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Cognitive radio-based framework and self-optimizing temporal-spectrum block scheduling for QoS provisioning in WiMAX

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ABSTRACT

Cognitive radio (CR) is seen as a solution to the current low-usage of the radio spectrum and the problem of the fixed spectrum allocation. Quality of service (QoS) provisioning is an important issue in the deployment of broadband wireless access networks with real-time and non-real-time traffic integration in wireless spectrum. The connection-level and packet-level scheduling scheme is essential to guarantee the QoS requirements of different service classes. WiMAX orthogonal frequency division multiple access (OFDMA) system specifies the orthogonal frequency division multiplexing (OFDM) symbol mapping in a rectangular area manner. The rectangular mapping problem is known to be NP-complete. In this paper, we propose a novel Cognitive Radio-based QoS support framework and Cognitive Radio-based Self-optimizing temporal-spectrum block (TSB) scheduling which is a joint sub-carrier allocation and symbol-duration scheduling cum mapping scheme in WiMAX point-to-multipoint (PMP) WirelessHUMAN™ OFDMA systems. The proposed solution can intelligently explore unused spectrums and spread the system to non-active spectrums to significantly improve the capacity of the system and provide guaranteed QoS to real-time traffic. Extensive simulation experiments have been carried out to evaluate the performance of our proposal. The simulation results show that our proposed solution can expand the capacity of the WiMAX system while providing QoS to real-time and non-real-time traffic.

1. Introduction

Recently, broadband wireless access becomes ubiquitous. This makes the already heavily crowded radio spectrum much scarcer [1]. Cognitive radio (CR) is a promising technology to alleviate the increasing stress on the fixed radio spectrum. In cognitive radio based opportunistic spectrum access (OSA) networks, the secondary (unlicensed) users can periodically sense and identify available channels which are referred to as white spaces (WS) as the parts of the spectrum not in active use by the primary users. Based on the results of spectrum sensing, the secondary users dynamically tune its transceivers to the identified WSs to access the wireless channel without disturbing the communications of the primary users.

Broadband wireless access networks, e.g. WiMAX [2] systems, have received a lot of attention from academic and industrial researchers in the last few years as WiMAX systems have the ability to provide broadband wireless access and the potential ability to compete with existing wired and wireless networks. WiMAX can support four different QoS levels. QoS provisioning to such heterogeneous traffic with integrated real-time and non-real-time traffic is an important issue in the deployment of WiMAX systems. To tackle the QoS provisioning issue, one of the important QoS support mechanisms is the scheduling scheme. However, the detail of scheduling scheme has been left undefined in the IEEE 802.16d standard.

Scheduling scheme is essential in the provisioning of guaranteed QoS parameters, such as packet delay, packet

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loss rate and throughput. To design a scheduling scheme in WiMAX systems is especially challenging because a wireless communication channel has a high variable link error rate and a scarce capacity. The medium access control (MAC) protocol and scheduling solutions have to be developed specially in a cross-layer approach for this environment [3]. A few cross-layer MAC and opportunistic scheduling designs tailored for WiMAX have been proposed recently. With the help of several additional parameters for the preference metrics which are the priority of connections or users to be determined by the opportunistic scheduler for its transmission service, the proposed schemes were shown to have the capability to achieve satisfactory performance in the given network conditions.

However, those scheduling decisions are made based solely on bandwidth requirements, system capacity, QoS of connections and Physical (PHY) time-varying channel without considering the mapping constraint. Actually, Downlink (DL) and Uplink (UL) resource scheduling are done in two steps in WiMAX OFDMA systems. In the first step, those proposed schedulers decide the number of sub-carriers and the number of slots in units of symbol-duration to be allocated to each subscriber station (SS) and those allocated sub-carriers and symbol-durations are further distributed to each connection at the SS. In the second step, the mapping algorithms allocate the scheduled UL data bursts from each SS into two-dimensional rectangular "areas" [2] whereby the length of the area is the number of sub-carriers and the width is the number of OFDM symbols.

The two-dimensional rectangular mapping problem is a variation of bin-packing problem. We define this two-dimensional bin as a temporal-spectrum block (TSB). Now, we have a "tiling" problem where the objective is to fill a given area with TSBs. This packing problem is known to be NP-complete [4]. There have been many proposals to tackle this problem. However, there is no easy way to achieve optimality with simple computation.

Autonomic computing (AC) is supposed to be a novel way to reduce the computational complexity of the scheduling and bin-packing problem. The overarching goal of AC is to realize computer, software systems and applications that can manage themselves in accordance with high-level guidance from humans [5].

The existing state-of-the-art scheduling solutions and mapping strategies tackle the issue of QoS provisioning separately. From the system's point of view, sub-carrier allocation scheme, symbol-duration scheduling scheme and mapping strategy have to be considered collaboratively based on the PHY radio conditions in order to provide much more efficient QoS provisioning to the heterogeneous traffic in WiMAX systems.

Motivated by the technology of CR to tackle fixed spectrum-allocation problem; inspired by the self-optimizing function of AC to manage complexity, in this paper, we propose a novel cross-layer CR-based QoS support framework and a cross-layer CR-based joint sub-carrier allocation and symbol-duration scheduling cum a mapping scheme to provide QoS to heterogeneous traffic in WiMAX PMP OFDMA system.

The proposed framework has two outstanding modules, which are the CR-based intelligent spectrum management module (ISMM) and Autonomic Self-optimizing Scheduling cum Mapping Module.

With a cross-layer approach, the proposed ISMM uses the adaptive and cooperative sensing scheme as suggested in paper [6]. It periodically senses unused portions of the spectrum. It can intelligently exploit unused spectrums and spreads over them. Thus, the WiMAX system can operate under more than one frequency to improve the system capacity significantly and provide better QoS to real-time traffic in the system.

To the best of our knowledge, the proposed solution is the first piece of the solution with the following features in the literature. The proposed Autonomic Self-optimizing Scheduling cum Mapping Module can perform sub-carrier allocation, symbol-duration scheduling and TSB mapping collaboratively by an intelligent self-optimizing approach. Our proposal can guarantee QoS requirements for different types of service classes while expanding the capacity of the system. We have the following major contributions in this work.

(1) The proposed framework is equipped with a CR-based ISMM at the PHY layer. It exploits unused portions of the spectrum. If the BS or an SS transmits a packet belonging to BE service class, the packet could be transmitted in WS. As a result, the system throughput can be improved significantly.
(2) The proposed scheduling algorithm takes the mapping constraint into consideration. It has a unique feature which is the associative cooperation of the scheduling and mapping scheme.The mapping scheme can influence the scheduling decision, in other words, it can fine-tune the scheduling decision by the self-optimizing function of AC. The complexity of scheduling and mapping can be reduced significantly. The QoS requirements of real-time traffic can be satisfied while higher system throughput can be achieved.

The rest of the paper is organized as follows. In Section 2, we describe the research background, various aspects of the MAC and PHY layers of WiMAX system and the existing proposals related to our work. In Section 3, we describe our proposed cross-layer CR-based QoS support framework and CR-based self-optimizing joint sub-carrier allocation and symbol-duration scheduling cum mapping scheme. In Section 4, we present a channel model and a queueing model to analyze the average packet delay theoretically. In Section 5, we present our simulation model design and the simulation results. Finally, in Section 6, we conclude the paper with a summary.

2. Research background

The main technical background that relates to our work is presented in this Section, which includes the introduction of WiMAX system, Intelligent Spectrum Management, AC and existing opportunistic scheduling schemes and