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Collision-Aware Rate Adaptation in multi-rate WLANs: Design and implementation

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Abstract

Many rate adaptation algorithms have been proposed for IEEE 802.11 Wireless LAN devices and most of them operate in an open-loop manner, i.e., the transmitter adapts its transmission rate without using the feedback from the receiver. A key problem with such transmitter-based rate adaptation schemes is that they do not consider the collision effect. Accordingly, they often result in severe throughput degradation when many transmission failures are due to frame collisions. In this paper, we present a transmitter-based rate adaptation scheme, called CARA (Collision-Aware Rate Adaptation), and its MadWifi-based implementation. The key idea of CARA is that the transmitter combines adaptively the RTS/CTS (Request-to-Send/Clear-to-Send) exchange with the CCA (Clear Channel Assessment) functionality in order to differentiate frame collisions from transmission failures due to channel errors. The effectiveness of CARA schemes is evaluated via extensive ns-2 simulations and testbed experimentations.

Introduction

The transmission rate adaptation has gained interests as for a dominant issue to enhance the performance of IEEE 802.11 WLAN (Wireless LAN) technology. While the 802.11 PHYs (Physical layers), e.g., 802.11a/b/g, provide a multi-rate feature, the standard does not specify any algorithm and/or protocol to utilize them efficiently. In the past few year, many rate adaptation schemes have been proposed in the literature [1], [2], [3], [4], [5], [6], [7], [8], [9], [10], [11], [12], [13], [14], [15], [16], [17].

The effectiveness of a rate adaptation scheme depends on how fast it can respond to the variation of the wireless channel condition. Moreover, since multiple stations often compete for the shared wireless medium in an 802.11 system, frame collisions are inevitable due to the contention nature of the 802.11 DCF (Distributed Coordination Function). Therefore, the effectiveness of a rate adaptation scheme also depends greatly on how the collisions are detected and handled.

In a rate adaptation scheme, a transmitter may adapt its transmission rate with or without using the feedback from the receiver, where the feedback information could be either SINR (Signal to Interference and Noise Ratio) or the transmission rate desired by the receiver. Depending on whether to use the feedback from the receiver, rate adaptation schemes can be classified into two categories: *receiver-based*, i.e., with the feedback, and *transmitter-based*, i.e., without the feedback. Unfortunately, most existing transmitter-based schemes malfunction severely when there are many contending stations in the network, because they can not differentiate frame collisions from transmission failures caused by channel errors. This results in decreasing the transmission rate over-aggressively due to many collision-induced transmission failures. For example, the widely-adopted ARF (Automatic Rate Fallback) scheme [1], [2] does not work properly in multi-user environments because it decreases the transmission rate upon consecutive frame collisions, which has been reported in [18] based on both simulation and empirical results. In contrast, the collision effect is mitigated with receiver-based schemes, such as RBAR (Receiver-Based Auto Rate) [14] and OAR (Opportunistic Auto Rate) [15], thanks to the interaction between the transmitter and the receiver.

In this paper, we design a transmitter-based rate adaptation scheme with collision awareness, called CARA (Collision-Aware Rate Adaptation). The key idea of CARA is that the transmitter combines adaptively the RTS/CTS (Request-to-Send/Clear-to-Send) exchange with the CCA (Clear Channel Assessment) functionality to differentiate frame collisions from channel-error-caused transmission failures. Considering its wide adoption in many commercial 802.11 devices, ARF is chosen as the baseline rate adaptation scheme for CARA. CARA specifies three different methods: (i) CARA–RTS that identifies collision via RTS Probing and makes collision-aware rate-decrease decisions; (ii) CARA–CCA that identifies collision via RTS Probing as well as CCA Detection, based on which the rate-decrease decisions become enhanced; and (iii) CARA–RI that makes collision-aware rate-increase decisions while identifying collision via CARA–CCA. The preliminary results of CARA were originally presented in [16]. At that time, CARA was the first effort in applying adaptive usage of RTS/CTS exchange and CCA functionality to differentiate frame collisions from channel-error-caused transmission failures. Since then, a few rate adaptation schemes have been proposed to improve upon CARA, such as RRAA (Robust Rate Adaptation Algorithm) in [11] and PBRA (Probabilistic-Based Rate Adaptation) in [12]. Nonetheless, they are all designed based on the idea of adaptive RTS/CTS that is similar to that in CARA. In this paper, we present the complete details of the CARA design and describe its implementation on the MadWifi platform [4].

In particular, we make the following contributions.

- CARA has the originality in rate selection with collision awareness in IEEE 802.11a/b-based wireless networks.
- CARA works in a purely transmitter-based manner. No feedback information from the receiver is required in its collision-aware rate decisions.
- We provide the complete view of CARA from its algorithmic design to the implementation details, running upon a practical device platform.
- The effectiveness of CARA has been thoroughly evaluated, considering various aspects: (1) constant vs. varying channel qualities; (2) static vs. mobile stations; (3) single vs. multiple contending stations; (4) non-hidden vs. mutually hidden stations; (5) one-hop vs. multi-hop topological settings; (6) simulation vs. real testbed environments; and (7) superiority check to many existing algorithms.

The rest of the paper is organized as follows. Related work is reviewed in Section 2. Section 3 briefly overviews the IEEE 802.11 MAC, the RTS/CTS exchange in IEEE 802.11, and the ARF scheme. The details of the CARA design are described in Section 4, followed by Section 5 that presents in-depth simulation study on CARA. Section 6 discusses the CARA implementation on the MadWifi platform and experimental results. Finally, the paper concludes in Section 7.

Section snippets

Related work

In receiver-based schemes [14], [15], after the receiver specifies its desired transmission rate and feeds it back to the transmitter as part of the modified RTS/CTS exchange, the transmitter adjusts its transmission rate accordingly. Since the rate adaptation is dictated by the receiver, rate selection decisions are not affected by frame collisions. However, in order to support such a feedback loop, the CTS (and possibly RTS) frame format should be modified to convey the extra information that …

IEEE 802.11 CSMA/CA

The mandatory MAC scheme, DCF specified in IEEE 802.11 standard [19] is based on CSMA/CA as illustrated in Fig. 1a. Even with random backoff, a transmitted frame may still collide with other frames when two or more stations finish the backoff at the same time. Such frame collisions cannot be completely eliminated due to the contention nature of DCF, and the problem becomes worse as the number of contending stations increases. Besides collision, a frame transmission failure may also be caused by …

CARA: Collision-Aware Rate Adaptation

In this section, we present the design details of CARA. CARA specifies three different methods to differentiate frame collisions from channel-error-caused transmission failures: (i) CARA–RTS that identifies collisions via RTS Probing and makes collision-aware rate-decrease decisions; (ii) CARA–CCA that identifies collisions via RTS Probing as well as CCA Detection, based on which the rate-decrease decisions become enhanced; and (iii) CARA–RI that makes collision-aware rate-decrease/-increase …

Performance evaluation via simulation study

We conduct diverse simulation runs using the ns-2. In order to consider many different and realizable scenarios, which may not be straightforwardly evaluated in a real testbed, our simulation study includes multiform topological settings with the following factors: distribution of stations, number of nodes, existence of hidden stations, mobility, channel quality, and number of hops. After describing the details for the simulation setup, we show evaluation results and the corresponding analysis. …

CARA implementation and experimentation

As a proof of concept, we implement CARA–RI, CARA–RTS, and ARF in our Linux-based WLAN testbed. In this section, we first describe the implementation details and the experimental setup, and then present evaluation results. …

Concluding remarks

In this paper, we present the design and implementation details of a novel collision-aware rate adaptation scheme called CARA for IEEE 802.11 WLANs. The key idea of CARA is that the transmitter combines adaptively the RTS/CTS exchange with the CCA functionality in order to differentiate frame collisions from frame transmission failures caused by channel errors. CARA specifies three different methods: (i) CARA–RTS that identifies collision via RTS Probing; (ii) CARA–CCA that identifies collision …

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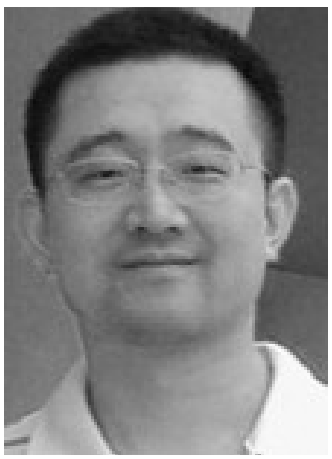

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