Predictive Channel Selection for over-the-Air Video Transmission Using Software-Defined Radio Platforms

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Abstract. This paper demonstrates a predictive channel selection method by implementing it in software-defined radio (SDR) platforms and measuring the performance using over-the-air video transmissions. The method uses both long term and short term history information in selecting the best channel for data transmission. Controlled interference is generated in the used channels and the proposed method is compared to reference methods. The achieved results show that the predictive method is a practical one, able to increase the throughput and reduce number of collisions and channel switches by using history information intelligently.

Keywords: Cognitive radio · Spectrum databases · Dynamic spectrum access

1 Introduction

Cognitive radio (CR) techniques have been studied intensively for over a decade, focusing mainly on dynamic spectrum access oriented operation. Numerous techniques have been developed and analyzed, including spectrum sensing, power and frequency allocations, beacon signaling, and spectrum databases. Only a subset of the proposed techniques have been implemented and tested in real systems to see their practicality. This paper focuses on channel selection problem in a changing radio environment and demonstration of the proposed method in a practical system.

Importance of history information and knowledge on primary traffic patterns in channel selection was shortly discussed already in [1]. Later, the problem has been studied intensively and prediction methods for both stochastic and deterministic traffic have been developed [2–8]. For example, a deterministic long-term component can be seen in several bands such as cellular mobile communication systems due to daily rhythm of the users [3]. Traffic pattern estimation method for exponential traffic has been proposed in [4]. A more general method able to classify traffic patterns and select the prediction method based on this information is proposed in [5]. Switching delay has been included in the channel selection to decide whether to switch a channel or not based on channel prediction and switching overhead in [6]. The method is developed further in [7] where an adaptive sensing policy is developed to detect the primary user appearance as fast as possible. Sequential channel sensing policy is studied also in [8].

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The sensing procedure and channel selection can be made faster by reducing the number of channels to sense in the first place. Both short term and long term information can be used to guide the process. A channel selection method that was described in [9, 10] uses long term information on the use of primary channels to select the most promising ones to be sensed and exploited by cognitive radios at the requesting time. These channels are investigated in more detail over short term to find the best channels for data transmission. Both long term and short term data are stored in databases to be able to predict which channels look most promising for secondary use.

The proposed hybrid method that uses both sensing and databases is a promising approach to be used e.g., in different spectrum sharing scenarios of future fifth generation (5G) systems, and also in military environments. A hybrid method is the most probable step in-between pure database access and sensing based access to the spectrum. This paper demonstrates the described method by implementing it in a software-defined radio system. Verification is performed by transmitting video over a cognitive link and measuring the performance regarding error rates, channel switches, and throughput. Achieved results are compared to reference methods that are not using prediction in the channel selection.

The paper is organized as follows. Section 2 describes used channel selection methods starting from the intelligent hybrid one. Section 3 defines the demonstration environment and measurement results are presented in Sect. 4. Time domain analysis and discussions about possible improvements to the demonstrator are given in Sect. 5. Conclusions are drawn in Sect. 6.

2 Description of the Channel Selection Methods

2.1 The Smart Channel Selection Method

Simplistic view of the method is shown in Fig. 1. In the first phase a CR sends query to the long term database to receive a set of promising channels among M possible ones. The set is selected e.g., based on the long term spectrum occupancy data. Time and capacity estimations can be used to define channels that are suitable, offering needed time for the requested transmission. Given N channels are sensed to know whether they are free or not and the sensing information is stored in the ST database.

The short term database classifies the type of traffic in different channels which enables use of specific prediction methods for each traffic type, making prediction results accurate. Then, future idle times are predicted using the classification result and the history data. The P channels with the longest idle times are selected into use and the rest N–P channels are returned to be offered to other users requesting access to spectrum. After channel selection is made, the CR can send data for predefined period of time, sensing periodically the channel to be sure that it is still free for transmission. Thus, use of long term database shortens the sensing time by reducing the channels to be sensed. The use of short term database reduces the channel switching rate and collisions with primary users. Therefore, more time is left for data transmission and consequently, capacity of the system is increased.

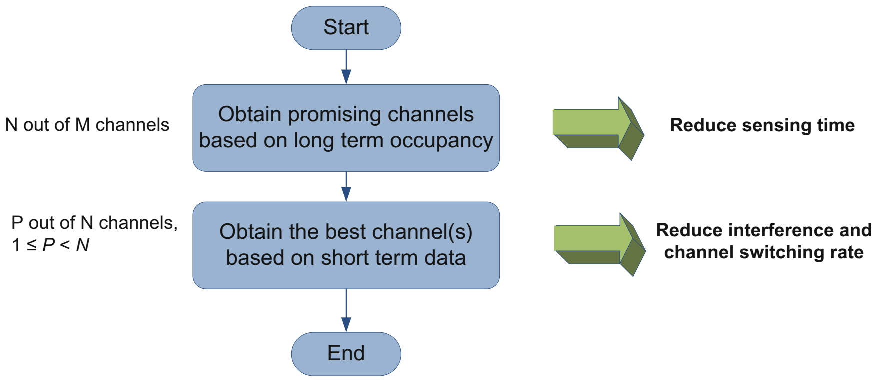

Fig. 1. Simplistic view of the proposed method.

2.2 Methods to Compare

No Channel Switching at all. The simplest way to operate in the spectrum is to stay always in the same channel. Thus, the first method to compare is no channel switching at all–method. If there is interference in the channel, the system suffers and there is degraded quality of service during that period of time. The system may also be required to stop transmitting totally and wait until the channel is free again.

Change to the Next Predefined Frequency. An improved step to the previous method is to change frequency when there is interference in the current channel. This can be done in many different ways. The simplest one is to predefine the next frequency to switch into. The advantage of this method is to be able to find a good channel to operate. A disadvantage is that it may take several switches since the channel to switch into may also be under interference.

Change to the Free Frequency. It is wise to switch into a channel that is available for transmission even though it requires more resources in sensing and finding those potential channels. This method may randomly select any of the free frequencies or jump into next free frequency whenever interference occurs at the current operational channel. This kind of reactive channel switching is proposed e.g., in [11, 12]. Since only instantaneous information about the availability of channels is used, switching may need to be performed quite often, depending on the primary user spectrum use.

3 Demonstration Environment

Figure 2 presents a block diagram of the measurement set-up. We are using SDR platforms for a data link, five interfering transmitters, and a spectrum sensor. A photograph of the environment is shown in the Fig. 3. The measurement environment is physically located at VTT premises in Oulu, Finland.

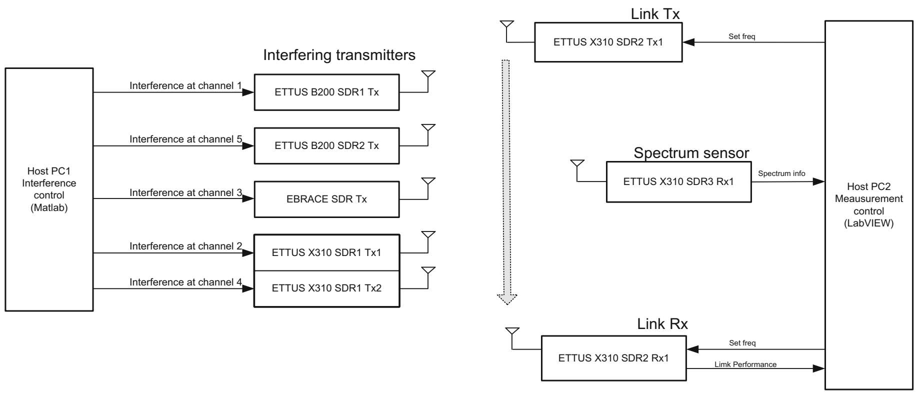

Fig. 2. Block diagram of the measurement setup.

Fig. 3. Demonstration setup.

Interference generation is made using Matlab controlled SDR-platforms. We use USRP B200 and X310 platforms from Ettus Research [13] together with the EBRACE SDR platform which, like the USRPs, is also a field-programmable gate array (FPGA) based SDR platform. The SDR platforms are used to generate continuous data to five different frequency bands. The type of the platforms is not important for the measurements. In fact, many other controllable interference sources could be used with the same effect. The transmission power of the interfering transmitters has been set high enough to cause strong interference to the selected band. The lengths of the continuous busy and idle times are both parametrized for each frequency separately.

In general, data traffic transmitted in a network can be characterized by traffic patterns. These patterns can be classified as [1]: (1) deterministic patterns, where the transmission is ON, then OFF during the fixed time slot, and (2) stochastic patterns, where traffic can be described only in statistical terms. Thus, values for busy and idle times in the demonstrator can be set either with fixed values or e.g. exponentially distributed random values.

Suppose we have a vector of n samples of idle times from the channel i, $\mathbf{X}^i = (x_1^i, x_2^i, \ldots, x_n^i)$. Assuming exponentially distributed idle times with traffic parameter $\lambda_{\mathrm{OFF}} > 0$ the probability density function of the exponential distribution is

$$f(x) = \begin{cases} \lambda_{\mathrm{OFF}} e^{-\lambda_{\mathrm{OFF}} x}, & x \geq 0 \\ 0, & x < 0 \end{cases} \tag{1}$$

The maximum likelihood (ML) estimate for the idle time is $\hat{T}_{\mathrm{OFF}} = \bar{x}$, where $\bar{x} = (1/n)\sum_{j=1}^{n} x_j$ is the sample mean [5]. Thus, the best prediction of the next idle time is the average of the previous ones. The same model applies also for busy times. In practice, traffic patterns of different channels might vary over time. Thus, the observation interval for average calculation should be restricted.

Interference detection for the used channel is done by measuring the block error rates (BLER) in the receiver. BLER is defined as the ratio of the number of erroneous blocks received to the total number of blocks sent, expressed as a percentage. It is used in 3GPP Long Term Evolution (LTE) systems during link radio monitoring, typically aiming to have the BLER below 10 %. It can be improved e.g., by adaptive modulation and coding or by changing to a new frequency. In our proof-of-concept implementation, once the block error rate exceeds a threshold value we decide to change the channel. The next channel is selected according to methods presented in Sect. 2.

Spectrum measurement for other channels is done in 100 MHz bandwidth, and by also selecting the system bandwidth to be 100 MHz, all of the used channels can be monitored simultaneously. This keeps the spectrum sensing simple in our measurement set-up. For each used frequency, after averaging over a few measurements, we use a simple threshold to decide whether the channel is interfered or not. If the measured power level is above the threshold, the channel is considered interfered. Measurement control reads this binary (busy/free) information and decides the next free frequency where to jump to if a channel change is needed.

Actual data link is in our case a modified real-time LTE link based on National Instruments LabVIEW Communications LTE Application Framework version 1.0 [14] where we have added the frequency switching algorithms. With the data link we can measure the throughput, error rate and number of frequency changes. Measurements were done with LTE Modulation and Coding Scheme (MCS) number 24, i.e. with 64QAM and code rate 3/4, and using 20 MHz bandwidth. Throughput was recorded both for all of the physical downlink shared channel (PDSCH) data and for the user data, which in our case was video data streamed over the link. The graphical user-interface (GUI) of the measurement control is presented in Fig. 4. User interface shows in real-time which channel is currently used, which channels are under interference, and

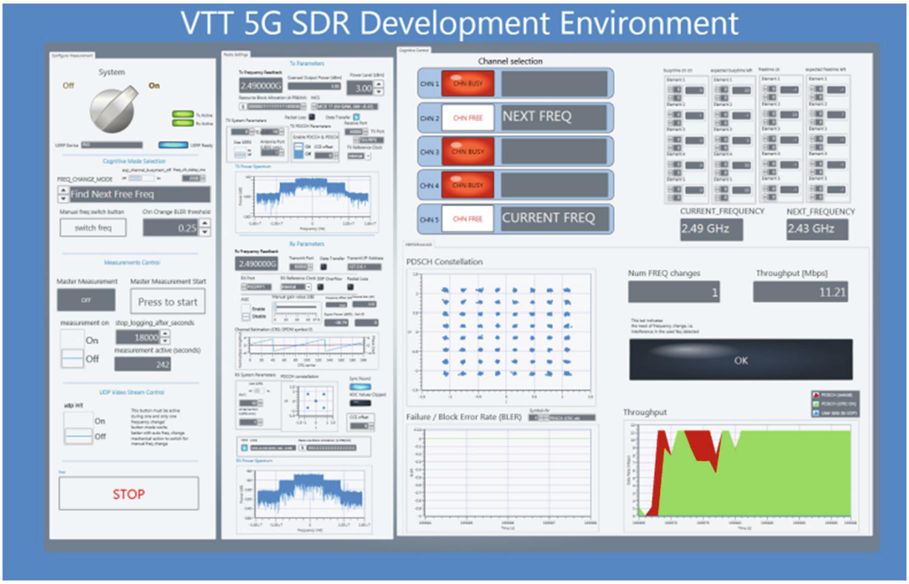

Fig. 4. Graphical user interface.

what is the next channel to switch into when interference occurs. The GUI shows also spectrum information and enables selecting the different channel selection methods on the fly.

Measurements presented in this paper were made in the 2.4 GHz industrial, scientific, and medical (ISM) band which is not fully controlled environment. We noticed that there was also other traffic present at the band during the measurements. The total 100 MHz bandwidth was divided into five equal size channels. Especially, channels 1, 2 and 3 were slightly interfered but the channels 4 and 5 were mostly free of other traffic. The other traffic was mostly general WiFi traffic in the office environment. The measurements were made during the night time and during the weekends when the amount of this other, uncontrolled traffic was very small. Our radio link used a turbo code with 3/4 code rate, and frame error rate (FER) was low on all channels if we ourselves were not generating any controlled interference with our interference generators.

4 Results

Measurement results for video transmission with different channel selection methods are given in Figs. 5 and 6. Measurements were conducted for each method over a 13500 s period. The presented results are average results over four consecutive measurement periods. For brevity, the used methods are named as:

Mode0: No channel changes

Mode1: Change to next (predefined) frequency

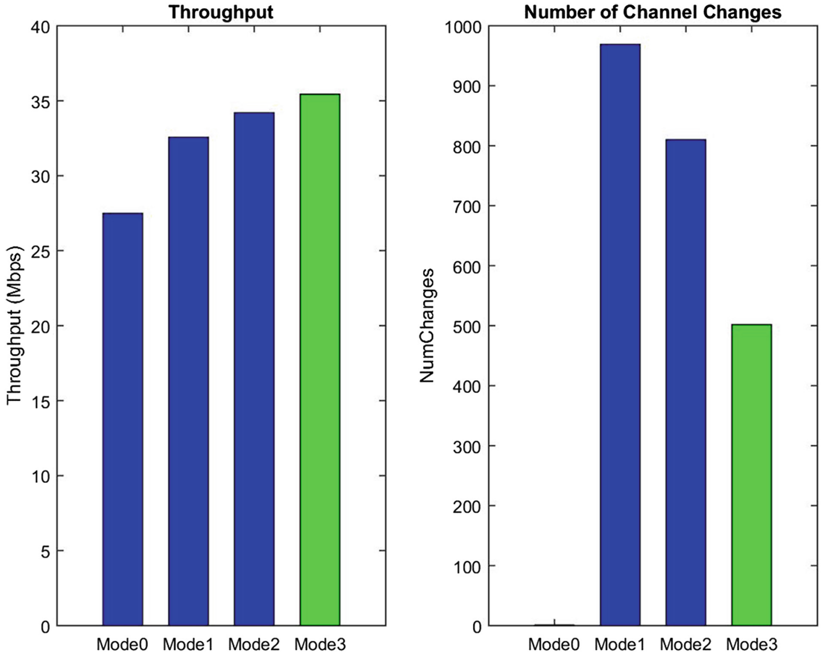

Fig. 5. Measured throughput and number of channel changes with all the methods, random interference traffic.

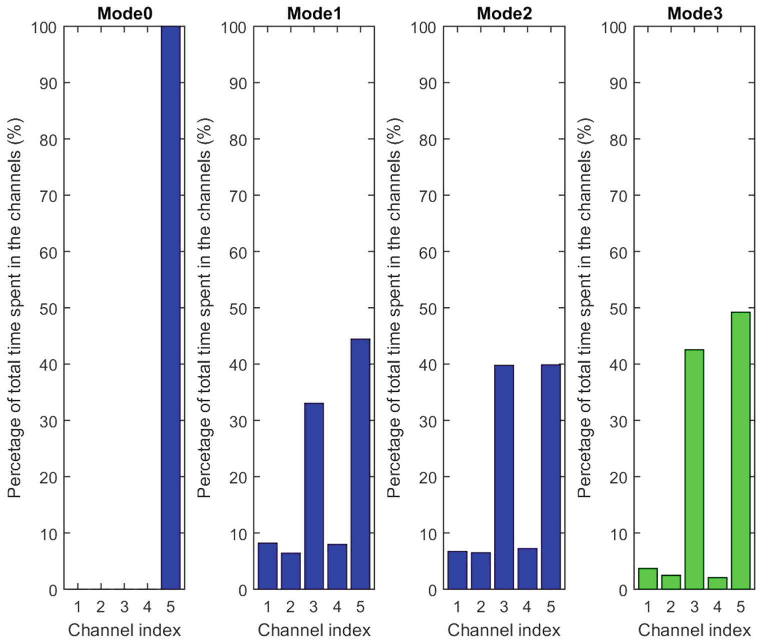

Fig. 6. Percentage of time used in channels, random traffic.

Mode2: Change to next free frequency

Mode3: Change to the best free frequency

Figure 5 shows the measured throughput and number of channel changes for all the channel selection methods with the random interference. The busy and idle periods for used channels are given in Table 1. The given values represent both mean values for exponentially distributed interference traffic and fixed values for deterministic traffic. Same values are used with each mode to have a fair comparison. As is seen in the figure, the more intelligence is added to the channel selection method the higher the achieved throughput is. Mode0 suffers during the interference since it is not able to change the channel. Ability to switch improves right away the performance. The proposed method, i.e., Mode3 achieves the highest throughput since it is able to predict and select the channels offering longest idle times for transmission and thus, minimize the number of channel changes over the experiment.

Figure 6 shows in more detail how different modes use different channels. The Mode0 uses all the time the best channel. Mode1 and Mode2 select the next channel randomly and use bad channels 1, 2, and 4 quite much. Mode3 concentrates the operation on the two best channels with longest idle periods, avoiding the use of other channels whenever it is possible. Only when there are no good channels free, the bad channels are used. The results with the deterministic traffic shown in Fig. 7 confirm the same conclusions. The advantage of the intelligent method is roughly the same regardless the type of the interference traffic in the channels.

The previous results were achieved with two good and three bad channels. We made also experiments with one, three, and four good channels to see the impact. When there are three good channels the trend looks still the same. However, the advantage is not that large anymore since the random methods also tend to select good channels more often. With four good channels the intelligent method still concentrates on three best ones since almost all the time some of them is available. When there is only one good channel to be used the performance is heavily dependent on the quality difference between channels. Purely from the throughput perspective the Mode0 can be better than other random methods since waiting in the good channel can be better than switching all the time among bad ones. Also in this case the intelligent method provided the best performance in measurements. From the quality of experience point of view, it is often better to change the channel since the waiting times and related video stoppage can be quite long. This is especially true if the interference is strong and continuously occurring in periods of several seconds.

Table 1. Idle and busy periods for used channels.

	Channel 1	Channel 2	Channel 3	Channel 4	Channel 5
Idle time	11 s	5 s	37 s	8 s	56 s
Busy time	17 s	8 s	10 s	5 s	21 s

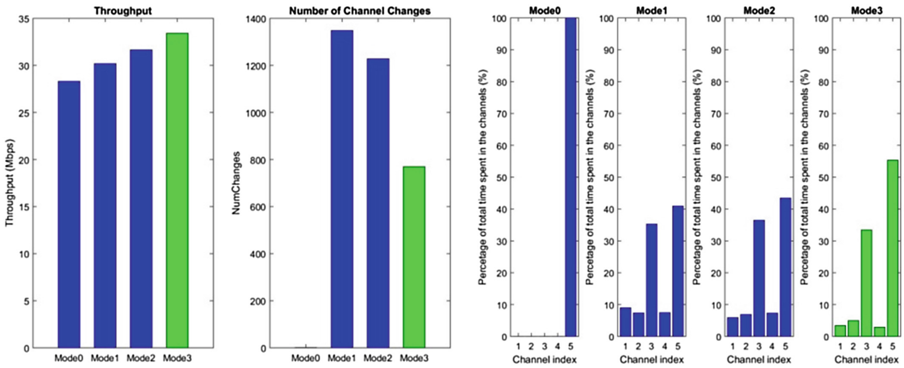

Fig. 7. Performance results with deterministic interference traffic.

5 Time Domain Analysis

The impact of the intelligent method in time domain can be seen in Fig. 8. The use of the long term database shortens the sensing time due to reduced number of sensed channels. The short term data reduces the number of channel switching by concentrating the operation on the channels with longest idle times. Thus, more time is left for data transmission.

This combination of databases is the main advantage of the proposed method when compared to other predictive approaches such as ones in [2–8]. The operation in the demonstration setup is presented in more detail in Fig. 9, showing the steps needed from the occurrence of the interference to synchronized data transmission in a new channel. The performance of the system could be improved through optimization of the sensing and switching times which could be achieved e.g., with a fully FPGA based decision making since FPGA processing speed is much faster than software based processing. This would speed up the procedures T1-T3 in Fig. 9 also by eliminating the

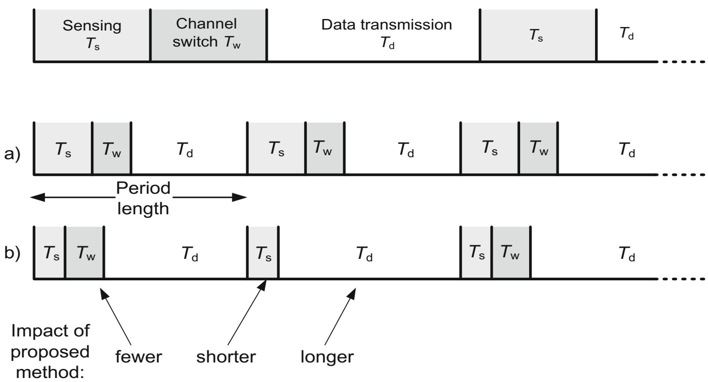

Fig. 8. Impact of the method: a) original frame b) with the intelligent method.

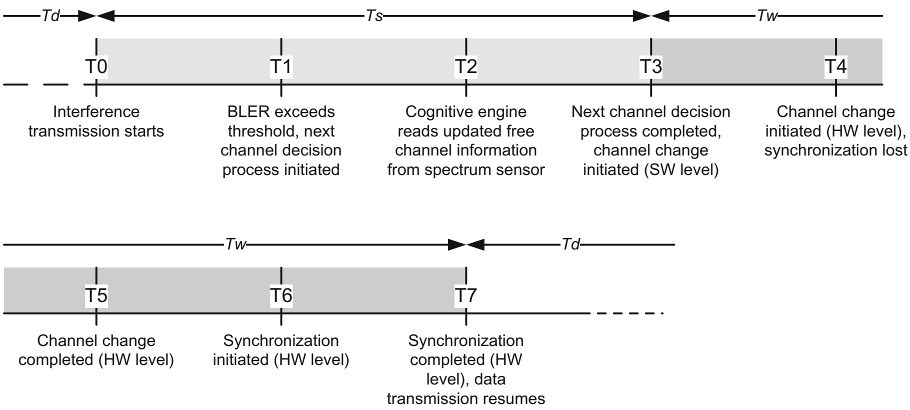

Fig. 9. Details of the time domain operation during a channel switch.

need to exchange control data through the interface between software and hardware layers in the LabVIEW framework. In the current setup the switching decisions are made with software which makes the total decision cycle clearly longer.

6 Conclusions

Use of history information enables a radio system to operate efficiently in a spectrum sharing radio environment. This paper has studied the channel selection problem by implementing a predictive method in a software-defined radio demonstrator and comparing its performance in the same system to several reference methods. Achieved results show that the proposed method increases the throughput and decreases interference towards other sharing systems. The quality of experience was clearly better for video streaming studied in the demonstration setup when the proposed predictive method was used.

As a possible future step, the setup can be developed further by inclusion of steerable antenna techniques such as the method proposed in [15] to improve the sharing in spatial domain. In addition, current implementation did not include the classification algorithm to be able to recognize the traffic pattern in the channels and select the optimal prediction method accordingly. An improvement to the operation would be also the speed-up of frequency switching by implementing a fully FPGA based decision making. Finally, the measurements could be made in totally interference-controlled environments with a channel emulator and/or in an isolated chamber.

References

1. Haykin, S.: Cognitive radio: brain-empowered wireless communications. IEEE J. Sel. Area Comm. **23**, 201–220 (2005)
2. Clancy, T.C., Walker, B.D.: Predictive dynamic spectrum access. In: SDR Forum Technical Conference, Orlando (2006)

3. López-Benitez, M., Casadevall, F.: An overview of spectrum occupancy models for cognitive radio networks. In: Casares-Giner, V., Manzoni, P., Pont, A. (eds.) Networking Workshops 2011. LNCS, vol. 6827, pp. 32–41. Springer, Heidelberg (2011)
4. Gabran, W., Liu, C.H., Pawelczak, P., Cabric, D.: Primary user traffic estimation for dynamic spectrum access. IEEE J. Sel. Area Comm. **31**, 544–558 (2013)
5. Höyhtyä, M., Pollin, S., Mämmelä, A.: Improving the performance of cognitive radios through classification, learning, and predictive channel selection. Adv. Electron. Telecommun. **2**, 28–38 (2011)
6. Kahraman, B., Buzluka, F.: A novel channel handover strategy to improve the throughput in cognitive radio networks. In: International Wireless Communications and Mobile Computing Conference, pp. 107–112 (2011)
7. Zhang, C., Shin, K.G.: What should secondary users do upon incumbents return? IEEE J. Sel. Area Comm. **31**, 417–428 (2013)
8. Shokri-Ghadikolaei, H., Fischione, C.: Analysis and optimization of random sensing order in cognitive radio networks. IEEE J. Sel. Area Comm. **33**, 803–819 (2015)
9. Höyhtyä, M., Vartiainen, J., Sarvanko, H., Mämmelä, A.: Combination of short term and long term database for cognitive radio resource management. In: 3rd International Symposium on Applied Sciences and Communication Technologies, Rome (2010)
10. Höyhtyä, M., Sarvanko, H., Vartiainen, J.: Method and device for selecting one or more resources for use from among a set of resources. U. S. Pat. Appl. US20130203427 A1 (2013)
11. Jing, X., Mau, S.-C., Raychaudri, D., Matyas, R.: Reactive cognitive algorithms for co-existence between 802.11b and 802.16a networks. In: IEEE Global Telecommunications Conference, St. Louis, pp. 2465–2649 (2005)
12. Feng, S., Zhao, D.: Supporting real-time CBR traffic in a cognitive radio sensor network. In: IEEE Wireless Communications and Networking Conference, Sydney, (2010)
13. Ettus Research. http://www.ettus.com/
14. National Instruments. http://www.ni.com/
15. Paaso, H., Mämmelä, A., Patron, D., Dandekar, K.R.: DoA estimation through modified unitary MUSIC algorithm for CRLH leaky-wave antennas. In: 24th International Symposium on Personal Indoor and Mobile Radio Communications, London, pp. 311–315 (2013)