Computer Simulation of Uncoordinated Dynamic Channel Access Method in Cognitive Radio Network for Radio Terminal Device

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Abstract. An implementation of the cognitive radio networks raises an issue of the medium access control (MAC) protocol researching, in particular MAC protocol impacts on the access delay to radio channels. In this paper uncoordinated access method is studied where the event of spectrum and channel accessing is random and determined by probabilistic value from 0.1 to 0.99 named as channel availability. The subject of research was impact of channel availability on the access delay with simulation on the base ns2 program simulator with CRNC patch.

Keywords: cognitive radio, radio terminal device, software-defined radio, dynamic spectrum access, media access control protocol, simulator ns2

INTRODUCTION

Cognitive radio (CR) is a new wireless communication concept, that can help to use all available radio resources at a local area more efficiently [1–3]. Cognitive radio has a clear ability to be concerning as self-configurable and self-planning platform including set of different software and hardware.

Cognitive radio is based on the radio spectrum access technology with dynamic spectrum access, DSA. Generally, DSA technology explores an opportunistic spectrum access. It means that available spectrum segments are used in an intelligent manner with help of advanced spectrum analysis and probing for unoccupied radio frequencies. For this purpose advanced methods like as machine learning, game theory are accepted. CR and DSA forms a new paradigm for radio spectrum and radio channel access and a great challenge for traditional use of fixed and non-distributed spectrum and radio channel using. Traditional wireless and cellular systems (2G, 3G, 4G, WiFi, WiMax) was designed on the base of centralized principle of spectrum using with a licensed spectrum and predefined terminal construction features. But this approach was appropriable just for centralized spectrum control.

Now this scheme has a drawback in term of flexibility and adaptability which are the important point of advantage of cognitive radio. There are two types of users sharing a common spectrum under DSA rules:

- Primary (licensed) users who have absolutely priority in spectrum utilization within the defined frequency bands.

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- Secondary users who must access the spectrum in a temporary manner with DSA technologies.

There is a situation on practice when the part of frequency band previously licensed for primary user, is not being utilized by this kind of user for a short period of time. In traditional wireless systems there are no technologies that can help to use these random chance for data transmission through unexpected “white spaces” [4]. Cognitive radio technologies with software defined radios (SDR) [5] are more adaptable than traditional radio terminals. This new type of radio communication terminal device on the base of SDR can work under continuously changing radio environment and support conflict-free coexisting with other wireless devices that use lots of physical protocols, datalink – media access control layer protocols and network layer protocols.

STANDARDIZATION ASPECTS OF COGNITIVE RADIO

These days cognitive radio technologies, equipment developments and productions are the matter of innovations because DSA access with combination with an intellectual control and transmission technologies bring new paradigm of the spectrum access. The problem is that these new CR devices would be able to avoid co-channel interference in wireless communications. For that reason a great standardization working activity regular take place in the cognitive radio technologies and SDR. These efforts are implemented by the Institute of Electrical and Electronics Engineers (IEEE), International Telecommunication Union (ITU), European Telecommunications Standards Institute (ETSI) and European Computer Manufacturers Association (ECMA) [6].

One of the first standard consider cognitive radio principles, technologies and DSA was IEEE 802.22, initiated in 2004. This standard has been designed for data transmission devices in the wireless regional area network (WRAN) where radio terminal uses white spaces in the TV frequency spectrum. Because the importance of CR researching area is great, in 2004 was initiated some standardization project called IEEE P1900. These projects became a part of IEEE Standards Coordinating Committee 41 (IEEE SCC41) in 2006 and finally IEEE SCC41 was renamed as IEEE Dynamic Spectrum Access Networks Standards Committee (DySPAN-SC). In the focus of this committee is development of the research ideas into commonly used standards of CR. Next, ECMA-392 standards was finally published in 2012 with information concerning physical layer and media access control layer for cognitive network and personal devices/terminals functioning and operating in digital TV frequency based.

The efforts of the ETSI Reconfigurable Radio Systems Technical Committee are concentrated on the software-defined radio (SDR) architecture, function and use case standards. This couple of ETSI CR and SDR standards addressing the regional conditions and requirements of the European regulators in telecommunications and TV white spaces (TVWS) standards adapted to the digital TV signal characteristics in European Union.

In 2012 the cognitive radio systems was defined by ITU-R Communication Sector (ITU-R) as a radio system employing advanced technology that provides the telecommunication system the clear facilities to obtain knowledge of its radio environment with help of sensing and probing technologies and equipment, to adjust operational parameters and characteristics including PHY, MAC and network protocols attributes.

RESEARCH ISSUE IN CR PHYSICAL AND DATA LINK LAYERS

On the base of discussed standards there are three base parts in the cognitive cycle of DSA decision making [7]:

1. Analysis of the radio environment and search of free frequencies, which is performed in the receiver of by radio communication terminal CR device.

2. Dynamic spectrum access management, transmit power control, both of which are performed in the transmitter by radio communication terminal CR device.

3. Global feedback, enabling the transmitter to act in context of information about the radio environment feedback to it by the receiver.

Furthermore, it’s need to add a stage of cognitive management information transfer with media access control protocol. MAC protocol used data had collected at the stage 1, 2 and stage 3.

On the base of receiver information and with help of its own information, including MAC layer, cognitive radio system can learn from the obtained results and probing. The knowledge used by the CR/SDR includes parameters of operational radio environment, information of geographic area and wireless networks at this area, internal and external state of radio communication devices like as base stations and user terminals, existing policies of spectrum access, usage segment of spectrum and users’ needs, quality of service and preferable network and terminal demands.

There are a lot of methods for obtaining knowledge, for example getting information from special programmable component of SDR with spectrum sensing, from geo location data base (GLDB) with information about white spaces, and with access to a cognitive pilot channel (CPC) [8, 9].

To avoid interference and to aim the opportunistic spectrum access the couple of information to making decision about DSA has to include received signal power, load of desired channel, signal to interference and noise ratio (SINR).

For spectrum access a special coordinating devices are used. These devices can collect and provide useful information like as available frequency bands, radio access technologies (RAT) in association with base stations, access points and user terminals, restriction to the transmission power values. The coordination of base stations’ and radio terminals’ positions and positions of another telecommunication systems can be obtained using global position system (GPS) or wireless systems coordinating and positioning features.

Next in this paper the subject of research will be case with uncoordinated access as a more common point in CR system. The idea is that the estimation of the access delay [10] for uncoordinated manner of access will be an upper estimation of access delay when secondary users have to wait for a time to get access to the spectrum and radio channel resource.

Since early 2000s a numerous different platforms and prototypes of radio communication terminal with supporting of cognitive radio have been designing. A common view of main functional block for the physical and data layer of radio communication terminal with supporting of cognitive radio is on the Figure 1 (inspired by [1, p. 69]).

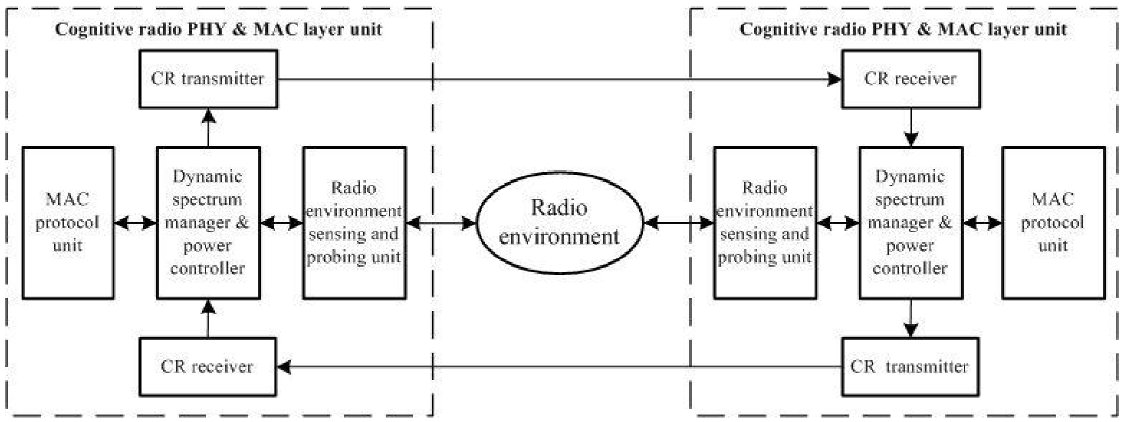

Figure 1. Functional block scheme of radio terminal device with supporting of cognitive radio features

Cognitive radio transceivers have the features that support changing their transmitter parameters in wide values range. These parameters are the type of modulation, transmission power, operating spectrum and communication technology. This device regards as software defined radio that can sense a wide spectrum range, probing and identify temporary unused spectrum segments and use these unoccupied frequency bands for data transmission or receiver.

The subject of further research with computer modelling will be a MAC protocol unit [11, 12]. Before describing a process of simulation, it is necessary to make some preliminary commentaries.

In the cognitive networks, the list of available channels is a variable parameter. Therefore, the issue of best acceptable channels selection is discovered. This problem solution in term of open system interconnection (OSI) model is at the data-link level where is a control access protocol that grants an access to the transmission medium. As it said above, it is a medium access control protocol with specificity in the context of cognitive network and DSA.

MAC protocol operation bases on received data from the physical layer. This data used to solve the problem of recognition of temporary unoccupied radio frequencies. The next step is decision making process about which of the unoccupied channels could be using, how to get access to this selected channel. However, information from data link layer help to find the optimal direction / transmission path, indicating a list of available channels for the network layer. In return, the network layer can transfer to the link layer an information about which channel has an appropriable quality of service (QoS) for the data transferring session initiation. As a result, the MAC protocol unit at the Fig. 1 for uncoordinated spectrum access has support following main functions:

- The control and prevention of interference in the primary users of radio frequency spectrum.
- Prevention of conflicts of access to the channel for the secondary users.
- Realization of the selection process and finding the best in the predefined criteria, unoccupied radio channel.

The MAC protocol performance research is discussed in [11] with a summary that to the MAC protocol for CR network some special features are added. In this circumstance in this paper the network simulator ns2 is used. The computer model of uncoordinated access method to the cognitive network based on the Cognitive Radio Cognitive Network (CRCN) patch for network simulator ns2 on the base of Linux Ubuntu 10.04 operating system [13, 14].

CRNC Settings for Uncoordinated Access Method Simulation

The CRCN patch has the input data as the amount of radio terminal devices with SDR features and the overall number of radio channels. The main modelling scenario provides a description of queues and channels for each SDR scenario with help of the TSL program library. Finally, the network simulator ns2 with CRCN patch has the following functionality for simulation cognitive MAC protocol unit:

1. The description of multi-channel data transmission medium.
2. The interface description for radio channel selecting.
3. A possibility to change and choice transmission power value.
4. Interference information.
5. Information about the motion or position of radio terminal devices.

The CRCN patch provides a needful opportunities to describe the collisions on the MAC layer. Before start of modelling process user has to add description of multichannel transmission medium layer structure in the form of program code component (see in Fig. 2).

```
Component 1. Select the number of interfaces and channels of distribution zone to
TCL script
set val(ni)                2;# number SDR
set val(channum)   2;# channels available for SDR
Component 2: New facilities in the channel specified in the first component.
for {set i 0}  {$i<[expr $val(ni)*$val(channum)]} {incr i} {
                           set chan_($i)[new $val(chan)]}
}
Component 3: Setting the SDR and the channel
$ns_node-config -ifNum $val(ni) -channel $chan_(0)
$ns_node-config -ChannelNum $val(channum)
Component 4: Communication objects in an array of channel
for {set i 0}  {$i<[expr $val(ni)*$val(channum)]} {incr i} {
                           $ns_add-channel $i $chan_($i)
}
```

Figure 2. A fragment of the CRCN code with different number of channels

In fact, the choice of unoccupied channel depends on the MAC layer cognitive radio features or depends on the algorithm with exploration of the public key DSA (digital signature algorithm).

Next, in the program code to the "sendDown" procedure the function "WirelessPhy" be added. This function includes the description of the frame transmission process when the frame transmits to the physical layer.

However, to avoid access conflicts or to reduce interference between adjacent nodes the special channel index is used in CRNC. This channel index obtained from the MAC layer or from DSA algorithm.

For example, the index "channelindex" determines the packet header, which carries data for cognitive routing (see in Fig. 3).

```
Module WirelessPhy: The interface for selecting channel MAC
void WirelessPhy::sendDown(Packet*p)
{
            ...
            //Send the packet
            //channel_>recv(p,this);
            //send packet over the channel specified by channel index.
            multichannel [hdr_cmn::access(p)>channelindex_]>rexv(p,this);
            ...
}
```

Figure 3. A fragment of the CRCN code to select the MAC-level channel

An addition there is recommendation to use mechanism for the prevention of collisions that used as a part of ns2 features.

In this paper, we are considering the model of "hello" packets transition and the routing of these messages at the same time on several radio interfaces of radio terminal with aim to establish communication session. This simulation uses described functionality of the CRNC patch. A particular channel can be assigned by means of simulator to specific interface radio terminal device with SDR features. The assignation may be carried out by MAC level or can be transmitted from the network level. The graphical user interface (GUI) allows to define process and data that necessary to CRCN. At the network layer the routing protocol named as “ad hoc on-demand distance vector” (AODV) is used by procedure of routing simulation.

The test carried out on multi-channel static network structure. The aim of test is verification of network operability with procedure network layer sends available channel data to the data link layer. In the routing procedure, the algorithm AODV making decisions on the use of the assigned channel. Since management of multi-channel structure is performed by simulator for MAC protocol layer only, the test includes two stages. In the first stage, each node sends a packet to the upper OSI layer and provides with information about the unoccupied channel(s). In the second stage, the node will use the already selected channel to transmit and receive data. Simulation parameters shown at the Table 1.

Table 1. Simulation CRNC parameters

Description	Value
Simulation tool	NS-2 (with CRNC patch)
Network area	100 m × 100 m
Number of nodes	10, 20
Number of channels	2, 5, 10
Channel availability (availability)	0.01 to 0.99
Simulation time	50 s

It is need to say, that evaluating the probability of channel availability was described in [15]. In [16] a special monitoring network was proposed for channel availability classification. In [17] the results of statistical modelling of channel availability were shown.

The three options of multichannel structure performed for simulation. At the first option there were 2 channels, at the second option there were 5 channels and in the end there were a 10 channels. An overall number of nodes was 10 in the first experiment and was 20 in the second experiment.

ANALYSIS OF COMPUTER SIMULATION RESULTS

For comparative analysis, all network nodes provided results, but the simulation results do not provide accurate values because modeled by a random processes. In order to estimate probability p of event, where event was a channel occupation, the probing simulation was done with result in 14 success attempts of channel occupy during 50 tests, since probing p = 0.28. The accuracy evaluation (closeness in estimation) in all simulation experiments was set to $\varepsilon < 0.01$. With the 95 % confidence interval for the 30 points used for plot composition, the number of tests in the one statistical experiment was determined as 9939, round to 10000. During simulation process was realized three experiments with 10000 tests in one experiment for 10 and 20 nodes respectively.

The nodes placed static in random order. These nodes selected randomly as senders or receivers data. The queue service time of each network described by the exponential distribution. The node selection is randomly. In addition, necessary to note that availability defined as the probability that a channel is available for the secondary user as result of sensing and probing process. The data rate was in interval from 0.3 Kbit/sec to 0.5 Kbit/sec as for low-rate sensor [18]. On the Fig. 4 and the Fig. 5 the number of the channels sets as “C”.

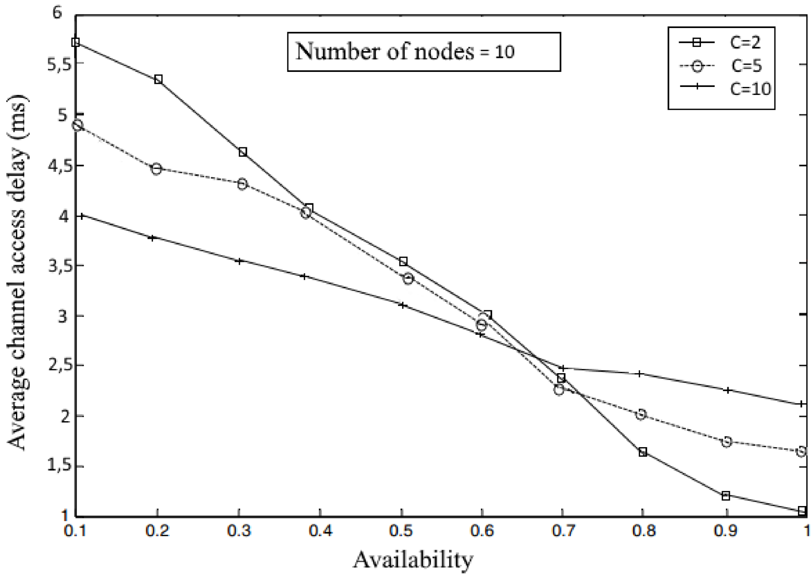

Figure 4. The channel access delay by using 10 nodes

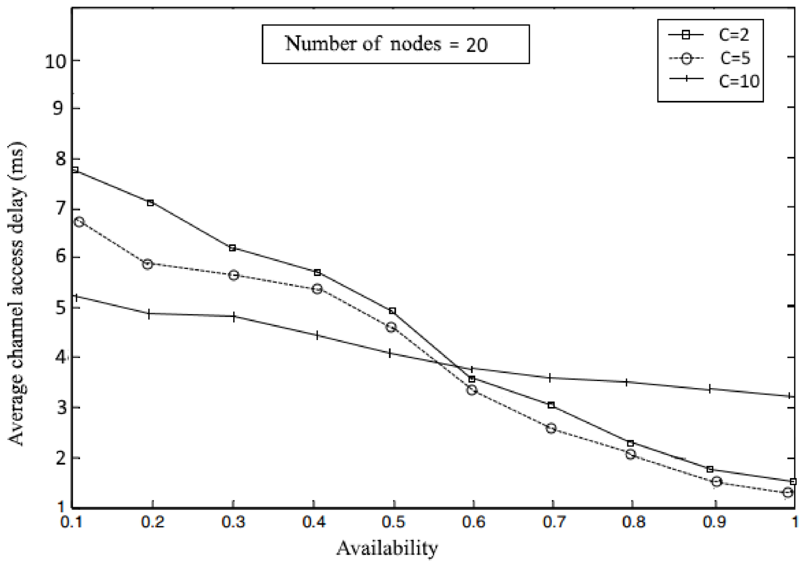

Figure 5. The channel access delay by using 20 nodes

Simulation is carried out with a different number of channels (C = 2, 5, 10), nodes get access to the channel at the same time, this procedure leads to access delay and collisions in the simulated network.

When availability value is observed from 0.1 to 0.6, there is high-delay access scheme, but when the availability is increasing the number of collisions is reduced. The matter of the observation is visible crossing point of lines on the plot in Fig. 4 and Fig. 5. On the plot's right side from the crossing point (for availability value from 0.65 to 0.99) is not too much changing of the channel access delay (delay changing from 2.5 ms to 1 ms) as in interval of availability value from 0.1 to 0.6 (delay changing from approximately 5.7 ms to 2.5 ms). Moreover, on the Fig. 4, as example, after graphs crossing, the scheme with C = 2 channels is a bit more better than scheme with C = 5 and 10 channels in context of channel access delay. Since in real network there is a possibility with specific value of availability emerging to decrease number of accessible channels without greater increasing of average channel access delay. This result could be used in radio devices tune-up and for network design, planning and analysis.

On the Fig. 5 the simulation result shows the visible crossing point of graphs and there is no big differences between graph for C = 5 and C = 2 in channel access delay context. There is no big advantage of scheme with C = 2 on the Fig. 5 like on the Fig.4, but the number nodes on the Fig.5 is double number of nodes on the Fig. 4.

It is need to remark there are some rises and falls in the plot at the Fig. 4 and Fig. 5 because the process of channel selecting is a random and the channel availability is random value too.

The results of simulation show there is a threshold value availability for static ad-hoc network in context of average channel access delay. If the value availability will be bigger than threshold value (approximately 0.6…0.65 in Fig. 4 and Fig. 5) then network with smaller number of channels looks better than network with bigger number of channels as an effect of cognitive network features.

In the future DSA with cognitive radio principles and software configurable radio-terminals create a wide range opportunities for reconfigurable radio networks in military, social works, medicine, radio access technology new generation including cognitive wireless sensor networks.

CONCLUSION

In the future DSA method with cognitive radio principles and software configurable radio-terminals create a wide range opportunities for research and applications in military, social works, medicine, radio access technology new generation. The great aim of these technologies is to improve the spectrum efficiency using for radio terminal devices with SDR features.

The actual issue is the research of future parameters estimation of the cognitive radio networks, like as access delay for secondary users. The results of computer simulation for uncoordinated access method shows that access delay value depends of availability of radio channels. There is a possibility to decrease number of accessible channels without dramatically average channel access delay changing at the network with low-rate nodes. For the further studying, the problem of the access delay for coordinated access method and network with high-rate nodes will be important.

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