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Access granularity control of multichannel random access in next-generation wireless LANs

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ABSTRACT

As the next-generation Wireless LANs (WLANs) will provide the ubiquitous high-data-rate network coverage, the traditional contention-based Medium Access Control (MAC) scheme may be unable to fulfill the requirement of efficient channel access. To address this problem, several research works have proposed the random access systems combined with Orthogonal Frequency Division Multiplex Access (OFDMA) technology. Access granularity control is a crucial issue in this combination. Specifically, this issue focuses on how to tune the subchannel bandwidth and the number of accessible subchannels towards the maximum channel utilization. This paper analyzes access granularity control in an OFDMA system that adopts a multichannel Carrier Sensing Multiple Access (CSMA) MAC and resolves contention by the frequency-domain backoff. The theoretical analysis verifies the significance of access granularity control. In addition, the simulation experiments demonstrate that the proposed dynamic access granularity control algorithms notably outperform the traditional ones that divide channel band statically and adjust the number of accessible subchannels empirically.

1. Introduction

Random access protocol is widely applied in Wireless Local Networks (WLANs) as a fundamental Medium Access Control (MAC) scheme. At the same time, it plays an important role in the emerging heterogeneous networks depending on its flexibility. The next-generation WLANs are expected to achieve more than 1 Gb/s network coverage. Moreover, the number of short packets grows due to the spread of Machine-to-Machine (M2M) communications. In these emerging scenarios, the conventional random access MAC, e.g. 802.11 Distributed Coordination Function (DCF), may cause a drastic drop of channel utilization [1,2]. The root of this inefficiency is the fact that the impact of protocol overhead (such as backoff, inter-frame space, preamble and signaling) becomes increasingly notable when the high data rate causes a short data transmission time. For example, a backoff time slot in a 150 Mb/s 802.11n system is equal to 0.11 times the transmission duration of a 1500 byte packet, whereas this ratio rises to 1.05 in a 1.4 Gb/s 802.11 ac system [3].

An effective approach to amend the MAC efficiency of a high-data-rate WLAN is to combine random access with Orthogonal Frequency Division Multiplex Access (OFDMA) technology. In several recent works, it has been shown that systems exploiting this approach can improve the throughput in certain scenarios. In the systems proposed by [4,5], the channel contention among terminals is resolved in the frequency domain by randomly dispersing their channel access requests into different busy/idle state patterns of

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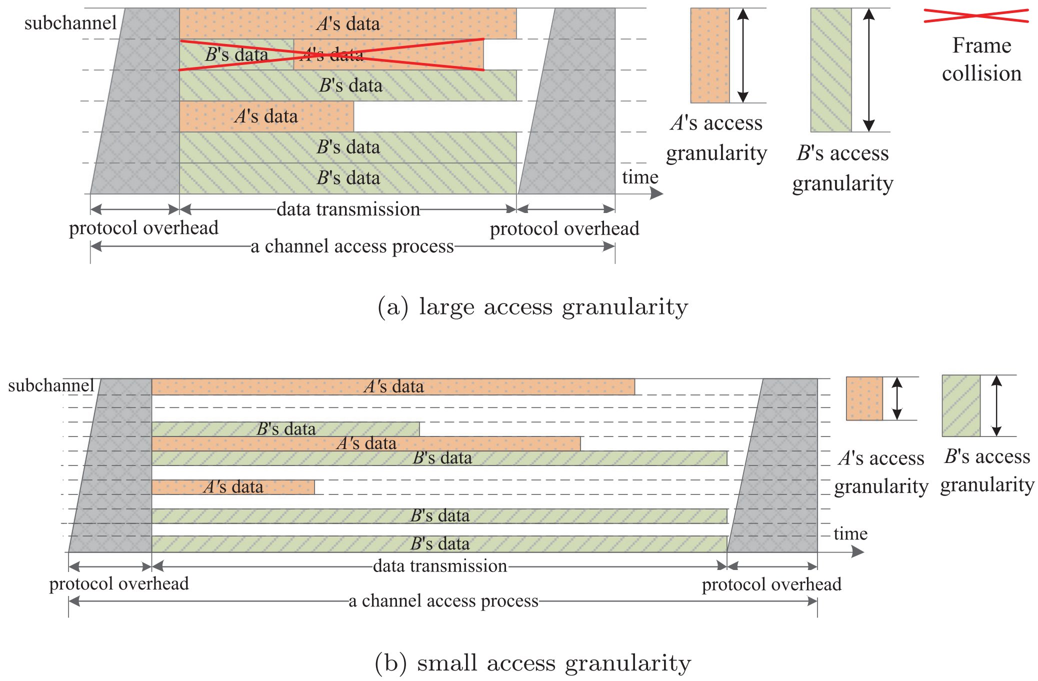

(a) large access granularity

(b) small access granularity

Fig. 1. An illustration for the influence of access granularity. Two contenders are assumed, say *A* and *B*.

subcarriers. This frequency-domain backoff mechanism is proved to efficiently decrease the probability of frame collision. However, because the terminals transmit a frame with the whole frequency band, a low channel utilization may still arise when applications frequently generate small packets (e.g. in VoIP and M2M communications). In the works [6–8], the presented systems can substantially mitigate the impact of protocol overhead by the sub-channelization and the multichannel concurrent data transmissions. Nonetheless, the systems cannot efficiently control the network congestion, because the terminals always intend to access all the idle subchannels. This drawback has been amended by an approach proposed in [9], whereby the number of accessible subchannels (i.e. the number of subchannels that a terminal is allowed to access) can be dynamically tuned. However, the appropriateness of the dynamic tuning in [9] cannot be ensured, because the work lacks the support of an accurate throughput model. Furthermore, we notice that all the existing Multichannel Random Access (MRA) systems[1] adopt static sub-channelization approach. As a consequence, when packet size decreases or data rate rises, the reduced data transmission time will magnify the impact of protocol overhead and degrade the throughput performance.

The loss of channel utilization in the preceding MRA systems can be ascribed to their static and inappropriate access granularity control schemes. The access granularity here is defined as the amount of spectrum resource that each terminal attempts to use. It influences MAC efficiency in the aspects of channel contention intensity and the ratio of protocol overhead to data transmission time. As shown in Fig. 1a, if the access granularity is large, the frame collision may frequently occur due to the intense resource contention. At the same time, the protocol overhead may become notable because of the short data transmission time. In contrast, if the access granularity is small as shown in Fig. 1b, the extended data transmission time can effectively weaken the impact of protocol overhead. Nonetheless, the small access granularity also can cause a large proportion of idle spectrum, which degrades the system throughput. From above all, to maintain an efficient channel access, the system should adaptively control the access granularity according to the current traffic pattern and the network congestion status.

In this paper, we focus on the analysis of access granularity control in an OFDMA Carrier Sensing Multiple Access (CSMA) system, which extends the traditional time-domain backoff in single-channel CSMA to the frequency domain (the detail can be found in Section 3). To reflect the influence of access granularity, our analytic model takes the channel contention and the varying impact of protocol overhead into account jointly. The given definition and Fig. 1 indicate that the access granularity is subject to the subchannel bandwidth and the number of accessible subchannels in an MRA system. Therefore, how to tune them for access granularity control is the major issue that this paper will address. It needs to be pointed out that a system with static sub-channelization can mitigate the inefficiency of constant subchannel bandwidth, by making the subchannel bandwidth relatively small and adaptively assigning few or many subchannels to a node. However, this solution cannot displace the dynamic tuning of subchannel bandwidth

[1] Multichannel random access in this paper is used to exclusively signify the systems which combine random access with OFDMA technology. In addition, we regard the single-channel system as a special case of multichannel system.