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Co-design of dynamic scheduling and H-infinity control for networked control systems ☆

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ABSTRACT

A novel co-design scheme of TOD dynamic scheduling strategy and the robust H-infinity controller for a class of networked control systems (NCSs) with communication constraints and random time delay is proposed in this paper. The NCSs with communication constraints and random time delay is modeled as a discrete-time switched system with parameter uncertainties, and a procedure for robust H-infinity controller design under TOD scheduling strategy based on the Lyapunov function and switched system theory is proposed to guarantee the asymptotic stability of close-loop system. Finally, a simulation example demonstrates the efficiency of the proposed method.

1. Introduction

Networked control systems (NCSs) are distributed systems in which communication between sensors, actuators, and controllers is supported by a shared real-time network. Compared with the traditional control system, the NCSs can offer several advantages such as reduced system wiring, low cost, high reliability, information sharing, and remote control [1]. However, the introduction of the network in the control system brings many challenges for the analysis and design of NCSs, such as network-induced delay, packet dropout and communication constraints. Therefore, many novel control designs of NCSs has been extensively investigated. Network induced delay is an important factor to degrade control performance of NCSs, the problem has been intensively studied in control community [2–4], meanwhile the control and scheduling problem of NCSs with communication constraints remains to be deeply investigated. Communication constraints can be distinguished into medium access constraints, bit rate constraints and information rate constraints. In recent years, most of research concentrate on media access constraints [5–11] and bit rate constraints [12–14] problem. The notion of medium access constraints implies that a limited number of nodes can be allowed to access the network and transmit data at same instant.

NCSs with communication constraints are modeled as a class of hybrid systems in [7], a procedure for design of dynamic output feedback controller and scheduling protocol is presented to guarantee quadratic stability based on Lyapunov functions method of weak partial state control. In [8], a class of NCSs with communication constraints and time-varying transmission intervals is modeled as a discrete-time switched linear uncertain system and be transformed into a polytopic system with norm-bounded uncertainties, and then a class of quadratic protocol is proposed to guarantee the system uniformly globally exponentially stable. However these results ignored the impact of delay, and assume that only one node can access the network and transmit data at every transmission instant. In [9], the NCSs with limited bandwidth was modeled as the mixed logical dynamical (MLD) framework, then the scheduling and control strategy were mixed into a integrated quadratic

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programming formulation and then a co-design method of scheduling and control was presented, but network induced delay was not considered in the literature. In [10,11], the problem of co-design of scheduling and control for the NCSs with multiple distributed transmission delays and communication constraints was investigated. However in the results mentioned above, scheduling strategy is static and the results are quite conservative.

In this paper, a class of NCSs whose a part of nodes can access the shared network and transmit data are considered because of the influence of communication constrains. If only one node can access the network, bandwidth utilization will be relatively low, that means under the allowance of available bandwidth, as many as possible nodes can access the shared network and transmit data packets. A novel co-design scheme of TOD (Try-Once-Discard) dynamic scheduling strategy and the robust H-infinity controller for a class of networked control system with media access constraints and random time delay is proposed. The NCS is modeled as a discrete-time switched system with parameter uncertainty which comes from random time-delay, the robust H-infinity controller is designed to maintain the asymptotic stability and robust performance of the closed-loop systems by using Lyapunov function method and switched system theory.

The paper is organized as follows. Section 2 gives the dynamical model of NCSs with communication constrains and random time delay in a unified framwork. A novel Codesign strategy for TOD dynamic scheduling and robust H-infinity control is presented in section 3. Numerical example and simulation results are given in Section 4 to verify the proposed scheme. Finally, section 5 gives some brief conclusions.

2. Problem formulation

The structure of networked control system to be considered is shown in Fig. 1, and the controlled plant is described by the linear time-invariant system model as follows:

$$\begin{cases} \dot{x}(t) = A_p x(t) + B_p \hat{u}(t) + H_0 w(t) \\ z(t) = C_1 x(t) + H_1 w(t) \end{cases} \tag{1}$$

where $x(t) \in R^n$, $\hat{u}(t) \in R^m$ and $z(t) \in R^p$ are the state vector, control input vector and controlled output vector, respectively. $w(t) \in L_2[0, \infty)$ is the external disturbance. A_p, B_p, C_1, H_0 and H_1 are constant matrices of appropriate dimensions.

In Fig. 1, the plant consists of n sensors and m actuators, they are connected with controller through shared network. τ_k^{sc} is the sensor-to-control time delay, τ_k^{ca} is the control-to-actuator time delay. The assumptions in the above NCSs are as follows:

1. The sensors are time driven with sampling period h, and controller and actuators are event driven.
2. $\tau_k = \tau_k^{sc} + \tau_k^{ca}$ is time-varying, and $0 < \tau_k < h$.
3. Owing to the communication constraints, only $d_s (0 < d_s \leqslant n)$ states and $d_c (0 < d_c \leqslant m)$ control signals are allowed to be transmitted through network at every transmission period.

The system (1) can be rewritten into discrete time model as follows:

$$\begin{cases} x(k+1) = Ax(k) + B_0 \hat{u}(k) + B_1 \hat{u}(k) + H_0 w(k) \\ \qquad z(k) = C_1 x(k) + H_1 w(k) \end{cases} \tag{2}$$

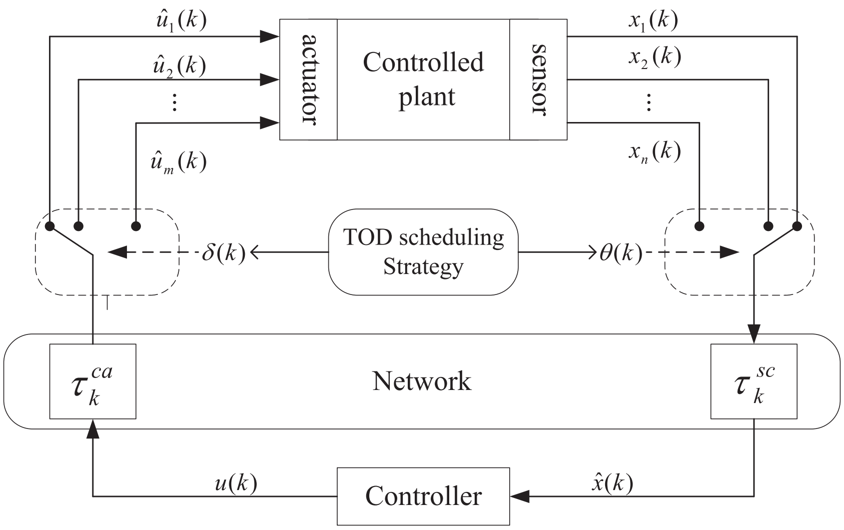

Fig. 1. The structure diagram of networked control system.