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Dynamic Load Balancing for Heterogeneous Cognitive Radio Networks

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***Abstract*—In cognitive radio networks (CRNs), secondary networks (SNs) are regulated in order to prevent them from accessing a channel if primary networks (PNs) are currently occupying the channel. However, there not exists any regulation how to coordinate the channel access among multiple heterogeneous SNs. In this paper, we consider a centralized approach to explicitly coordinate the channel accesses among SNs coexisting in the same CRN; these SNs can exchange channel information through a coexistence manager (CM). We propose a channel accessschedulingschemethatdifferentiatesthequality-of-service (QoS) by assigning priority values and provides a certain level of fairness by taking the queue waiting time into consideration. Through various simulations, we show that the proposed scheme achieves the QoS differentiation among contending SNs while improving both the throughput and fairness performance in CRNs.**

***Index Terms*—Coexistence, cognitive radio networks, priority scheduling, quality-of-service.**

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.InCRNs, unlicensedsecondarynetworks(SNs)areonly permittedtoaccessthechannelonlywhentheydonotinterfere 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 be- coming another urgent issue because the interference induced by the channel usage of SUs may significantly hamper the throughput performance of other SNs in cognitivenetworks.

The Federal Communications Commission (FCC) has approved the opening of the unused spectrum in TV bands to unlicensed devices. The possibility of spectrum availablyity 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 inthisrange.AndIEEE802.19.1standardisatearlystageof

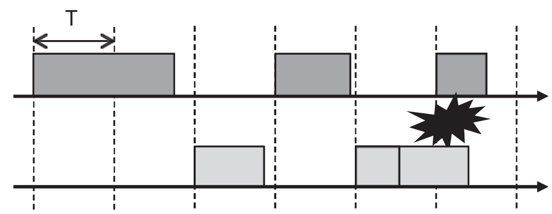

Fig. 1. A coexistence scenario of PN and SNs.

development for potential coexistence between heterogeneous CRNs.

Asthevarietyofcognitivenetworksincreases,itisexpected 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 thecoexistenceproblem.[3]proposedapriorityschedulerwith 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 multiplepriority values.

In this paper, we consider the coexistence among heterogeneousSNswithdifferentmaximumtolerabledelayrequirement, 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 requirements through a coexistence manager(CM).

II. SystemModel

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 andSNs.

In Fig. 1, a PN and multiple heterogeneous SNs exist, where

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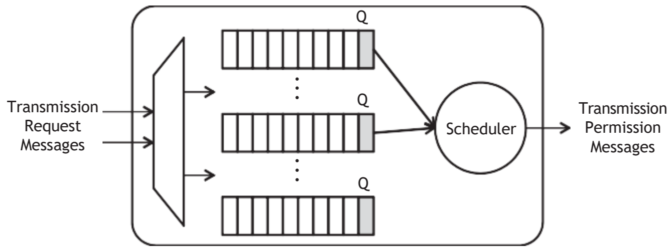

Fig. 2. The channel access scheduling operation in the CM.

$t_n$is the n-th sensing time by SNs, and $T_s$is sensing time interval between successive sensing times. If the PN occupies the channel at a specific time t_n, then SNs sense the channel every $T_s$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 t_1. In this case, no SN attempts to utilize the channel were made during transmission of the PN between t_1 and t_3 in order to avoid the interference with thePN.
- **[Success]** SNs are able to have opportunity to use the channel between t_3 and t_4 since the channel is perceived as idle at t_3. 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 t_5, the SNsattempttogainaccesstothewirelesschanneland 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 tobegin.

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 ofservice (QoS) requirements for the PN and SNs in the CRN.

III. Dynamic Channel Access SchedulingScheme

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.,

$$\max \sum_{n=1}^{N} p_n \cdot x_n \qquad (1)$$

subject to

$$\sum_{n=1}^{N} s_n \cdot x_n \le T_s$$

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

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. Notethatif$x_n=1$,theframeinthe$n$-thqueueisselected.

In (1), we give a higher priority to a data frame that has shortermaximumtolerabledelaybecausesuchaframeismore sensitive to transmission delays. For example, if a multi-media dataframefailstobetransmittedwithinitsmaximumtolerable 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 calculatedas

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

where$d_n$is the maximum tolerable delay of the data frame at the head in the n-thqueue.

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:

$$p_n \longleftarrow p_n + M_n \cdot a, \qquad (3)$$

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 prioritycanacquireanopportunitytoaccessthechannel.

IV. Simulation

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 alsoassumethatthemaximumtolerabledelaysofSNsare100, 80, 60, 40, 30, and 20 ms [5]. Again, data frames that are not successfully transmitted within its maxim tolerable delay are regarded to belost.

Figure 3 shows the simulation results of the average delay with respect to the priority values when the idle time period is

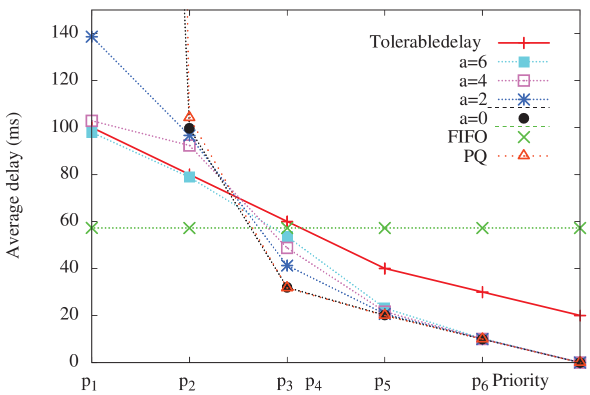

Fig. 3. The average delay time for multiple SNs with different maximum tolerable delay

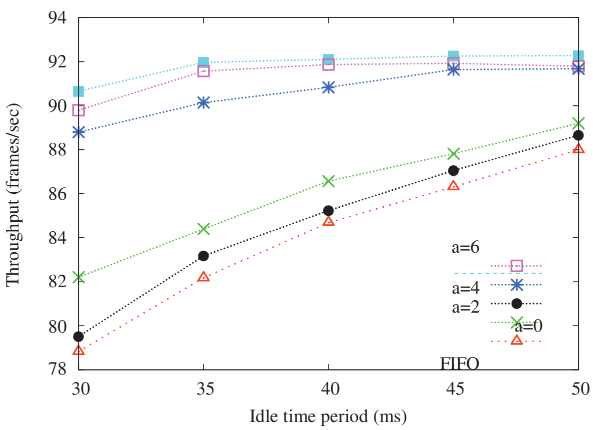

Fig. 4. The network throughput with respect to the idle time period

50 ms. Note that p_1 is lowest priority value, and p_5 is highest priority value with the smallest maximum tolerable delaytime. 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)andtheproposedschemewith$a$=0,thedataframes 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 tolerabledelay.

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 throughputfortheproposedschemewith$a$=0isalsolowsince 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, withan overall improvement in throughput performance of about 15%.

V. Conclusion

We have studied the channel access scheduling issues when multiple heterogenous 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 thetherequirementsformaximumtolerabledelaywhile achieving a high throughput performance.

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