Rate Adaptation for Robust Data Transmissions Utilizing Multi–AP Reception and Packet–level FEC

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Abstract: This letter proposes a rate control for robust data transmissions utilizing multiple access points (APs) combined with packet–level forward error correction (FEC). Beacon frames received from multiple APs are used to select an appropriate set of PHY and FEC rates to be employed for uplink transmissions, which is based on a machine–learning technique. With computer simulations, we show that the proposed rate control achieves the required reliability while significantly reducing the occupancy period of the shared channel.

Keywords: Wireless LAN, Broadcast, Packet–level FEC, Rate Control

Classification: Wireless communication technologies

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1 Introduction

Improving robustness of wireless data transmissions is desired in many industrial fields, especially in factories with the advent of the concept of factory
automation. A common use-case is data transmissions (e.g., video data) from a station (STA) to an access point (AP) through wireless LAN (WLAN) interface, which are further forwarded to a central server. In general, unicast transmissions are employed between each STA and its connected AP. However, unicast transmissions have the problem of single point of failure: once a connected link suffers from communication failures for a long period of time due to shadowing, fading, and interference, quality of services (QoSs) of users become unacceptable. In order to solve this problem, we have proposed robust data transmissions exploiting broadcast (Multi-AP) transmissions combined with packet-level forward error correction (FEC) [1]. With our Multi-AP transmissions, each STA transmits data to multiple APs located inside its communication range with a single transmission by exploiting broadcast nature of wireless medium. Some APs can receive data transmitted by a STA even if the other APs failed. We also apply packet-level FEC in order to further enhance the reliability of data transmissions: a data packet lost at all surround APs can be successfully recovered thanks to redundant packets. In [1], we have confirmed with simulations and experiments that the proposed Multi-AP transmissions improve robustness in comparison to unicast transmissions.

The important parameters to be controlled for Multi-AP transmissions are the physical layer (PHY) rate and FEC rates, which affect not only packet delivery rate (PDR) but also airtime (channel occupancy period) of the shared channel. In conventional unicast transmissions, these rates can be controlled with the approach of trial-and-error by using the link-level acknowledgement (ACK) or received signal strength indicator (RSSI) of a single target receiver [2]. However, the link-level ACK is not implemented for the broadcast mode of WLAN used in our Multi-AP transmissions. Furthermore, unlike unicast transmissions, there can be multiple points of receptions for broadcast transmissions, which requires us to consider RSSIs for multiple receivers.

In this letter, we propose an adaptive rate control for Multi-AP broadcast transmissions. The novelty lies in the design of rate selector based on a machine-learning technique, which solely counts on the information obtained from beacon frames periodically transmitted by surrounding multiple APs.

2 System Model

We consider a scenario where a STA transmits data to a central server through multiple APs and gateway (GW) (see Fig. 1). The data transmissions between STA and APs are supported by IEEE 802.11 wireless LAN while APs, GW, and server are connected by wired connections, e.g., Ethernet. The STA employs a broadcast mode of IEEE 802.11 and transmits data to multiple APs within its communication range. The packets received at each AP are forwarded to GW. In order to enhance the reliability, we employ packet-level FEC (hereafter, we call it simply as FEC). With packet transmissions using FEC, when STA has $K$ data packets to transmit, it transmits
$N$ packets ($N \geq K$) at an application level. Here, $N - K$ packets are redundant packets, and its FEC rate is calculated as $K/N$. At GW, if any set of $K$ packets out of $N$ packets are successfully received, it can recover the original $K$ data packets [3].

3 Proposed Adaptive Rate Control

In order to adaptively control PHY and FEC rates in our Multi–AP transmissions described in Sec. 2, we propose a rate control that exploits information obtained from beacon frames periodically transmitted by surrounding APs. Specifically, we exploit RSSIs and beacon delivery ratio (BDR). The RSSIs reflect the channel conditions for STA–AP links while BDR accounts for interference level at the communication area. Here, interference is considered to be caused by radio devices sharing the same unlicensed band, which do not necessarily follow carrier sense multiple access (CSMA) protocols. Based on these information, STA attempts to select the best rate for uplink transmissions to multiple APs.

In this letter, in order for each STA to select an appropriate rate, we resort to a machine–learning approach. A rate selector is designed, which outputs the optimal set of PHY/FEC rates as shown in the bottom of Fig. 1. The training data is constructed by computer simulations. In this letter, as shown in Fig. 1, we generate RSSIs and BDR at different locations within the considered $130m \times 130m$ area where 9 APs are deployed. Then, at these locations, the best PHY/FEC rate, which satisfies the target application–level (i.e., after FEC decoding) PDR (APDR) with minimum fractional airtime, is obtained. PDR is defined as the ratio of the number of successfully decoded data to that of data transmitted by STA at application level. On the other
hand, fractional airtime is the fraction of time during which signals transmitted by STA occupy the channel. The best rate is recorded as labelled data for the considered input of RSSIs and BDR. We consider path loss with its coefficient of 3, correlated shadowing with a first-order auto regression (AR) model with $\sigma_{\Phi dB} = 4$ dB and $X_c = 75$ m [5], and block Rayleigh fading. The transmission power of STA and APs are set to be 20 mW, and application data with 1496 bytes are assumed to be transmitted by STA with the period of 1/30 s. The packet/beacon error rates are calculated based on NIST error model [4]. We also generate packet/beacon loss caused by interference randomly with a parameter called interference error rate, ranging from 0 % to 30 %. The considered PHY rates are 6, 12, 18, 24, 36, 48, and 54 Mbps while FEC rates of 1, 2/3, 1/2, 2/5, and 1/3 are employed. The PHY rate of beacon frame is fixed at 6 Mbps. The training data is constructed every 1 s. As a learning algorithm, we employed stacked autoencoder with two hidden layers [6].

4 Simulation Results

We test the performance of the proposed rate control by using a STA moving around the considered area shown in Fig. 1, where the same simulation model as training phase is employed. The velocity of STA is 1 m/s with direction uniformly selected from $[0, \pi/2]$. The initial position is set to be $(0, 0)$ in Fig. 1. Figs. 2 and 3 show APDR and fractional airtime against interference error rate, respectively. Since there is no existing scheme to control PHY/FEC rate for Multi–AP transmissions considered in our work, we compare the performance of Multi–AP transmissions employing the proposed rate control with that employing the fixed PHY/FEC rate. Here, we consider two extreme cases: one is the most optimistic selection where PHY and FEC rates are respectively set to be 54 Mbps and 1, and the other is the most pessimistic one with 6 Mbps and 1/3. The target APDR for the proposed rate control is set to be 99 %.

Fig. 2. APDR against interference error rate of transmissions with the proposed rate control and those with fixed PHY/FEC rates.
From these figures, we can first see that the case with PHY rate of 6 Mbps and FEC rate of 1/3 achieves high APDR close to 100% while it exhibits large fractional airtime. This is because this set of PHY and FEC rates generates a large number of redundant packets with large packet size. On the other hand, the case with PHY rate of 54 Mbps and FEC rate of 1 achieves the smallest fractional airtime thanks to the reduced redundancy while it shows the worst APDR, which degrades as the interference error rate increases. On the other hand, the trade-off between APDR and fractional airtime is well-controlled by the proposed rate control as seen in Figs. 2 and 3: the proposed rate control achieves high APDR with small fractional airtime. The fractional airtime of the proposed rate control gradually increases as the interference error rate increases as shown in Fig. 3. This is because the proposed rate control tends to select more conservative rates as learned by the training data for larger interference error rate, which is required to achieve the target APDR. In fact, we have confirmed that the proposed rate control achieves the target APDR of 99% for any value of interference error rate as shown in Fig. 2. From these results, we can confirm that the proposed rate control adaptively selects the appropriate set of PHY and FEC rates according to the link and interference conditions over the communication area.

5 Conclusions
In this letter, we have proposed an adaptive rate control for robust data transmissions utilizing Multi-AP receptions combined with packet-level FEC. The proposed scheme solely counts on the beacon frames received from surrounding APs for STA to decide the appropriate set of PHY/FEC rates to be employed for its uplink transmissions. The best set of PHY/FEC rates is selected by a rate selector, which learns the best rate for a given input by training data. Our numerical results show that the proposed rate control can well-control the trade-off between reliability and airtime.
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