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sGSA: A SDMA–OFDMA greedy scheduling algorithm for WiMAX networks

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ABSTRACT

Future wireless networks need to address the predicted growth in mobile traffic volume, expected to have an explosive growth in the next 5 years mainly driven by video and web applications. Transmission schemes based on Orthogonal Frequency Division Multiple Access (OFDMA) combined with Space Division Multiple Access (SDMA) techniques are key promising technologies to increase current spectral efficiencies. A Joint SDMA–OFDMA system has to allocate resources in time, frequency and space dimensions to different mobile stations, resulting in a highly complex resource allocation problem. In contrast to related work approaches, in this paper we take a comprehensive view at the complete SDMA–OFDMA scheduling challenge and propose a SDMA–OFDMA Greedy Scheduling Algorithm (sGSA) for WiMAX systems. The proposed solution considers feasibility constraints in order to allocate resources for multiple mobile stations on a per packet basis by using (i) a low complexity SINR prediction algorithm, (ii) a cluster-based SDMA grouping algorithm and (iii) a computationally efficient frame layout scheme which allocates multiple SDMA groups per frame according to their packet QoS utility. A performance evaluation of the proposed sGSA solution as compared to state of the art solutions is provided, based on a comprehensive WiMAX simulation tool.

1. Introduction

Mobile wireless networks are faced with an ever increasing demand for higher data rates, expected to grow exponentially in the next years due to the smartphone market success and its corresponding set of bandwidth hungry applications, specially video and web. Transmission schemes based on Orthogonal Frequency Division Multiple Access (OFDMA) and Multi-User Multiple Input Multiple Output (MU-MIMO) techniques are promising technologies to increase current spectral efficiencies. The performance of MU-MIMO relies on the precoding capability of the transmitter and, in order to take full advantage of such a technique, a Base Station (BS) needs full Channel State Information (CSI) on the properties of the communication link to each Mobile Station (MS). A well-known MU-MIMO mode is Space-Division Multiple Access (SDMA) which can be used in the downlink direction to allow a group of spatially separable MSs to share the same time/frequency resources.

SDMA–OFDMA systems have to allocate resources in time, frequency and space dimensions to different MSs resulting in a highly complex resource allocation problem. Therefore, in order to reduce the complexity of such a system the overall problem can be divided into several subproblems, each conquering the different dimensions separately [1]. However, these subproblems still hold a high level of complexity and thus, suboptimal strategies are often proposed in the literature [2].

In contrast to related work approaches, in this paper we take a comprehensive view at the complete SDMA–

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OFDMA scheduling challenge and propose a SDMA–OFDMA Greedy Scheduling Algorithm (sGSA) for WiMAX systems. Specifically, we focus on the WiMAX IEEE 802.16-2009 [3] standard, which provides scalable OFDMA capabilities as well as additional MIMO PHY features. According to our proposed *sGSA* approach the SDMA–OFDMA scheduling solution is divided into three main steps:

1. SINR prediction – estimation of the SINR experienced by each MS in an SDMA group.
2. SDMA grouping – partitioning of the MSs into a set of SDMA groups, where spatially compatible MSs are arranged in the same SDMA group.
3. Frame partitioning – partitioning of an OFDMA frame into multiple containers each representing a single SDMA group.

This paper is an extension of the work from the authors in [4] which is currently under submission. The paper at hands extends [4] by (i) designing a low complexity SINR prediction algorithm to reduce the computational load of the overall SDMA–OFDMA scheduling solution, (ii) evaluating the computational load reduction and corresponding SINR prediction error impact, (iii) recalculating all results in the performance evaluation section accordingly and (iv) considering additional factors in the system performance evaluation as number of operations, signaling overhead and buffer size limitations.

The rest of the paper is structured as follows. Sections 2 and 3 provide the IEEE 802.16-2009 basic elements considered in our solution and summarize the most relevant work in the area. Next, Section 4 formalizes the problem description and formulates the SDMA–OFDMA scheduling as an optimization problem. Section 5 describes our proposed sGSA solution along with the designed algorithms required. In Section 6 a performance evaluation is conducted through simulations. Finally, Section 7 concludes the paper.

2. SDMA–OFDMA support in IEEE 802.16e

The focus of this paper is an IEEE 802.16e TDD OFDMA system where Base Stations (BSs) access the channel by means of Downlink (DL) and Uplink (UL) subframes. Each subframe is split into a set of OFDMA symbols in time and logical subchannels in frequency, where the mapping between physical subcarriers and logical subchannels is determined by a *permutation scheme*. 802.16e supports different permutation schemes being *Partial Usage of SubCarriers (PUSC)* the most widely used. PUSC is a distributed permutation scheme that achieves a frequency diversity gain by mapping a set of subcarriers randomly spreaded across the available bandwidth into each logical subchannel. In the rest of the paper we will consider PUSC as the permutation scheme used by our system.

PUSC works in the following way. First, the available physical subcarriers are divided into *clusters* of 14 contiguous subcarriers, containing each cluster 2 pilot subcarriers and 12 data subcarriers (as depicted in Fig. 1). The pilot subcarriers in each cluster are used by a receiver to estimate the channel between transmitter and receiver and thus demodulate the received data subcarriers. Then, in order to achieve the intended diversity gain, physical clusters are randomly renumbered, using a random seed local to each BS, and sequentially mapped to each logical subchannel. Each logical subchannel is hence composed of two PUSC clusters.

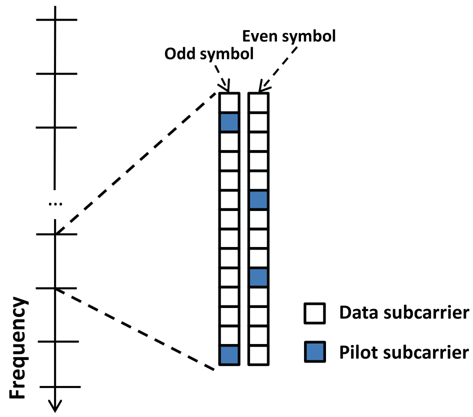

Fig. 1. DL PUSC cluster structure.

Leveraging PUSC, a BS can implement beamforming or SDMA in a transparent way for the Mobile Stations (MSs) by simply using *dedicated pilots*. When beamforming or SDMA is utilized a BS uses a set of beamforming weights or a precoding matrix, *W*, in order to shape its antenna pattern towards its intended receivers. Thus, if the same beamforming weights are used for the pilot subcarriers and the data subcarriers within each cluster, a receiver will simply perceive the beamformed transmission as a modified channel, and will transparently demodulate the beamformed data. In order to do so, a BS signals the use of dedicated pilots to a MS, such that the MS only uses the pilot subcarriers belonging to its own data allocation to demodulate the received data. Given the use of dedicated pilots and the cluster structure in PUSC, 802.16e BSs must use the same beamforming weights or pre-coding matrix for each PUSC cluster (i.e. 14 contiguous subcarriers). However, BSs are allowed to use different beamforming weights for different PUSC clusters.

Fig. 2 illustrates how SDMA can be implemented over an 802.16e TDD OFDMA DL subframe. Note that the initial MAP messages used to signal the data allocations to each MS in the DL subframe are transmitted omnidirectionally. However, successive time frequency allocations within the OFDMA frame can be shared among different MSs, if these are spatially separable. For instance, we can see in Fig. 2 how the BS chooses to allocate the same time frequency resources for MS1 and MS2 because they can be separated in the space domain. The lower part of Fig. 2 illustrates how the individual PUSC clusters randomly map to each logical subchannel, and how the BS, by applying a different pre-coding matrix to each cluster, is able to concurrently steer different spatial beams in different time frequency regions within the OFDMA frame. Notice that in