Adaptive Tuning of IEEE 802.11 MAC for Improving Control Performance in Cyber-Physical Systems

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***Abstract*—In this paper, we study the problem of parameter tuning in IEEE 802.11 for improving control performance in cyber-physical systems (CPS). Our main idea is to exploit the fact that control performance depends more on delay distribution rather than just the average delay. Our contributions are two folds: *i)* Instead of trying to minimize the average network delay, we control the delay variance that can be more critical to control performance. *ii)* In order to validate our approach, we implement a CPS testbed, where a remote controller controls a drone via an IEEE 802.11 network. We examine the tracking error of the controller for a given reference. Our preliminary results show that the proposed approach can significantly improve control performance.**

I. Introduction

Recently, the confluence of cyber and physical systems has transformed conventional embedded systems into so-called cyber-physical systems (CPS), which are mainly characterized by close integration and coordination among computational and physical processes by means of networking [1], [2].

Since physical systems are generally controlled through a network in CPS, the control performance in CPS heavily relies on network characteristics. This problem has been traditionally studied in the automatic control community, which is called networked control systems (NCS) [3]. In the problem setting of NCS, the main focus is mostly on the stability of physical systems while the network is typically modeled as a source of delay and packet loss.

In this paper, we study the problem of parameter tuning in IEEE 802.11 for improving control performance in CPS. Though there exist substantial studies on tuning of network parameters for CPS, most of existing work have focused on the average network characteristics with respect to system stability. Our main idea is to exploit the fact that control performance depends more on delay distribution rather than just the average value of delay. Our contributions are two folds: *i)* Instead of trying to minimize the average network delay, we control the delay variance that can be more critical to control performance. *ii)* In order to validate our approach, we implement a CPS testbed, where a remote controller controls a drone via an IEEE 802.11 network.

In the network literatures, the system parameters of the IEEE 802.11 protocol are typically tuned for minimizing the average delay. However, this does not necessarily guarantee best control performance. Rather, control performance relies on delay distribution. For example, a network with larger average delay and smaller delay variance may give better control performance than that with smaller average delay and larger delay variance.

First, we use an exact delay model of the IEEE 802.11 protocol with heavy tailed characteristics in [4], and obtain the distribution of medium access control (MAC) access delay as a function of MAC parameters such as the initial contention window size, the number of backoff stage, the maximum contention window size, and the maximum number of retransmission. Then, we tune these MAC parameters for minimizing the variance of MAC access delay. As a practical solution, we use a gradient-based algorithm to set the parameters in an adaptive manner according to actual network delay measurement in real time.

Second, in order to verify our approach, we consider a CPS testbed equipped with camera localization capabilities, where a remote controller controls a drone via an IEEE 802.11 network. We evaluate the control performance of our CPS testbed with IEEE 802.11 MAC access delay. We examine the tracking error of the controller for a given reference. Our preliminary results show that the proposed approach can significantly improve control performance.

II. Problem Formulation

In this section, we formulate an optimization problem of minimizing the variance of network delay with constraints on maximum packet loss and average delay bound. Here, we consider a saturated IEEE 802.11 WLAN delay model, similarly as in [4].

Our objective is to minimize the variance of MAC access delay while maintaining the average delay and packet loss below thresholds. In this manner, we can provide better control performance while providing certain level of system stability. The overall formulation is as follows:

$$\begin{aligned} &\underset{M}{\text{minimize}}\ DV(M) \qquad (1)\\ &\text{subject to } L(M) \le L_{\text{max}}, A(M) \le A_{\text{max}}, M \in \mathcal{M}, \end{aligned}$$

where $DV(\cdot)$, $L(\cdot)$, $A(\cdot)$ denote the delay variance, packet loss, and average delay, respectively. In addition, the decision

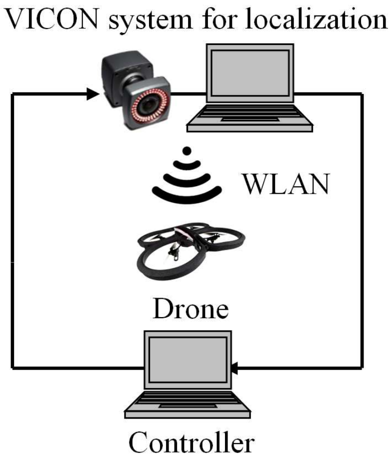

Fig. 1. CPS testbed with VICON localization system, where a drone is controlled through Wireless LAN.

variables $M = (W, m, K)$ are component-wisely the initial contention window size, the number of backoff stage, and the maximum number of retransmission, respectively, and $\mathcal{M}$ is the feasible set of M.

III. Preliminary Results

A. Simulation Setup

We carry out simulation study of networked control of a drone with the IEEE 802.11 MAC delay model using MATLAB/Simulnk. The overall system is shown in Fig. 1. A PD controller is used for the simulation. The sampling period h is set to 0.01 s. In this simulation, the output of the plant tracks the reference input of $r = 1$. The packet size is $l = 33$ bytes, and the number of nodes is $n = 10$.

B. Simulation Results

As shown in Fig. 2, the controller gives larger overshoot and settling time as the MAC parameter m increases. Fig. 3 shows specific values of the average absolute tracking error up to 0.5 s, which are 0.1107, 0.1279, 0.1451, and 0.1515, respectively. As expected, the tracking error is the smallest when there is no network-induced delay. In a similar manner, we can tune the network parameters. Our preliminary result gives a parameter set of $W = 64$, $m = 4$, $K = 7$ for $n = 10$, $l = 33$ bytes.

IV. Conclusion and Future Work

We have evaluated the control performance with respect to the variance of IEEE 802.11 MAC access delay by tuning key MAC parameters. Our main idea is to take into account the delay distribution rather than simply considering the average delay for better control performance in CPS. Our preliminary simulation results show that our approach can give better control performance. For future work, we are currently working on implementation of a CPS tesebed equipped with the VICON system. We will validate our approach by a means of empirical study in our future work.

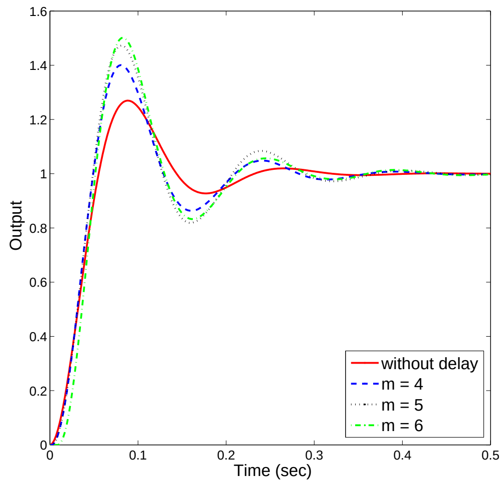

Fig. 2. Effect of the delay variance with different MAC parameters of $m = 4, 5, 6$.

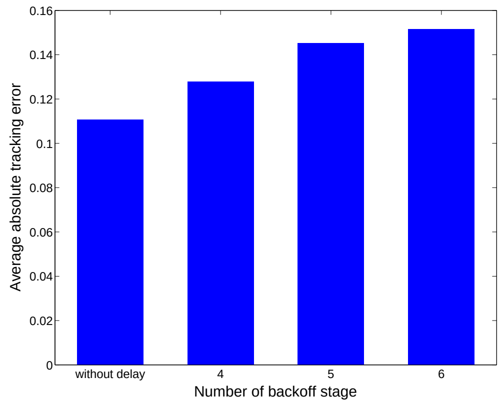

Fig. 3. Average absolute tracking error of the controller.

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