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Optimal channel assignment with aggregation in multi-channel systems: A resilient approach to adjacent-channel interference ☆

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ABSTRACT

Channel assignment mechanisms in multi-channel wireless networks are often designed without accounting for adjacent-channel interference (ACI). To prevent such interference between different users in a network, guard-bands (GBs) are needed. Introducing GBs has significant impact on spectrum efficiency. In this paper, we present channel assignment mechanisms that aim at maximizing the spectrum efficiency. More specifically, these mechanisms attempt to minimize the amount of additional GB-related spectrum that is needed to accommodate a new link. Similar to the IEEE 802.11n and the upcoming IEEE 802.11ac standards, our assignment mechanisms support channel bonding, and more generally, channel aggregation. We first consider sequential assignment (i.e., one link at a time), and we formulate the optimal ACI-aware channel assignment that maximizes the spectrum efficiency as a subset-sum problem. An exact exponential-time dynamic programming (DP) algorithm, a polynomial-time greedy heuristic, and an ϵ-approximation are presented and compared. Second, considering a set of links (batch assignment), we derive the optimal ACI-aware exponential-time assignment that maximizes the *network's* spectrum efficiency. The optimal batch assignment is compared with the sequential assignment. Results reveal that our proposed algorithms achieve considerable improvement in spectrum efficiency compared to previously proposed schemes.

1. Introduction

Adjacent-channel interference (ACI) is a form of power leakage that is attributed to imperfect filters and amplifiers in the radio device. The harmful impact of ACI on the throughput of IEEE 802.11a and IEEE 802.11n networks was demonstrated in [1,2], respectively. Most channel assignment algorithms in the literature do not account for ACI (see Fig. 1(a)). Fig. 1(b) shows the actual power spectral density of two channels in a practical communication system. To mitigate ACI, *guard-bands* (GBs) are needed between adjacent channels that belong to different links.

However, introducing GBs constrains the spectrum efficiency. In [3], the authors studied two models for utilizing GBs in a dynamic spectrum access (DSA) network: “GB reuse” and “no GB reuse”. According to the “GB reuse” model, GBs can be shared by two different (interfering) links. In contrast, in the “no GB reuse” model, two adjacent transmissions require their own GBs. As explained in [3],

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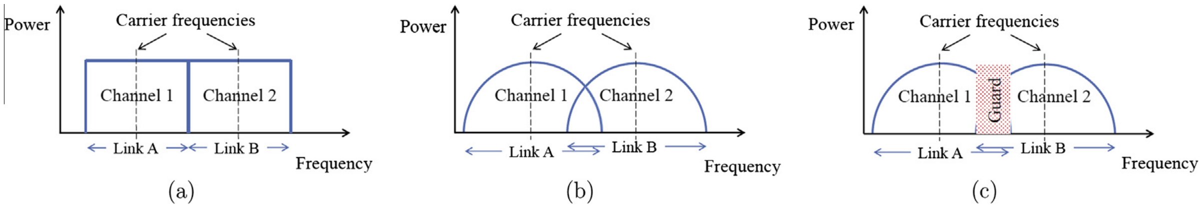

Fig. 1. GBA channel assignment. (a) Ideal power spectral density, (b) power spectral density in a practical communication system, and (c) power spectral density under the "GB reuse" model.

the "GB reuse" model is suitable for discontinuous-OFDM (D-OFDM) systems, whereas the "no GB reuse" model is suitable for FDM-based systems. In this paper, we adopt the "GB reuse" model. This model is illustrated in Fig. 1(c), where the same amount of GB is allocated between channels 1 and 2, irrespective of whether link *B* is active or not over channel 2. As shown later in this paper, the GB-aware (GBA) channel assignment algorithm in [3] for the "GB reuse" case does not achieve the maximum spectrum efficiency.

To support applications with high rate demands, the IEEE 802.11n and the upcoming IEEE 802.11ac standards have adopted the concept of channel bonding [4–8]. This concept refers to the bundling of multiple adjacent channels, which can then be treated as a single frequency block whose data rate is approximately the sum of the data rates of the individual channels. By bonding two 20-MHz channels, IEEE 802.11n supports a single 40 MHz channel [9]. In traditional single-input single-output (SISO) systems (e.g., IEEE 802.11a/b/g), channel bonding causes a reduction in the transmission range and a greater susceptibility to interference [10,11]. However, with the incorporation of MIMO technology in IEEE 802.11n devices, the problems faced by SISO systems due to channel bonding can now be mitigated [12,13]. In [5,6], the authors conducted experimental studies in the 5 GHz band to characterize the behavior of channel bonding. They observed that ACI needs to be mitigated in order to perform intelligent channel bonding. The IEEE 802.11ac standard enhances the throughput beyond the IEEE 802.11n using an 80 MHz channel bonding technique [7,8].

The concept of channel bonding can be extended to non-adjacent channels, and is referred to as *channel aggregation*. For example, LTE-Advanced employs channel aggregation techniques, allowing 4G mobile operators to aggregate spectrum from non-adjacent bands to support links with high demands [14]. With channel aggregation, LTE-Advanced supports up to 100 MHz system bandwidth, with the potential of achieving more than 1 Gbps throughput for downlink and 500 Mbps throughput for uplink [15]. Implementation challenges of channel aggregation have been studied in [15,16]. Recently, distributed channel aggregation has been studied in [17–19] in a game theoretic framework. The proposed schemes in [17–19] do not account for ACI. Although co-channel interference has been extensively studied in the context of distributed channel allocation [20,21], ACI has been largely overlooked.

Main Contributions–The main contributions of the paper are as follows:

1. We formulate and obtain the optimal (sequential) GBA channel assignment for a single link, adopting the "GB reuse" setting. The per-link channel assignment problem is formulated as a subset-sum problem (SSP) [22]. An exact exponential-time dynamic programming (DP) algorithm, a polynomial-time greedy heuristic, and an ϵ-approximation are presented.
2. We formulate and obtain the optimal GBA channel assignment for multiple links (batch approach), under the "GB reuse" setting.
3. We evaluate the exponential-time optimal sequential and batch assignment mechanisms and compare them with polynomial-time heuristics and ϵ-optimal approximations.

Paper Organization–The remainder of this paper is organized as follows. In Section 2, we present the system model followed by the problem statement. The single-link optimal channel assignment is explained in Section 3. Polynomial-time greedy and ϵ-approximate algorithms are also presented in the same section. In Section 4, we address the problem of optimal GBA channel assignment for multiple links. We provide an exponential-time exact algorithm along with an approximate sequential algorithm. We evaluate our assignment algorithms in Section 5. Section 6 gives an overview of related work. We provide directions for future research in Section 7. Finally, Section 8 concludes the paper.

2. Problem statement

We consider a single-hop wireless network with a set of channels $\mathcal{M} = \{1, 2, \dots, M\}$ and a set of links $\mathcal{L} = \{1, 2, \dots, L\}$. Without loss of generality, we assume all channels to have the same bandwidth, denoted by W (in Hz). An available (unassigned) channel can be reserved as a GB, or assigned for data communication. All available channels support a common rate of r Mbps. In Section 7, we provide directions for extending our work to a multi-rate setup. Each link $j \in \mathcal{L}$ has a rate demand $d_j \overset{\text{def}}{=} \alpha_j r$ Mbps, where α_j is an integer between 1 and M. Given the current spectrum status, our objective is to satisfy the demands of one or more links in $\mathcal{L}$ while maximizing the spectrum efficiency (defined shortly). Fig. 2 shows an example of a spectrum status.

The spectrum efficiency is defined as the fraction of the available spectrum that can be used for data communications. Let $h_{ij},\ i \in \mathcal{M}$ and $j \in \mathcal{L}$, be a binary variable; $h_{ij} = 1$ if channel i is assigned to link j as a data channel, and zero