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Priority-Based Scheduling for Cognitive Radio Systems

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Abstract. Cognitive radio is becoming one of the most important technologies improving the utilization of the limited radio resources, the major bottle neck of the development of the next generation radio systems. In this paper, an adaptive downlink scheduling for real time and non-real time applications with the consideration of the primary user activity is proposed. The proposed algorithm satisfies different traffic models based on the QoS level of each traffic type and the spectrum availability and aiming to design an efficient scheduling algorithm to ensure an interference-free environment for the primary users. Furthermore the objective of this paper is to design an efficient scheduling algorithm to achieve a good tradeoff between system throughput, delay and fairness while accounting for the primary users' activities. The performance of the proposed algorithm has yield almost a 10% relative throughput gain compared to existing schemes while maintaining the same waiting time values.

Keywords: cognitive radio, OFDMA, packet scheduling, primary user, priority, QoS.

1. Introduction

Cognitive radio systems are considered as a promising solution for addressing the spectrum scarcity problem by using an opportunistic spectrum access approach, where frequency bands that are not used by their licensed users, such as the TV users, can be utilized by cognitive radios. Making efficient use of the radio resources is becoming a very challenging task due to the scarcity of radio resources, time-varying channel conditions, and very diverse quality of service (QoS) requirements. Adaptive resource allocation techniques, which involve adaptive modulation and coding (AMC) and hybrid multiple access, have been recently recognized as a key approach to enhance resources utilization and provide better QoS guarantees [1]. Orthogonal Frequency Division Multiplexing (OFDM) has also been identified as a promising candidate mainly due to its great flexibility in dynamically allocating the unused spectrum among secondary users, as well as its ability to monitor the spectral activities of licensed users at no extra cost [2].

The wireless link scheduling problem can be viewed as deciding which users should transmit in each time frame. The underlying challenge is to intelligently determine which and when users can access the allocated spectrum bands or channels to transmit their packets. In data networks, the packet scheduler is important for resource management. It needs to account for unique characteristics of time-varying and location-dependent channel conditions. Some research results in the literature have shown that the overall system performance, such as the system throughput, fairness, delay, and loss rate, will be significantly affected by the scheduling policy being used [3]. Many scheduling schemes have been proposed to address the resource allocation problem for traditional wireless networks as well as cognitive radio networks. In [4], a resource allocation algorithm is proposed to maximize the cognitive radio network (CRN) spectrum utilization based on a dynamic interference graph, and a realistic control framework to guarantee protection to primary users and reliable communications for cognitive nodes. In [5], an adaptive packet scheduling algorithm for real-time and non-real-time multi-service applications is presented, which makes the resource

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allocation adapt to the varying available spectrum in a CRN. A combined channel and power allocation strategy is proposed in [6]. This scheme guarantees a certain transmission data rate to each user in a CRN. Scheduling the secondary users under partial channel state information is considered in [7], which uses a probabilistic maximum collision constraint with the primary users. In [8], opportunistic scheduling policies for CRNs are developed, which maximize the throughput utility of the CR users subject to maximum collision constraints with the primary users (PUs).

We here propose an adaptive packet scheduling scheme that accommodates different traffic queues given different QoS levels of each traffic queue and the availability of each frequency channel.

2. System Model

In this paper, we consider an infrastructure based CRN providing communication services to secondary users (SUs). The SUs can sense the usage of the channels licensed to PUs. A channel can be either "active" (used by a PU) or "inactive" (available or a spectrum hole that can be used by an SU).

We consider one cell that is centrally controlled by a base station (BS) with uniformly distributed users throughout. The BS detects the transmission of primary networks, determines the channel availability, and allocates the channel to SUs based on the local measurements when the channel is inactive. At a specific timeslot, we assume that only one user transmits on an inactive channel and the SU does not share this inactive channel with other SUs. We focus on the downlink scheduling for transmission from the BS to SUs. The basic allocated resource unit is a time-frequency block (using the OFDMA access technique).

2.1. Traffic model

There are two main problems for modeling Internet traffic. First of all, Internet is based upon a distributed architecture that makes it flexible and adaptable. Secondly, the growth of the Internet has been difficult to predict. The IEEE 802.16 broadband wireless access working group has proposed a set of traffic models suitable for MAC/PHY simulations in 802.16 networks. The proposal provides not only the individual traffic models for each service but also the percentages necessary to define the mix of traffic arriving to an access point. The proposal includes three different services: voice, data (HTTP, TCP, and FTP) and streaming [9][10].

2.2. Data traffic

The generation of HTTP, TCP and FTP traffic is based on the superposition of four Interrupted Poisson Processes (IPPs). The IPP has two states wherein data is generated during the ON state according to a given distribution with an average rate h bits per symbol while during the OFF state, no traffic is generated. μ is the average number of transitions from the ON state to the OFF state per unit of time and, similarly, λ is the average number of transitions from the OFF state to the ON state per unit of time. The transitions among ON and OFF states are exponentially distributed whereas the distribution of the inter-arrival time during the active state (ON) gives rise to different types of IPPs.

2.3. Voice traffic

There is a special kind of the IPP in which the rate during the ON state is deterministic. Therefore, during the sojourn time in the ON state the process generates data with a fixed rate h and the time spent in ON and OFF states is exponentially distributed with average rate μ and λ, respectively. This model is the classical ON-OFF process, which has been widely used in the literature to model voice traffic. It is also called IDP (Interrupted Deterministic Process).

2.4. Video traffic

Finally, a video packet source is modeled by means of two Interrupted Renewal Processes (IRPs) fitting the most cited video trace in past ten years. This kind of traffic also presents self-similarity. In the IRP, the sojourn time is Pareto distributed rather than exponential and thereby it is not a Markov process anymore.

3. The Proposed Algorithm

Compared to conventional wireless communication systems, the uncertain availability of the channel is a unique feature of CRNs. The channel state information available to the secondary users is described by a probability vector $P_n^{(f)} = [P_1^{(f)}, P_2^{(f)}, ...P_N^{(f)}]$ where $P_n^{(f)}$ is the probability that channel n is free. We assume that this information is obtained either by sensing the channel, or through knowledge of the traffic statistics of the primary users, or a combination of both.

Let N be the total number of the available sub-channels, M the number of sub-channels during one scheduling period ($M = {}^{T_{sp}}\!/_{L}$) where T_{sp} is the scheduling period and L is the time slot length, $r(n) = 1, 2, ...N$ the number of remaining free slots of sub-channel n (at the beginning of each scheduling period $(r(n) = M)$, K the total number of SUs, and $q(i, j)$ the traffic queue of user i and traffic class j

3.1. Algorithm description

The proposed algorithm has the following steps: serving priority calculation, best sub-channel search, and modulation and coding scheme selection.

3.2. Priority calculation

In the first step, the priority function is calculated in order to sort the traffic queue based on the QoS of the class it belongs to and the type of traffic whether it is real-time or non-real time. The priority of user i requesting traffic class j is expressed as follows:

$$P(i, j) = c_j \exp[\alpha_j \frac{w_{ij}(t) - T_j}{T_j} - \beta_j \frac{\overline{b_{ij}}}{R_j L}] \tag{1}$$

where c_j is the adaptive service coefficient, α_j and β_j are weights for balancing the impacts of the delay and throughput of the traffic class j, $(\alpha_j + \beta_j = 1)$, T_j and R_j are respectively the maximum packet delay bound and the target bit rate of traffic class j, L is the time slot length, $w_{ij}(t)$ is the waiting time user i with traffic class j has incurred since its arrival until being served at time t, $\overline{b_{ij}}$ is the target number of bits to be transmitted by user i for traffic class j.

The priority function in (1) has a similar structure to that used in [3] with the following distinctions identifying our contributions:

- First, in [3], the priority function is proportional to the deviation of the achievable rate from the target bit rate. This criterion then requires ongoing calculation throughout the scheduling period and more importantly does not account for the actual data payload requirements. In this paper, the priority function is modified to be inversely proportional to the number of time slots needed, i.e., more weight is given to short payloads in an attempt to accommodate as many users as possible so long as the rate and waiting time targets are still fulfilled. From another perspective, given the opportunistic access of the SUs and the stochastic activity of the PUs, the less time a channel can be utilized, the more likely the transmission succeeds. The average number of time slots is calculated as ${}^{\bar{b}_{ij}}\!/_{R_j L}$ as per the priority function in(1).
- Second, as in [3], the coefficient c_j is introduced to assure special consideration of the real-time traffic. While c_j in [3] is statistical and discrete (takes on two values), it is here instantaneous and continuous (inversely proportional to the ratio between the total number of free channels and the number of non real-time classes), i.e.,

$$c_j = \begin{bmatrix} 1 + e^{-N/\bar{n}} & j \text{ is real-time} \\ 1 & j \text{ is non-real time} \end{bmatrix} \tag{2}$$

Where $\bar{n}$ is the number of non-real time traffic classes (MPEG and FTP).

3.3. Channel selection

The second stage now is to find the best sub-channels that have the best channel conditions for the top priority traffic queue $q(i, j)$.

3.4. Modulation and coding selection

Based on the knowledge of the received SNR range, the corresponding modulation and coding rate can be determined yielding the number of achievable bits on the corresponding sub-channel (selected in stage 2). Table 1 lists the received SNR ranges along with the corresponding achievable number of bits b_{in}

Table. 1: Modulation and Coding Scheme [3]

Received SNR range (dB)	**Modulation**	**Coding rate**	b_{in}
<10	QPSK	1/2	45
10~15	QPSK	3/4	68
15~17	16-QAM	1/2	90
17~20	16-QAM	3/4	135
20~23.5	64-QAM	2/3	180
>23.5	64-QAM	3/4	203

Our 3rd contribution (C3) is the execution of stages 2 and 3 jointly while accounting for the variations in channels availability. In particular, our criterion for channels selection/ordering is based on both channels quality and availability. Namely, based on the received SNR (a measure of the channel quality), we get the corresponding b_{in} (as in Table 1) and then order the currently available channels for each user based on the effective number of bits the channel can support, expressed as $b_{in}P_n^{(f)}$ where $P_n^{(f)}$ denotes the probability of channel n being free. If $b_{in}^{(j)}$ denotes the number of achievable bits by user i with traffic class j using sub-channel n ,we should select the best channels that can achieve that target number of bits $(\overline{b_{ij}})$ using$b_{in}^{(j)}P_n^{(f)}$

4. Numerical Results

The performance of the proposed algorithm is investigated in this section. The simulation parameters of the WRAN system specified in IEEE802.22 are shown in Table 2.

Table. 2: 802.22 simulation parameters

Parameter	Value
Cell radius	33km
Transmitting antenna highest of BS	100m
Receiving antenna height of users	10m
EIRP of BS	100w
Bandwidth of sub-channel	0.214MHz
Number of sub-channel	64
Length of a scheduling period	20ms
Length of a slot	0.317ms

The channel model used in the simulation consists of three models: large-scale path loss model, the shadow fading model and the multipath fading model [11]. The traffic model consists of three types: VoIP, MPEG and FTP. The traffic models parameters are given in Table 3. The algorithm parameters are assigned as follows: α_j is 0.5 for VoIP, 0.9 for MPEG, 0.7 for FTP and β_j is 0.5 for VoIP, 0.1 for MPEG, 0.3 for FTP.

We evaluate the performance of the proposed algorithm by comparison with the adaptive packet scheduling algorithm in [3]. The simulation results for K=100 users are given to show the performance of the two algorithms. We use APS-ref to denote the reference Adaptive Packet Scheduling Algorithm in [3] and APS-prop to denote our proposed algorithm.

Figure 1 compares the throughput of our proposed algorithm (APS-prop) to that of the reference one (APS-ref). As shown, our proposed scheme yields a relative gain of almost 10%. This throughput gain is achieved while maintaining the same waiting times (experienced by different users) as in the reference algorithm.

Table 3: Traffic model parameters

Traffic model	VoIP	MPEG	FTP
Simulation model	IDP	2IRP	4IPP
Distribution of the ON/OFF duration time	Exponential	Pareto	Exponential
Distribution of the interval between two packets	Constant	Exponential	Exponential
Packets rate (packets/s)	17.6	126.3	6.5
Packet size (bits)	528	1504	1536
Bit rate (kbps)	9.3	190	10

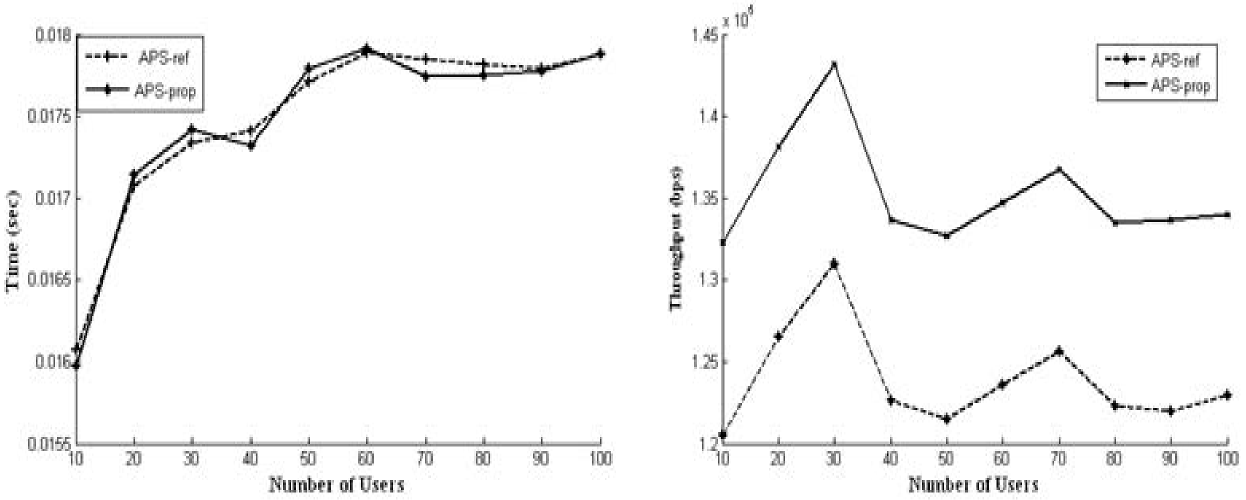

Fig. 1: Throuput and waiting time comparison of both APS-T-prop and APS-T-ref algorithms

5. Conclusion

In this paper, a priority based adaptive resource allocation and scheduling scheme has been introduced. This algorithm serves different traffic queues based on the QoS level of each queue and the variations of the available spectrum. We incorporate the effect of the channel availability or alternatively the primary user activity in the scheduling process as well as sub-channels selection. The proposed scheme exhibits almost a 10% relative throughput gain compared to existing schemes while maintaining the same waiting time values.

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