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Intelligent Scheduling Controller Design for Networked Control Systems Based on Estimation of Distribution Algorithm*

LI Hongbo (李洪波), SUN Zengqi (孙增圻)**, CHEN Badong (陈霸东), LIU Huaping (刘华平)

Department of Computer Science and Technology, Tsinghua University, Beijing 100084, China

Abstract: The use of communication networks in control loops has gained increasing attention in recent years due to its advantages and flexible applications. The network quality-of-service (QoS) in those so-called networked control systems always fluctuates due to changes of the traffic load and available network resources. This paper presents an intelligent scheduling controller design approach for a class of NCSs to handle network QoS variations. The sampling period and control parameters in the controller are simultaneously scheduled to compensate for the network QoS variations. The estimation of distribution algorithm is used to optimize the sampling period and control parameters for better performance. Compared with existing networked control methods, the controller has better ability to compensate for the network QoS variations and to balance network loads. Simulation results show that the plant setting time with the intelligent scheduling controller is reduced by about 64.0% for the medium network load and 49.1% for high network load and demonstrate the effectiveness of the proposed approaches.

Key words: networked control systems (NCSs); estimation of distribution algorithm (EDA); network-induced delay; packet dropout; network quality-of-service (QoS) variation

Introduction

Networked control systems (NCSs) are a type of distributed control systems with control loops closed via communication networks. Compared with traditional "point to point" control systems, NCSs facilitate resource sharing, reduce installation and reconfiguration costs, and improve flexibility. Therefore, NCSs have great potential in manufacturing plants, vehicles, aircraft, and spacecraft. With their many advantages and potential applications, NCSs have attracted much attention in the control and computer community in recent years, with many interesting results[1-12].

In NCSs, the controller design is one of the most important topics. Yue et al.[1] investigated the state feedback control for NCSs with network-induced delays and packet dropout via linear matrix inequality (LMI) approach. Luis and Panos[4] and Zhivoglyadov and Middleton[5] proposed a model based control approach for NCSs with network constraints. Nislsson et al.[6] and Hu and Zhu[7] investigated the optimal stochastic control approach for NCSs with the network-induced delay shorter and longer than the sampling period. These results have shown many advantages and have solved various problems. However, those studies have assumed that the control parameters and sampling period remain constant regardless of network quality-of-services (QoSs) variations. In practical circumstances, the network QoS always fluctuates due to changes of the traffic load and available network resources. NCSs are functionally related systems and

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** To whom correspondence should be addressed.
E-mail: szq-dcs@mail.tsinghua.edu.cn; Tel: 86-10-62777704

their performance depends not only on the control algorithms but also on the network QoS. Therefore, despite the progress made in the NCS controller design, it has become evident that advanced control methodologies with QoS variation compensation are required.

Although there has only been a limited amount of research on NCSs controller design with QoS variation compensation, there are some interesting results reported in the literature. In general, there are two main approaches. The first one is the sampling period scheduling approach, which enables NCSs to achieve a higher resource utilization rate and better control performance[8-10]. The second approach adjusts the control parameters to compensate for the network QoS variations[11,12]. Both methodologies show promising results. However, these approaches still have some limitations since the two approaches have been studied separately rather than having a networked controller that simultaneously adjusts the sampling period and control parameters. Moreover, the sampling period and control parameters have not been optimized for NCSs.

This paper presents a controller design approach that simultaneously adjusts the sampling period and control parameters for NCSs, where the sampling period and control parameters are optimized by using the estimation of distribution algorithm (EDA). The EDA is a population-based search algorithm introduced by Muhlenbein and Paa[13] for evolutionary computations. During the past several years, the EDA has received much attention as one of the fastest growing techniques for genetic and evolutionary computations. Many interesting results have been reported in the literature[14,15]. Since the EDA has many advantages, such as better speed, better solutions, and less tuned parameters, the EDA is used here to solve the optimization problem.

The objective of this paper is to construct an intelligent scheduling controller to handle network QoS variations by simultaneously scheduling the sampling period and control parameters based on network QoS variations. The method first optimizes the sampling period and control parameters offline for the NCS. Then, the controller schedules the sampling period and control parameters online based on QoS variations.

1 Problem Statement

The NCSs structure is shown in Fig. 1, where networks exist between the sensor and the controller nodes. The controlled plant, G_p, is given by

$$\begin{cases}\dot{\boldsymbol{x}}(t)=\boldsymbol{Ax}(t)=\boldsymbol{Bu}(t)+\boldsymbol{v}(t),\\ \boldsymbol{y}(t)=\boldsymbol{Cx}(t)\end{cases} \quad (1)$$

where $\boldsymbol{x}(t)$ is the state vector, $\boldsymbol{u}(t)$ is the control input vector, $\boldsymbol{y}(t)$ is the plant output and $\boldsymbol{v}(t)$ is the disturbance vector. $\boldsymbol{A}$, $\boldsymbol{B}$, and $\boldsymbol{C}$ are matrices with appropriate dimensions.

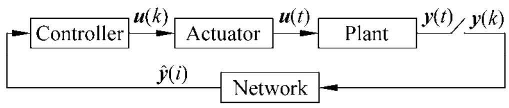

Fig. 1 NCSs structure

The actuator is event-driven with the event here being the arrival of a packet. The sensor is clock-driven with the sampling period denoted as h. Therefore, the system has serial pairs $\{\boldsymbol{y}(k),kh\}$. The sampling period can be adjusted online according to some mechanism for better NCSs performance.

Networks are unreliable data transmission paths with packets not only suffering network-induced delay and out-of-order packets, but even transmission loss as illustrated in Fig. 2. Packets arrive at the controller randomly because the network-induced delays are random. Let T_i ($T_{i+1}>T_i$) denote the packet arrival instant relative to the initial time, where the subscript "i" is the number of packets received by the controller. A serial pair $\{\hat{\boldsymbol{y}}(i),T_i\}$ corresponds the arrival of packets at the controller, where $\{\hat{\boldsymbol{y}}(i)\}$ is a subset of $\{\boldsymbol{y}(k)\}$.

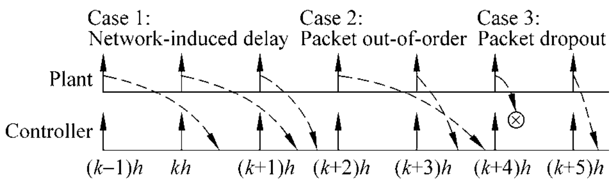

Fig. 2 NCSs timing diagram

The control objective is to design a networked controller based on $\{\hat{\boldsymbol{y}}(i),T_i\}$ to guarantee the NCSs stability and performance. The controller dynamics, G_c, can be described as

$$\boldsymbol{u}(k)=f(\{\hat{\boldsymbol{y}}(i),T_i\},\bullet) \quad (2)$$

where $(\bullet)$ represents other appropriate information such as the plant model.

Then, the closed loop NCSs can be represented as

$$\Sigma(G_\mathrm{p},\{\boldsymbol{y}(k),kh\},G_\mathrm{c},\{\hat{\boldsymbol{y}}(i),T_i\}) \quad (3)$$

Remark 1 In Eq. (3), $\{\hat{\boldsymbol{y}}(i)\}$ is a subset of $\{\boldsymbol{y}(k)\}$. If the element numbers in the two sets are not equal, some packets have been dropped. If the ele-