beacon protocol (CBP), which provides a harmful interference protection for low-power licensed devices operating in TV spectrum that is not used for broadcasts. The *available* channels are classified as *protected*, *unclassified*, *disallowed*, *operating*, *backup* and *candidate* channels in a decision process [13]. A license-exempt device monitors TV channel for a random number of super-frames to determine the presence or absence of primary users.

III. Cognitive Radio Prototype Design

A cognitive radio testbed prototype system as shown in Fig. 1 is built in MATLAB/Simulink R2010b and interfaced with a universal software radio peripheral-2 (USRP2) and RFX2400 RF Front-End from Ettus Research LLC for better performance, reusability and further extension. MATLAB has a rich family of toolboxes that allows building software-defined and cognitive radio to explore various spectrum sensing, prediction and management techniques [14]. The design philosophy of prototype is a flexibility and adaptability of software-defined radio. For re-configurability cognitive radio looks naturally to software-defined radio to perform its task. It is built on-top-of software-defined radio presented in [8]. All waveform-specific processing such as sensing, cognition and management are done on a host-PC and general purposes high-speed operations such as digital up and down conversion, decimation and interpolation inside the FPGA of USRP2. CR is a future radio technology but it is still bit far from mature in terms of real wireless applications due to limited availability of RF-Front-Ends for spectrum bands in a commercial market. The RFX2400 RF-Front-End is used which operates in 2.4GHz with a USRP2 main-board. The default IP address of USRP2 is 192.168.10.2, the host's Ethernet interface is set 192.168.10.1, and subnet mask is 255.255.255.0. The IP of USRP2 transmitter and receiver blocks in Simulink are set 192.168.10.255 along with *'Rapid Accelerator'* mode and *'faster runs'* compiler optimization level for high performance.

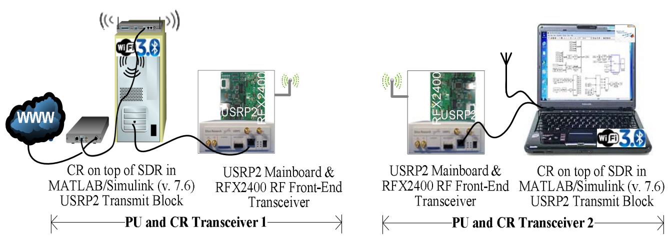

Fig. 1. Testbed system prototype

The testbed consists of two cognitive radio transceivers for simultaneous transmission and reception, and two primary users/-transceivers (WLAN & Bluetooth) operating in a same proximity. Bluetooth system hops over 79 RF frequencies, each 1MHz wide, over a bandwidth that ranges 2.402-2.480 GHz that are modulated using Gaussian frequency shift keying. Burst (slot) duration is 625µs. WLAN (802.11g) uses 13 RF channels allowed by ETSI (in Europe), each of 22 MHz wide that ranges 2.401-2.483GHz. It uses 52 subcarriers that are modulated using either BPSK/-QPSK or 16-QAM/64-QAM. Burst duration is 1 OFDM symbol of 3.3µs + 0.8µs guard time.

A CR prototype system conceptual model as shown in Fig. 2, observes an environment using spectrum sensing, makes decisions using a cognition process and changes operating behavior using a policy language by adjusting its radio parameters dynamically. The prototype system uses a software define radio for reconfigurability. The overall system development is spread over coming three sections for simplicity and reusability as sensing, cognition (prediction), and adaptation domains. Prototype would be able to predict the future occurrence of the PUs in both a frequency and time domains where PUs in green are measured ones, and in pink are expected ones of a radio environment, as shown in Fig. 3.

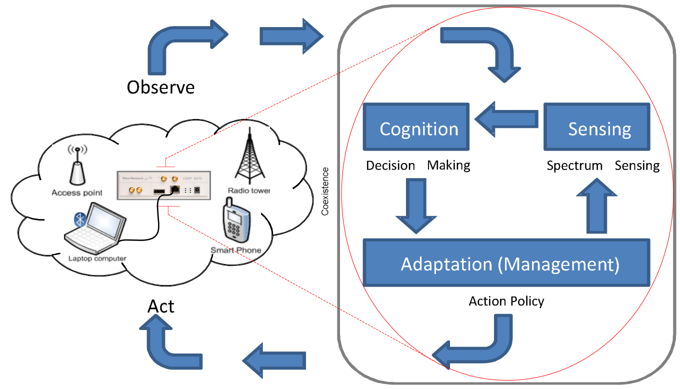

Fig. 2. Cognitive radio's conceptual model and coexistence

IV. Spectrum Sensing (PUs Detection)

The cognitive radio's spectrum sensing includes various detection techniques: interference based detection, cooperative detection and transmitter detection. Interference based detection is accomplished by estimating the interference temperature of the radio environment. Interference temperature defines a maximum permissible level of interference by utilizing interference temperature or antenna temperature metric [15]. A cooperative sensing among multiple users/radios can mitigate the sensitivity requirements on individual radios to improve a system-level probability of detection [16]. The transmitter detection techniques are considered to determine the presence or absence of a primary (incumbent) user. They are mainly categorized as coherent, semi-coherent or non-coherent; having complete, partial or no prior knowledge of a transmitter respectively.

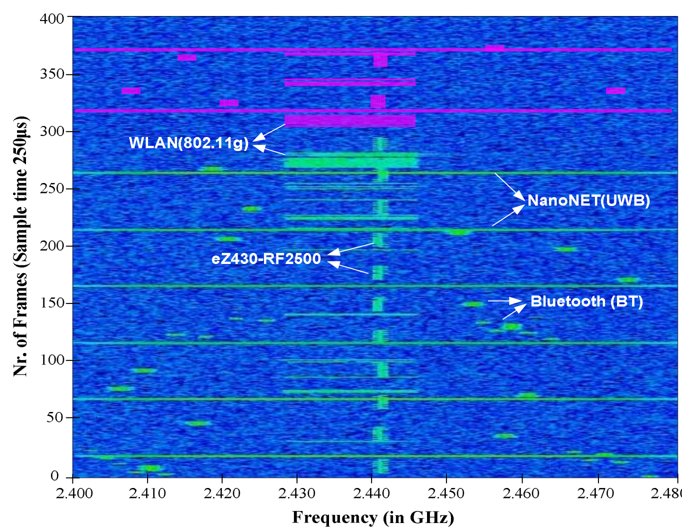

Fig. 3. Spectrogram of sensed and expected PUs

Sensing can be either reactive sensing (performed on demand) or proactive (performed for future). It can be realized either at PHY, MAC or jointly PHY-MAC layer to adopt spectrum-agile features. The PHY-layer sensing includes such as energy detection, matched filtering etc. The MAC-layer sensing requires an engineering knowledge of perspective PUs [17]. Its main issues are how to maximize the overall discovery of opportunities and how to minimize the delay in locating an idle channel in the licensed bands [18]. An Extended

Knowledge-Based Reasoning (EKBR) can improve the sensing efficiency at MAC by jointly considering a number of network states and environmental statistics [19]. A joint PHY-MAC spectrum sensing can be used, which employs a sequential probability ratio test at PHY layer and a probability-based sensing scheduling mechanism in the MAC layer [20]. We used advanced statistical techniques at PHY and a proactive spectrum access approach as proposed in [21] where secondary users utilize past channel histories to make predictions on future spectrum availability. It is based on channel selection and switching techniques to minimize the distributions to PUs.

A. Energy Detection: Spectrum Estimation

An energy detection approach is a common way of spectrum sensing to decide whether unknown signals exist or not. The receiver (sensing node) does not need any knowledge of the primary users' signal. The energy E of signal $x(t)$ can be measured by applying Rayleigh's energy theorem as follows:

$$E = \int_{-\infty}^{\infty} |x(t)|^2 \, dt < \infty \qquad (1)$$

If the energy of the signal satisfies (1) and the Fourier Transform $X(f)$ of $x(t)$ exists then,

$$\int_{-\infty}^{\infty} |x(t)|^2 \, dt = \int_{-\infty}^{\infty} |X(f)|^2 \, df \qquad (2)$$

The energy of a signal is preserved in both time domain and frequency domain as shown in (2) but the frequency domain representation is more flexible. The signal detection & analysis makes no difference in which domain it is measured [22].

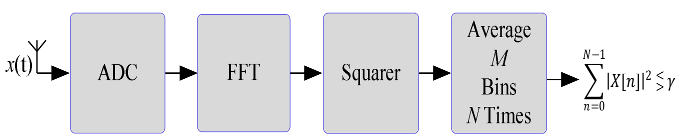

Fig. 4. Energy detection in frequency domain (block diagram)

The total signal power (energy per unit time) is proportional to the average magnitude squared (Fig. 4). A power spectrum describes an energy distribution of a time series in the frequency domain. Statistical spectral estimation methods are classified as parametric methods, nonparametric methods and subspace methods. The parametric methods are model-based methods (AR, MA and ARMA etc.) they require model parameters first. The nonparametric methods considered in this work do not require model parameters such as periodogram method, which is a normalized estimate of the power spectral density and modified periodogram methods (Bartlett, Welch etc.). The subspace methods (EV) are based on eigen-decomposition of an autocorrelation matrix [23].

Periodogram is an estimate of power spectral density which is calculated in units of power per radians per sample. It is asymptotically unbiased but not a consistent estimate. Welch's method splits an original data segment of N samples into overlapping K segments each with a subset of L samples and overlapping by D points. It allows a data window to be applied to each sequence and computes modified periodograms of the overlapping segments and averages the resulting periodograms to produce the power spectral density estimate [24]. Averaging periodograms reduces the variance in the estimated power spectral density by providing a better estimate of a PSD. The Welch's method properties are defined as follow [23] [24]:

$$\hat{P}_w(e^{jw}) = \frac{1}{KLU}\sum_{i=0}^{K-1}\left|\sum_{n=0}^{L-1} w(n)x(n+iD)e^{-jnw}\right|^2$$

$$\text{where} \qquad U = \frac{1}{L}\sum_{n=0}^{L-1}|w(n)| \qquad (3)$$

The expected value (called Bias) of Welch's estimate is,

$$E\left\{\hat{P}_w(e^{jw})\right\} = \frac{1}{2\pi LU} P_x(e^{jw}) * \left|W(e^{jw})\right|^2 \qquad (4)$$

Where $W(e^{jw})$ is the Fourier transform of the L-points data windows $w(n)$ used in (3). The data windows are used for smoothing. We used Hamming data window for the modified periodogram (Welch). The resolution however depends on the data windows, which is defined as:

$$Res\left[\hat{P}_w(e^{jw})\right] = 1.30\frac{2\pi}{N} \qquad (5)$$

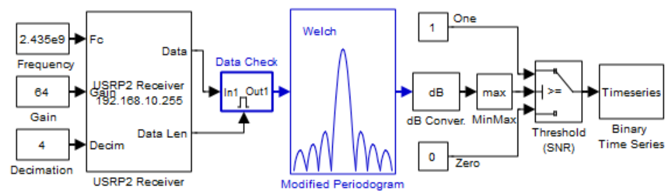

Fig. 5. Spectrum estimation using Welch estimation method

The PSD estimation is a non-coherent detection technique. It does not require any prior knowledge of PUs and it reduces the required set of samples as a function of $N = O(1 / SNR^2)$ [25]. A time series data using spectrum estimation is obtained by a decision rule: the threshold comparison and it is used later in next section for prediction, as shown in Fig. 5.

B. Other Sensing Techniques

There are various other spectrum sensing techniques such as a matched filter, cyclostationary detection, wavelet detection, autocorrelation detection and covariance detection etc. The detailed survey of various spectrum sensing techniques and algorithms for cognitive radio are presented in [25][26].

V. Spectrum Prediction (Cognition)

The statistical time-series modeling techniques can be applied to improve spectrum holes usage by predicting the PU's channel behaviors. Time series is a sequence of discrete time domain data points (samples) that are measured at uniform time interval in a radio environment. The series can be either deterministic or non-deterministic (i.e. statistical), if it is determined by a mathematical function, or by probability distribution respectively [27]. We concerned the later ones, they are categorized as follows:

- Linear Stationary Time Series Models
- Linear Nonstationary Time Series Models

A process is stationary if its equilibrium properties are unaffected by a change of time origin; that is, if the joint probability distribution of any set of observations is unaffected by shifting all the times of observation by any integer amount k, otherwise non-stationary. The stationary process, which is a normally a case in standard wireless technologies has a fixed mean, a fixed variance and the correlation only depends on lag. It is always necessary to consider underlying properties of the processes that generate the time series variables before selecting a model estimator. Only the linear stationary time-series models are considered they serve a vital role in the development of time series analysis and can be used for spectrum prediction in cognitive radios [28]. The non-stationary process theory is rooted in Bayesian estimator and Monte Carlo statistical methods [29].

To forecast a primary user channel behavior first we have to derive an adequate model for the particular time series under study, once an appropriate model has been determined for the series, the optimal forecasting procedure follows immediately. The stationary equilibrium properties are tested as follow [30]:

A. *Stationary Process Equilibrium Testing*

1) Mean and Variance of a Stationary Process: Mean μ, is a measure of a central tendency that summarizes the location of the distribution on a single variable, about which it fluctuates. Let a discrete stationary process X takes values $x_1, x_2 \ldots x_N$ and probability distribution $f(x)$ is same for all times t; the mean of a process can be estimated by a sample mean of the time series.

The variance σ^2 is measure of variability that indicates how much the samples are spread out around its mean. The variance of a process can be estimated by a sample variance of the time.

2) Autocovariance and Autocorrelation Coefficients: Autocovariance is determined by comparing a time series with itself shifted by a time *lag k*. Autocovariance between pairs of the time series x_t and x_{t+k}, separated by a *lag k* is defined as:

$$\gamma_k = \text{cov}[x_t,\ x_{t+k}] = E[(x_t - \mu)(x_{t+k} - \mu)] \tag{6}$$

The correlation coefficient (i.e. relationship consistency) is a measure that communicates *type* (either positive or negative) and *strength* (absolute value) of a relationship between sample points. Autocorrelation at lag k (i.e. covariance divided by the respective variance) is defined as:

$$\rho_k = \frac{E[(x_t - \mu)(x_{t+k} - \mu)]}{\sqrt{E[(x_t - \mu)^2]E[(x_{t+k} - \mu)^2]}} = \frac{E[(x_t - \mu)(x_{t+k} - \mu)]}{\sigma_x^2} \tag{7}$$

Since, for a stationary process, the variance $\sigma^2_x = \gamma_0$ is same at time $t+k$ as at time t. Thus, the autocorrelation at lag k is,

$$\rho_k = \frac{\gamma_k}{\gamma_0} \tag{8}$$

Which implies that ρ_0=1. Thus to conclude that a process is stationary if its $E[x_t]$, $Var[x_t]$ and $Covar[x_t, x_{t+k}]$ are constant for all t. Note that from (8), the autocorrelation function is dimensionless that means it is an independent of the scale of measurement of the time series.

B. *Regression-Based Predictive Modeling*

In time series analysis, the regression-based statistical models mostly used for prediction are categorized as follow:

- Autoregressive Moving Average Model
- Autoregressive Intergraded Moving Average Model

The *ARMA* and *ARMIA* Models are used for stationary and nonstationary processes, respectively. In this work only the stationary processes are considered. ARMA model is also called *pole-zero* model in signal and systems (i.e. communication theory). An ARMA model of order (p, q) is denoted by *ARMA(p, q)* and defined as follows:

$$X_t = \sum_{i=1}^{p} a_i X_{t-i} + \sum_{j=1}^{q} b_j \varepsilon_{t-j} + \varepsilon_t \tag{9}$$

Where a_i, are coefficients, p is an order and ε_t is a white noise of an autoregressive (AR) model and b_i are coefficients, q is an order and ε_{t-j} are error terms of a moving average (MA) model. AR and MA are two special cases of the ARMA model [28]:

1) AR (all-pole) model: $a_j = 0,\ 1 \le i \le p$
2) MA (all-zero) model: $b_j = 0,\ 1 \le j \le q$

C. *Autoregressive Predictive Modeling*

Only linear stationary time-series model based on autoregressive AR model is presented, it predicts time series values from a given time series by a linear weighted sum of previous terms in the series and a shock a_i also called coefficients. It is defined as follows:

$$X_t = \sum_{i=1}^{p} a_i X_{t-i} + \varepsilon_t \tag{10}$$

Correlation-based normal equations and cumulant-based equations are normally used for estimating the coefficients of a causal AR model. The exhaustive search method, optimization method and conversion method are used for estimating the coefficients of a non-causal AR model [31]. The correlation based normal equations also called Yule-Walker methods are used for *AR(p)* model coefficient determination. A partial autocorrelation function (PACF) is used to determine the order p in an *AR(p)* model. The PACF becomes *zero*, when the lag exceeds *p* [30]. A *System Identification Tool (ident)* is used in Simulink for WLAN channel prediction as shown in Fig. 6, where the measured and the predicted activities are much similarly, the error term is very low.

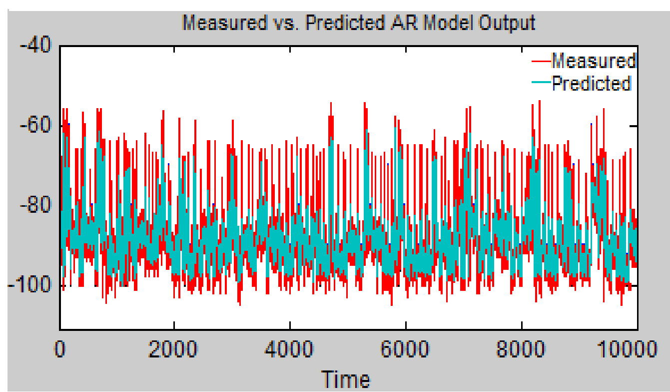

Fig. 6. WLAN channel behavior prediction using AR model

VI. Spectrum Adaptation (Management)

The spectrum management includes time, frequency and transmit-power controls and dynamic spectrum management allowing the radio terminals to operate in the best available frequency spectrum. SDR provides a software control for a variety of modulation method, filtering, wideband or narrowband operations, spread spectrum techniques and waveform requirements etc. For SDR reconfigurability; a cognitive radio looks naturally to a software-defined radio to perform its task (Fig. 7) as proposed in our previous work [8].

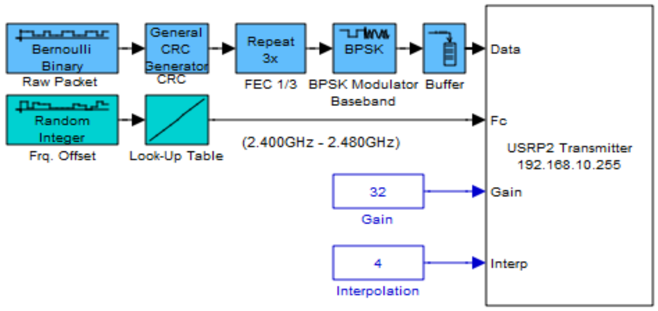

Fig. 7. Cognitive radio spectrum adaptation (management)

The more spectrum resource can be made available by improving spectrum utilization issues. Centralized, distributed or joint approaches can be used for improving spectrum management utilization and resource usage optimization. The former approach is network or radio node centric A distributed spectrum management approach may be used in which global network objectives may satisfied by a composite wireless network and local device & user objectives may satisfied by a radio node [32]. The overall performance can be improved by a medium access control (MAC) protocols [33]. A policy language is required to specify an interoperable, vendor-independent control of cognitive radio functionality; behavior for dynamic spectrum access resources and services [34].

VII. Conclusion And Future Work

The contribution of this paper is three-fold. Firstly, we presented a detailed survey of coexistence techniques used in IEEE 802 wireless networks family. Standard wireless technologies have limited coexistence mechanism as compared to cognitive radio which is an adaptive system. Cognitive radio would offer much larger coexistence mechanisms using the advanced cognition and forecasting techniques for various wireless communication systems. Secondly, we developed a prototype system (testbed) for experimenting and emulating the cognitive radios on-top-of software defined radios built in MATLAB/- Simulink and interfaced with an USRP2 main-board and RFX2400 daughter-board from Ettus Research LLC. Thirdly, Welch spectrum estimator is used for transmitter identification. Time series analysis and autoregressive modeling is used for forecasting the future behavior of primary users. The research challenges of cognitive radios are also briefly described.

The future work will be further practical realization of the advanced statistical signal processing techniques and the multichannel autoregressive data model realization.

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