Survey Report of Cognitive Radio Network Technology for MAC Layer Protocol.

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ABSTRACT

This paper presents the survey report of Cognitive Ratio technology for its implementation at the MAC layer. The CR MAC protocol can be classified according to infrastructure-based or infrastructure-less; use of DCCH and/or NDCCH; channel access mechanism; in-band or out-of-band channel; underlay or overlay mechanism. Non-Dedicated and dedicated Control Channel Protocols along with their implentation are discussed. After that Spectrum sensing and access techniques are proposed in detail. More over channel selection techique is elaborated. In the end the energy consumption, time and throught put are described based on the cognitve radio archtitucrre for MAC Layer.

Keywords: The author shall provide up to 5-6 keywords (in alphabetical order) to help identify the major topics of the paper. For eg; Engineering, magnetization, systems, conferences.

1. INTRODUCTION

Cognitive Radio Network is divided into infrastructure and infrastructure-less CR-MAC protocols. Section 2 provides an in-depth analysis of the non-dedicated and dedicated control channels and a comparison of the available well-known CRAHNs protocols. Section 3 discusses the applications of the single and multiple transceivers for the CRAHNs. Sections .4 to 6 provide detailed descriptions of the CRAHNs and how CR nodes sense and access the spectrum, utilize the spectrum effectively and switch to BDC if PU returns. Last section describes the CR-MAC protocols based on communication time, energy consumption and throughput.

2. EASE OF USE

A. Cognitive Radio Medium Access Control Protocols

CR is capable of sensing unoccupied band(s), confguring itself, utilising white space(s) and then establishing its connection over these white space(s). MAC is the second layer that plays a vital role for the SUs operation to exchange control and spectrum information via CCH (i.e. Dedicated Control Channel (DCCH) and/or Non-DCCH (NDCCH)) and switch to white spaces to communicate with each other [1]. The DCCH must be recognised and available for all SUs to access and utilise the spectrum without interference to the licensed users. Thus, the MAC protocol facilitates the CR nodes' channel access and the addressing mechanisms of the SUs as well as manages the re-configuration based on spectrum sensing. The CR MAC protocol can be further classified according to the following characteristics: infrastructure-based or infrastructure-less; use of DCCH and/or NDCCH; channel access mechanism; in-band or out-of-band channel; underlay or overlay mechanism; synchronous or asynchronous CRNs; dynamic or direct spectrum allocation based; single or multichannel; single or multi-radios; and cooperative or non-cooperative

B. Infrastructure-based CR Networks

Infrastructure-based CRN is based on a central entity such as an access point and a base station, which manages the cognitive activities in the network. The central entity is responsible for managing information for spectrum availability, mobility, management, security and cooperation among cognitive nodes in the infrastructure-based networks as shown in Figure 1. Cordeiro et al [2] has proposed IEEE 802.22, the first worldwide wireless standard for CR, but their applications are restricted to TV channels. Stevenson et al [3] has presented an enhanced version of IEEE 802.22 for Wireless Regional Area Networks (WRANs). Brik et al [4] has introduced the concept of Dynamic Spectrum Access Protocol (DSAP), to utilise DSAP servers and DSAP relay as centralised entities that coordinate spectrum access requests and permit multi-hop communication between DSAP clients similar to the Dynamic Host Configuration Protocol (DHCP). The centralised CRNs use Frequency Division Multiplexing (FDM) to segregate the spectrum into pre-determined frequency slots for the SUs communication [5]. In addition, the Time Division Multiplexing (TDM) technique is adopted to determine the activity of the PUs and exchange control frames among the server and clients without any channel selection criteria. A point to multi-point CRNs requires two steps for cooperation between primary and secondary users to maximise the coverage and throughput of the SUs

Figure 1. Infrastructure-based CRN

C. Infrastructure-Less Cr Networks

In infrastructure-less CRNs, the SUs can communicate directly with other SUs without a central entity and are responsible for all operations and functionality, as shown in Figure 2. SUs can leave and join the system at any moment without interfering with PU activity. Extensive research have been carried out in the area of CRAHNs which addresses multiple issues such as spectrum management, spectrum sharing on control and data channels, synchronisation of nodes, power saving, throughput, data dissemination and emergency message dissemination in vehicular networks [6] [7]. The CRAHNs are categorised on the basis of CCH that can be further classiied into DCCH and NDCCH. The following section discusses the characteristics of NDCCH and DCCH.

This paper focuses on CRAHNs based on DCCH, there is no central entity to govern the information among the SUs, including channel selection, communication time and energy management and throughput of the network. In addition, it is assumed that the CCH is dedicated and always available and reliable for SUs exchanging control information between the CR nodes for the DCHs. The following section discusses the CCH and its classifications for CRAHNs

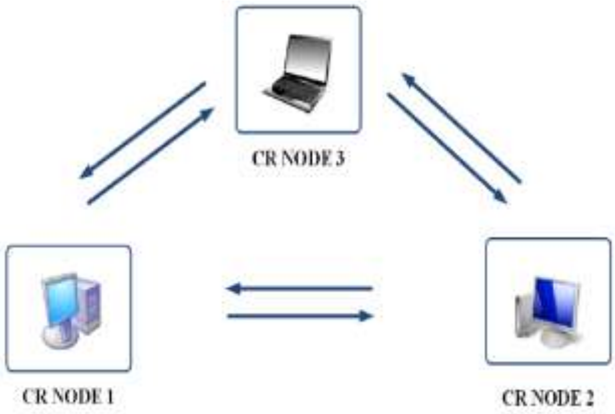

Figure 2: Infrastructure-less CRN

D. Control Channel

The CCH facilitates the SUs' exchange of their preliminary information before switching to DCH in infrastructure-less networks. The CCH can be classified into static and dynamic cases. Under the static mode, the CCH is called DCCH to the SUs or the Industrial Scientific and Medical (ISM) frequency spectrum with a frequency value of 2.4 GHz (IEEE 802.11b/g). In the dynamic case, the SU selects unused licensed channels to exchange control information [8]. The CCH is further classified into two main categories.

E. Non-Dedicated Control Channel Protocols

In this category, the SU selects and utilises one of the most reliable white spaces as a CCH to exchange all control information before starting the communication. The decentralised Adaptive MAC (A-MAC) protocol has assumed that NDCCH with N sets of channels utilise unused space effectively [8]. In A-MAC, a SU retains a Channel STatus Table (CSTT) and indexes the channels repeatedly. A-MAC adopted 802.11 Distribution Coordination Function (DCF) spectrum access mechanisms to select the most reliable channel as a CCH among the SUs with high probability to be stable. The channel stability is based on high bandwidth, reliability of the channel, channel condition, and channel usability, but there is no discussion about these parameters in the A-MAC protocol.

The Cognitive MAC (C-MAC) Protocol for Multi-Channel Wireless Networks has adopted the idea of a dynamic Rendezvous Channel (RC) to select the unused time slot and set this channel as a CCH which manages and coordinates all control and data communication [9]. The C-MAC considers simultaneous communication over all available DCHs, where each transmitter has an infinite frame to send to the receiver, as not being a practical approach in the CRAHNs. In addition, this transmission approach wastes network resources, consumes additional time and energy and introduces excess delay

The Synchronized MAC (SYN-MAC) protocol for CRNs select one of the common free channels to exchange all control information, using 802.11 DCF mechanism, with the neighbours while the rest of the available channels are utilised for data communication [9]. There might be the case that each SU has a choice of more than one common channel between the sender and the receiver. In this case, the SU sender and receiver need to agree on a common available channel which is known as the CCH. SYN-MAC is designed to avoid Denial of Services (DoS) attacks and the multi-channel hidden terminal problem. Concealed terminal problem happens when the SU is listed on a specific channel, but is unable to listen to communications taking place through a di_erent channel. If this problem happens in a multi-channel environment it is referred to as a multi-channel hidden terminal problem.

To conclude, the selection of the NDCCH is required for exchanging control information among the SUs, if there are no PU returns. In realistic and practical situations, the return of the PU is unpredictable and it may happen that the PU returns during the exchange of the SUs over the CCH. In such cases, the above articles must always consider backup CCH in their available channel list rather than scan and select new NDCCHs. In research relating to this issue, most of the researchers assumed that the CCH is NDCCH without discussing their selection process and did not go into what would happen if the PU were to return during the communication

F. Dedicated Control Channel Protocols

The authors of [10] [11] assume that the CCH is dedicated and is always available for exchanging the control information prior to any data communication. Based on the FCC's and other related committees' research, it is assumed in this paper that the CCH is dedicated and that only 30% of the spectrum is occupied most of the time. Another benefit of the DCCH is that it is available 24x7 without any permission . F2-MAC protocol overcomes the problems of channel sensing by using the channel hopping technique and adopt a rendezvous process to access the NDCCH, exchanging control information among the cognitive nodes [12]. Five types of control messages are used in the F2-MAC protocol. Two categories of control frames are similar to conventional RTS and CTS and are delivered through DCCH. The remaining three additional frames such as Data Channel Idle (DCI), DCI-ACK and Ready-To-Vacate (RTV) are delivered via DCHs. F2-MAC adopted the proactive channel strategy in which the activity of the PU is predicted and the SU selects the channel based on the prediction.

In TDMA based Energy Effcient Multichannel MAC protocol for CRAHNs (ECR-MAC), where each SU is equipped with a single transmitter/receiver to scan several channels [11]. One of the scanned channels is always used as a DCCH to exchange control information and the rest of the channels are available for data communication. The pair of SUs can only communicate if both Chapter 2. Related Work 29 cognitive nodes select the same channel and are within transmission range of each other. However, a main disadvantage of the ECR-MAC protocol is synchronisation, where the channel timeslot negotiations are completed prior to channel sensing, which may be affected by the out-of-date spectrum sensing results. In addition, the ECR-MAC is unable to continue the communication over the selected DCH if the PU returns.

The MAC protocol for Opportunistic Spectrum Access in Cognitive Radio Networks (OSA-MAC) specifying the DCCH, which is available all the time (i.e., this DCCH may be owned by the secondary service provider), to exchange all control information and to negotiate the channel for data transmission using four way handshaking [18]. The OSA-MAC protocol divides the time into the number of beacon intervals and all SUs are synchronised periodically. In addition, the OSA-MAC incorporates the spectrum sensing capabilities but must vacate the channel to minimise collision when the PU returns over the licensed channel. In OSA-MAC, saturation throughput is analysed under the assumption that the SUs always have data for transmission between the cognitive nodes.

To summarise, the protocols discussed in this subsection do not include an explanation of how the CCH was selected. The beneit of the DCCH is that it is available all the time without any permission and license requirements and SUs can exchange information over the DCCH and switch to the DCH for their communication. The protocols also assume that the CCH is dedicated and always available for exchanging control information prior to any data communication to achieve successful communication among SUs, thus saving energy and giving a high throughput. There is always a tradeoff among multiple factors in the development of new protocols including the DCCH, NDCCH, DCH, reliability, energy effciency, delay, throughput, security, cost, and BDC. One of the objectives of this paper is to design a protocol whose demerits do not degrade the reliability and effciency of the proposed protocol.

The selection process of the channel is called soft channel reservation as, when multiple idle channels are available, the last successful channel is considered to be the best channel for data communication. In [13], the enhanced channel selection strategy describes the selection of the best DCH is based on the power level sensed at the transmitter side. In contrast, the Receiver Based Channel Selection (RBCS) technique is proposed the selection of the best channel based on the SINR at the receiver side [14]. Similarly, the main objective of the Power Saving Multi-Radio-Multi-Channel MAC (PSM-MMAC) protocol [15] is to reduce the use of power during multi-channel operation. This PSM-MMAC protocol is extremely useful in light of the fact that some cognitive nodes are powered by battery.

To conclude, the SU with multiple transceivers solves the challenges of single transceiver protocols such as the ones posed by the hidden terminal problem, multichannel hidden terminal problem, improved sensing accuracy, better spectrum effciency, connectivity and channel switching, but it increases the cost of the network.

3. SPECTRUM SENSING TECHNIQUES

The spectrum sensing and accessing techniques play a vital role in the CRAHNs based on DSA networks. In spectrum sensing, the SUs gather the information regarding spectrum usage and the presence and returns of the PUs, through the physical layer. To improve the detection threshold, three approaches to detect the signal energy were demonstrated in [16][17]: matched filter detection, energy detection and cyclostationary feature detections. Matched filter detection is an optimal detection technique with low computational cost, but it requires prior knowledge of the PUs.

Cyclostationary detection needs partial knowledge of the PUs but comes at high computational cost. In contrast, the energy detection technique requires a short sensing time and is of low complexity. Additionally, it does not require prior information of the PUs. When selecting a sensing method, some trade-offs should be considered with respect to hardware and SU requirements, such as whether the sensing time is long or short and whether prior knowledge of the PU is required. The energy detection technique is useful during the initialisation of the activity of the protocol because the implementation is simple and effcient when compared to other techniques. In addition, it does not need prior information of the PUs signal features, which is not usually known by the SUs.

The energy detection technique would be unable to detect the return of the PU during the communication of the SUs over the DCH because of the high transmitted energy of the SU. Therefore, the cyclostationary technique is able to differentiate the PU and SU signals and signal the transmitting SUs to stop the communication on that DCH and switch to the BDC. The features of energy detection and cyclostationary techniques are nearer to the properties of the proposed CR-MAC protocol. However, the SUs' access of the geographic unused spectrum in the TV band (known as TVWS) has drastically enhanced the effectiveness of the band usage [10]. Since 2008, the FCC has authorised spectrum vendors to build a geographic database based on the unused spectrum of TV broadcasting [18]. To conclude, in this study, the energy detection technique is assumed to sense the activity of the PUs before starting the communication over the DCH and the cysclostionary technique is assumed during the exchange of the data frames over the DCHs.

4. SPECTRUM ACCESS TECHNIQUES

Due to the conventional wireless nature of the CR, the spectrum access mechanism is categorised into three approaches: time slotted, random access and hybrid access. SUs access the spectrum to transmit data when the spectrum is unused and vacate these unused spaces immediately if the PU returns. In the time slotted access mechanism, each SU can only communicate in its particular time slots. Each time slot has a listening period where SUs are synchronised and a communicating period for the exchange of control and data frames. The TDMA technique is used to access CCH to exchange FCL or to transmit data packets in DCH. In [7] [8] [19], the protocols have divided the channels into a fixed or different length of beacon intervals and each beaco n interval has a sensing window for sensing the spectrum and communication window for data communication. During the sensing period, cognitive nodes exchange information, and carry out channel negotiation and synchronisation, which handles the hidden node problem, mobility and medium reservation, and enables data transmission during the communication window. Data packets can be transmitted on the DCH followed by an ACK message as shown in Figure 3.

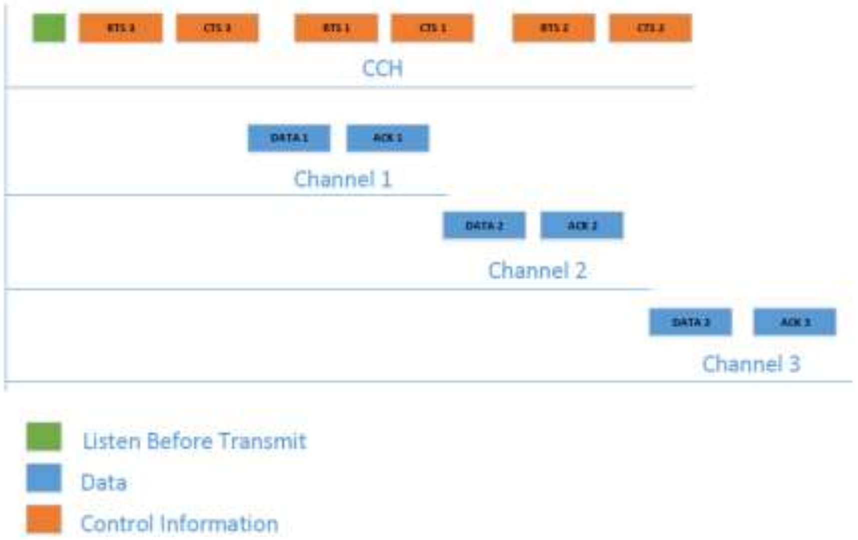

Figure 3. Flow of control and data information in the random access CR MAC protocol

Hybrid access MAC uses time slotted and random access techniques simultaneously, where control signals among SUs are synchronised via time slots and data transmission occurs through the random channel access, as discussed in [20][21]. The major drawback in these protocols is the usage of FIxed duration time slots, but the length of the time slots varies when nodes join and leave the network. To conclude, the time slotted technique requires a central entity to manage synchronisation in cognitive networks. In the Random Access technique, each SU competes for the medium to exchange control frames over the CCH and then switches to the DCH for data communication. In this study, the proposed CR-MAC protocol functionality is based on the Random Access mechanism. The hybrid access mechanism uses the time slots and random access methods simultaneously, but discussion of these methods does not fall within the scope of this paper

5. CHANNEL SELECTION PROCESS

In the CRNs, the selection of the control and data channels is the most important factor for the SUs. The SUs need to select the CCH and DCH for the exchange of control and data information. If the PU returns during the communication, the SU pauses the communication and pursues other available DCHs to resume the communication or re-start the entire process. There are a number of channel selection process, which are discussed in [22] [23] [24] for CRNs with and without selection criteria. The channel selection without any criteria is known as random channel selection. The SUs usually assume that the selected channels are equally good, but in fact, the selected channels could be heavily used by PUs. This frequent interval of PUs over the channels disrupts the communication of PUs and SUs. Therefore, the communication performance may be drastically degraded due to frequent channel switching. On the other hand, the SUs selection of channels with certain criteria is known as channel selection process. The prediction of the availability of the future spectrum band helps the SUs to switch to the best channel without or with the minimal appearance of the PU. The SUs must have the ability to decide whether to switch to the channel or not, with no or minimal interference to the PUs. These channel selection approaches are proposed to achieve multiple goals such as channel switching time minimisation, energy saving, throughput optimisation and maximisation, minimiminimisation of the channel switching time from control to data channel, maximisation of the channel utilisation, power allocation, SINR, data rate, packet scheduling, and load balancing [25][26].

6. TIME, ENERGY CONSUMPTION AND THROUGHPUT

The sections described above indicates the adopt multiple spectrum access techniques, such as time slotted and random and hybrid access to achieve higher network throughput and to save energy. For example, the CREAM-MAC protocol [23] introduces the integrated cooperative sequential spectrum sensing at the physical layer to improve the sensing time on CCH, reducing collisions at the MAC layer and thus improving network throughput. In addition, the ECR-MAC protocol [24] suggests the TDMA technique, which saves energy and increases aggregate throughput of the CRNs, but introduces a small window at the beginning of each interval which increases collision and additional sensing time among the CR users.

In [19], the CR-MAC protocol with statistical channel allocation selects the DCH that has the highest successful transmission probability to send packets based on the channel statistics which increases the network throughput Section 2 discussed the BDC, which allows SUs to continue the communication without renegotiating on the CCH, which reduces additional overhead if the PU returns. These factors have a direct impact on the performance of the CRNs; specially, they a_ect communication time, energy and throughput. Moreover, the authors of this section reserve the BDC and the BCCH to reconstruct and maintain the SU link when the PU returns and/or when the channel is degraded due to interferences.

In [18], the BCRP-MAC protocol reserves random BDC which reconstructs and maintains the backup link if the PU returns to the licensed spectrum band, thus improving network throughput. In [58], the SWITCH protocol operates over licensed and unlicensed spectrums. SWITCH uses the idea of the BDC and employs it to make the SU tremendously robust when it comes to the return of the PUs, which tremendously increases the network throughput. To summarise, the channel selection technique with criteria leads to the selection of a reliable DCHs which increases the probability of the successful communication and reduces re-transmission among the SUs. In addition, the introduction of the BDC reduces the overheads among the SUs, saves on communication time and energy and increases the network throughput of the CRAHNs.

CONCLUSION

This paper presents the survey report of Cognitive Ratio technology for its implementation at the MAC layer. The CR MAC protocol can be classified according to infrastructure-based or infrastructure-less; use of DCCH and/or NDCCH; channel access mechanism; in-band or out-of-band channel; underlay or overlay mechanism. Non-Dedicated and dedicated Control Channel Protocols along with their implentation are discussed. After that Spectrum sensing and access techniques are proposed in detail. More over channel selection techique is elaborated. In the end the energy consumption, time and throught put are described based on the cognitve radio archtitucrre for MAC Layer.

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