Channel Access Scheduling for Fair Distribution of Channels to Secondary Users in a CRN

S. Tamilarasan, K. Balakrishnan

Abstract – *A Cognitive Radio Network (CRN) is one where Primary Network has the priority of utilizing the spectrum. The Secondary Networks are regulated to make sure that they do not interfere in the channel access when a primary is active. However, when a primary is inactive, the secondaries are allowed access to the spectrum. But there does not exist a way to coordinate between the various secondary networks that access the spectrum in an event of the absence of the primary. In this paper, we propose a Channel Access Scheduling scheme, which is a centralized approach to coordinate the access of the channels by the various Secondary Networks that are part of the CRN. The scheduling scheme is based on a Coexistence Manager (CM) that coordinates the channel access between the secondaries. The CM takes into account parameters like QOS and waiting time in the queue to decide on which secondary accesses the channel. The simulation results show that the proposal improves throughput of the system and also improves fairness in channel allocation.*

***Index Terms*—Cognitive Radio Network, Channel Access Scheduling, Coexistence Manager, Throughput.**

I. INTRODUCTION

Cognitive radio networks (CRNs) are an advancing technology in wireless communications used to improve the channel utilization of limited spectral resources, especially as the demand for wireless frequency has rapidly increased in recent years. In CRNs, unlicensed secondary networks (SNs) are only permitted to access the channel only when they do not interfere with the operation of licensed primary networks (PNs); this access occurs through a software-defined radio that seeks to use an idle channel. And recently, the heterogeneity of both channel access policy and spectrum demand in SNs is becoming another urgent issue because the interference induced by the channel usage of SUs may significantly hamper the throughput performance of other SNs in cognitive networks.

The Federal Communications Commission (FCC) has approved the opening of the unused spectrum in TV bands to unlicensed devices. The possibility of spectrum availability subsequently has triggered new standardization activities within the IEEE working groups for the networks capable for operating in TV white space bands. For example, IEEE 802.22 WRAN has appeared in an attempt to develop physical and MAC layer specifications for WRAN operation in less populated rural areas. IEEE 802.11af standard was developed by modifying the conventional IEEE 802.11 standard to operate in this range. And IEEE 802.19.1 standard is at early stage of development for potential coexistence between heterogeneous CRNs.

As the variety of cognitive networks increases, it is expected that multiple SNs with heterogeneous network characteristics may coexist in same area. Most previous research has focused on mitigating the interference between PNs and SNs [1] [2]. In [3], [4], they proposed a priority-based scheduler to solve the coexistence problem. [3] proposed a priority scheduler with only two different levels, where the higher and lower priorities corresponded to PNs and SNs, respectively. Then, in [4], PNs had preemptive priority over SNs, and the priorities for SNs were further divided into multiple priority values.

In this paper, we consider the coexistence among heterogeneous SNs with different maximum tolerable delay requirement, depending on their service type (e.g., best-effort, multi-media, interactive services, and so on). We then propose a centralized approach to explicitly and dynamically coordinate the channel accesses among SNs under the assumption that SNs can exchange channel information and the traffic delay requirement through a coexistence manager (CM).

II. LITERATURE SURVEY

Minal S. Moon et al [5] have proposed an approach for channel selection for data communication using energy detection sensing technology. A new data called Preferable Channel List has been introduced in the proposal. PCL has been used for selection of channel in systems where the receiver is dominant. The proposed system gives reasonable throughput while keeping the delay at a minimum.

Dibakar Das et al [6] have used Lyapunov drift techniques using which caching and scheduling is performed between the primaries and secondaries. The priority of the resource is maintained using the Variable Primary Caching Policy (VPCP) algorithm. The simulation has been carried out to compare the performances of the proposed algorithm and the non-co-operative algorithm. The proposal also extends the analysis to a network with multiple channels.

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Indika A. M. Balapuwaduge, Lei Jiao, Vicent Pla [4] have proposed a queue-based channel assembling strategy for heterogeneous channel CRNs and analytical structure for performance evaluation of such networks. They achieved significant reduction in forced terminations of ESU services. This proposal is recommended if PUs are more active in a CRN.

Ozgur Ergul et al [8] suggests a methodology to minimize interference between SUs and interference caused to PUs. This can be investigated jointly with power control. This also minimizes interference in the network, which increases performance and ensures minimum impact on PUs. But, the approach does not necessarily ensure satisfaction of different user QoS demands.

Yahia Tachwali et al [10] proposes a methodology to Maximize spectrum utilization by maximizing number of channels used or number of SUs served, when each SU selects only one channel. However, the drawback of this approach is that it does not consider different requirements of SUs. In multi-radio multi-channel SUs the complexity can be very high and can be achieved only in centralized spectrum assignment.

III. PROBLEM DEFINITION

From the literature survey, it is very clear that the dynamic channel allocation routine that uses priority as its basis does not exist for a CRN. This becomes more difficult when there is a network with nodes requiring heterogeneous services. In such situations, it is possible that critical parameters like delay may be ignored. Hence, a proposal is made in this paper for providing a dynamic approach for allocating resources while keeping priority scheduling as one of the core concepts for a CRN.

As already mentioned, a CRN consists of two categories of nodes or users namely Primary and Secondary. These users have heterogeneous network and service requirements. While it is the PU that have access to the channels in the spectrum by default, it is the responsibility of the SU Base Station (SU-BS) to allocate the unused channels to the SUs. For this, the SU-BS uses a metric called Channel Quality Indicator (CQI) that helps the SU-BS make a decision on which of the secondary should get the unused channel. This metric CQI is compared with another metric called Signal-to-Interference-Noise-Ratio (SINR) to make this decision.

The capability of the cognitive radio to have knowledge of the spectrum and thereby detect opportunities of unused channels is mainly because of the property of spectrum sensing. This sensing is carried out by the base stations of the secondary network. Spectrum sensing can either be In-Band or Out-Band. Through Out-Band sensing, the BS tries to find out if there are any spectrum opportunities. The In-Band sensing is used to determine if there is any primary user present that needs a channel in the spectrum.

IV. SYSTEM MODEL

In this system, we consider a PN, multiple heterogeneous SNs, and a CM over a single wireless channel. In cognitive networks, SNs are regulated in order to prevent them from accessing the channel if PNs are currently utilizing the channel. The CM is responsible for coordinating the channel access operations among heterogeneous SNs as well as between a PN and SNs.

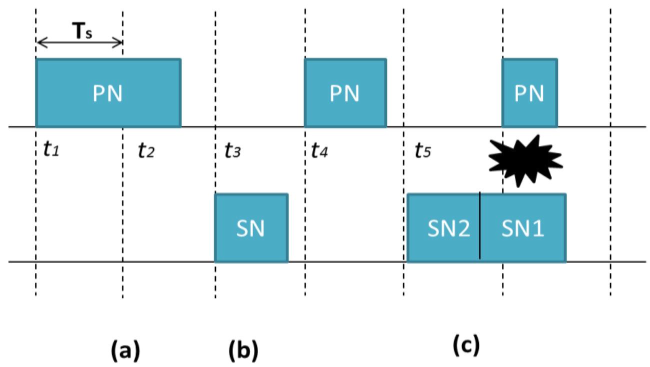

Fig. 1. A coexistence scenario of PN and SNs.

In Fig. 1, a PN and multiple heterogeneous SNs exist, where tn is the n-th sensing time by SNs, and Ts is sensing time interval between successive sensing times. If the PN occupies the channel at a specific time tn, then SNs sense the channel every Ts and report the channel condition information to the CM. Upon the notice from SNs, the CM decides which frame is to be transmitted based on the channel access scheduling policy, as long as the PN is not currently occupying the channel.

A detailed description of the possible coexistence cases between a PN and multiple SNs is as follows:

• **[Busy]** As shown in Fig. 1(a), the first frame of the PN is transmitted at the specific point t1. In this case, no SN attempts to utilize the channel were made during transmission of the PN between t1 and t3 in order to avoid the interference with the PN.

• **[Success]** SNs are able to have opportunity to use the channel between t3 and t4 since the channel is perceived as idle at t3. In Fig. 1(b), the SNs successfully transmit their frames because the transmission of SNs finishes before the PN requires use the channel.

• **[Collision]** After the SNs sense the idle channel at t5, the SNs attempt to gain access to the wireless channel and transmit their frames. Unlike Fig. 1(b), the transmissions of SNs last until the start of PN frame as shown in Fig. 1(c). As a result, these two frames collide and fail to be transmitted, leading to throughput degradation. Therefore, if the transmission of a frame does not finish until the next interval, the channel access scheduler in the CM should not allow such a transmission to begin.

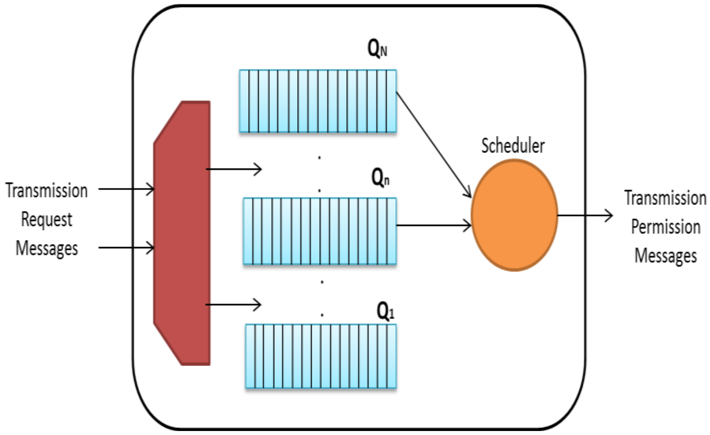

Fig. 2. The channel access scheduling operation in the CM.

Figure 2 illustrates the CM operation, which consists of N queues and a scheduler, where N is the number of priority values, and Q_n is the queue with the n-th highest priority.
When an SN has a data frame to transmit, it sends a transmission request message that includes the network identity and the data transmission duration to the CM in order to acquire the channel use permission. After the CM receives the transmission request message from the SN, it places the message in the corresponding queue according to the priority value of the frame. When the channel becomes idle, the scheduler in the CM chooses a frame from its queues, and then sends the transmission permission message to the SN that sent the request message for the selected frame. As such, the CM must have appropriate channel scheduling policy to efficiently utilize the channel and satisfy the quality of service (QoS) requirements for the PN and SNs in the CRN.

Dynamic Channel Access Scheduling Scheme

The proposed scheduling scheme aims to select a set of data frames from N queues such that the total sum of priorities is maximized while ensuring that the transmission duration does not exceed the remaining idle time. We formulate this scheduling problem as a knapsack problem, i.e.,

$$max \sum_{n=1}^{N} Pn \,.\, Xn \qquad (1)$$

Subject to

$$\sum_{n=1}^{N} Sn \,.\, Xn \le Ts$$

$$X_n \in \{0, 1\}$$

where P_n is the priority value of the data frame at the head of the n-th queue, S_n is the corresponding data transmission time, T_s is the interval between two sensing times, and X_n is a binary decision variable for the data frame in each queue. Note that if $X_n = 1$, the frame in the n-th queue is selected.

In (1), we give a higher priority to a data frame that has shorter maximum tolerable delay because such a frame is more sensitive to transmission delays. For example, if a multi-media data frame fails to be transmitted within its maximum tolerable delay, it cannot be used; in practical terms it can e regarded as lost. Therefore, the priority value of a data frame in the n-th queue can be calculated as

$$P_n = d_n^{-1} \qquad (2)$$

where d_n is the maximum tolerable delay of the data frame at the head in the n-th queue.
We also dynamically update the priorities of data frames in order to mitigate the starvation problem. In (1), the CM tends to select only the data frames with the highest priories with the data frames having low priorities being rarely selected. To solve this problem, we gradually increase the priorities of data frames that are not selected at the head of the queues as follows:

$$Pn \leftarrow Pn + Mn \,.\, a \qquad (3)$$

which M_n is the number of waiting time slots in the head of the n-th queue, and a is the increase of the priority value. As a becomes larger, the data frames having a initially low priority can acquire an opportunity to access the channel.

V. Simulation Results

To evaluate performance of our proposed channel access scheduling scheme, we conducted various simulations using MATLAB. During the simulations, the data transmission times were randomly selected to be between 5 ms and 15 ms; we also assume that the maximum tolerable delays of SNs are 100, 80, 60, 40, 30, and 20 ms [5]. Again, data frames that are not successfully transmitted within its maxim tolerable delay are regarded to be lost.

Figure 3 shows the simulation results of the average delay with respect to the priority values when the idle time period is 50 ms. Note that p1 is lowest priority value, and p5 is highest priority value with the smallest maximum tolerable delay time. The average delays for First in First out (FIFO) are almost the same regardless of the priority value. In terms of the priority queue (PQ) and the proposed scheme with a=0, the data frames with low priorities have extremely long average delay time because the transmissions of data frames with higher priority take precedence over those with lower priority. It is seen that when a = 6, the maximum tolerable delay is lower than the requirement of the tolerable delay.

Figure 4 depicts the network throughput results with respect the idle time period. The throughput performance is seen to increase as the idle time period is increased from 30 ms to 50ms. The reason is that when the available channel access time is increased, more frames belonging to SNs are successfully delivered. Since the FIFO and PQ transmit data frames without consideration of the idle time constraint in (1), they show a low throughput performance. Note that the throughput for the proposed scheme with a=0 is also low since the frames with lower priority have extremely long delay time.

However, our proposed scheduling scheme with an appropriate value of a outperform the conventional schemes, with an overall improvement in throughput performance of about 15%.

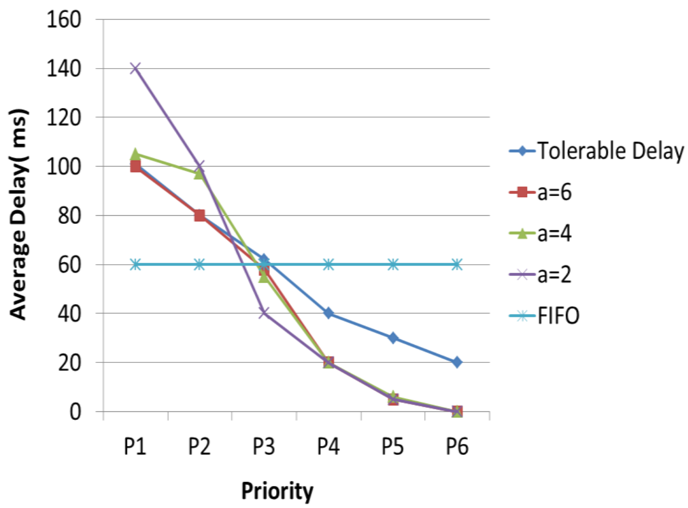

Fig. 3. The average delay time for multiple SNs with different maximum tolerable delay.

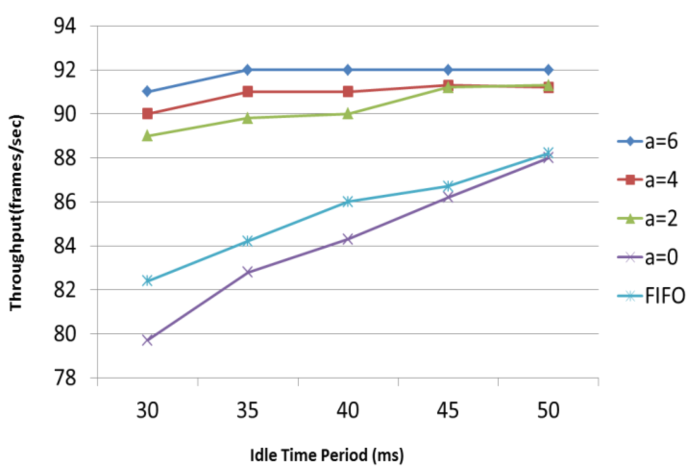

Fig. 4. The network throughput with respect to the idle time period

VI. CONCLUSION

We have studied the channel access scheduling issues when multiple heterogeneous SNs coexist and share a single channel. The proposed channel access scheme was formulated as a knapsack problem to maximize the sum of priorities of data frames under the constraint of limited transmission time. Specifically, the priorities of data frames in the queue were dynamically adjusted according to the wait time in the head of the queues in order to mitigate the starvation problem in priority scheduling. As a result, through various simulations, we showed that our proposed scheduling scheme can meet the requirements for maximum tolerable delay while achieving a high throughput performance.

REFERENCES

[1] Y. Li, and A. Nosratinia, "Hybrid Opportunistic Scheduling in Cognitive Radio Networks," in Proc. of the *Wireless Communications, IEEE Transactions on*, pp. 328-337, January 2012.

[2] R. Urgaonkar, and M. J. Neely, "Opportunistic Scheduling with Reliability Guarantees in Cognitive Radio Networks," in Proc. of the *IEEE International Conference on Computer Communications (INFOCOM 2008)*, Phoenix, USA, pp. 1301-1309, April 2008.

[3] C. Zhang, Z. Wang, and J. Li, "Cooperative Cognitive Radio with Priority Queuing Analysis," in *IEEE International Conference on (ICC)*, Dresden, Germany, pp. 1-5, June 2009.

[4] P. Zhu, J. Li, and X. Wang, "Scheduling Model for Cognitive Radio," in Proc. of the *IEEE Cognitive Radio Oriented Wireless Networks and Communications (CrownCom 2008)*, Singapore, pp. 1-6, May 2008.

[5] J. Deng and R.S. Chang, "A Priority Scheme for IEEE 802.11 DCF Access Method," in *IEICE Transactions on Communications*, pp. 96- 102, January 1999.

[6] Dibakar Das, Alhussein A. Abouzeid, "Co-Operative Caching in Dynamic Shared Spectrum Networks", IEEE Transactions On Wireless Communications, VOL. 15, NO. 7, July 2016, PP: 5060-5075.

[7] A ChSudhir, B Prabhakar Rao, "Priority Based Resource Allocation for MIMO-Cooperative Cognitive Radio Networks", Journal of Scientific & Industrial Research, Vol 75, Nov-2016, PP:667-670..

[8]Ozgur Ergul, A. Ozan Bicen, Ozgur B. Akan, "Opportunistic reliability for cognitive radio sensor actor networks in smart grid", Ad Hoc Networks, 2015, PP: 1-10

[9] Paulo M. R. dos Santos, Mohamed A. Kalil, OleksandrArtemenko, Anastasia Lavrenko, Andreas Mitschele-Thiel, "Self-Organized Common Control Channel Design for Cognitive Radio Ad Hoc Networks", 2013 IEEE 24th International Symposium on Personal, Indoor and Mobile Radio Communications: Mobile and Wireless Networks, PP:2419-2423.

[10] Yahia Tachwali, Brandon F. Lo, Ian F. Akyildiz, Ramon Agust´i, "Multiuser Resource Allocation Optimization Using Bandwidth-Power Product in Cognitive Radio Networks", IEEE Journal On Selected Areas In Communications, Vol. 31, NO. 3, March 2013, PP: 451-463.