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State estimation for networked systems with Markovian communication constraints and multiple packet dropouts☆

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Abstract

In this paper, the state estimation problem for discrete-time networked systems with communication constraints and random packet dropouts is considered. The communication constraint is that, at each sampling instant, there is at most one of the various transmission nodes in the networked systems is allowed to access a shared communication channel, and then the received data are transmitted to a remote estimator to perform the estimation task. The channel accessing process of those transmission nodes is determined by a finite-state discrete-time Markov chain, and random packet dropouts in remote data transmission are modeled by a Bernoulli distributed white sequence. Using Bayes' rule and some results developed in this study, two state estimation algorithms are proposed in the sense of minimum mean-square error. The first algorithm is optimal, which can exactly compute the minimum mean-square error estimate of system state. The second algorithm is a suboptimal algorithm obtained under a lot of Gaussian hypotheses. The proposed suboptimal algorithm is recursive and has time-independent complexity. Computer simulations are carried out to illustrate the performance of the proposed algorithms.

1. Introduction

In the past decade, networked systems have attracted much research interest due to their successful applications in a wide range of areas such as control, fault diagnosis, signal

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processing, information fusion, etc [1–4]. Compared with the conventional point-to-point system connection, networked systems have advantages in installation, wiring, implementation and maintenance cost. Nevertheless, many challenging problems, such as communication delays, packet dropouts and fading measurements, arise from the introductions of these network media.

For such systems, there are already many available results on control and stabilization problems [5–9]. The authors formulated a control problem with a communication channel connecting the sensor to the controller in [5], and the decentralized control problem for networked discrete event systems with communication delays was studied in [6]. In [7], an H_∞ controller design method for networked systems with bounded packet dropouts was presented. The authors provided several stability results for networked systems with asynchronous renewal links in [8], and the static output-feedback stabilization problem of discrete-time networked systems with time-varying network-induced delays and packet dropouts was investigated in [9]. On the other hand, the state estimation problem for this class of systems has been widely studied and a rich body of research results has been reported in the literature [10–19]. To mention a few, the optimal linear estimation problem for networked systems with multiple packet dropouts was dealt with in [20]; the optimal design problem of state estimation for networked systems subject to random delays and packet drops was studied in [21]; and a robust H_∞ filter for stochastic uncertain discrete time-delay systems with missing measurements was developed in [22]. Moreover, a Kalman filter approach for state estimation of discrete-time networked systems subject to persistent unknown inputs was proposed in [23].

In networked systems, many spatially distributed sensors and estimators are connected via a multi-purpose communication network. The introduction of communication networks, especially, wireless networks and wireless sensor networks, facilitates the estimation and control of distributed large-scale systems. However, the use of communication networks introduces new restrictions on data transmissions among sensors and estimators. One of the fundamental restrictions is referred to as the medium access constraint, that is, nodes are not permitted to access the network simultaneously where the choice of which node to access the network is determined by a specified media access control protocol which may be random or deterministic [24]. A few studies concerning with the state estimation problem of systems with communication constraints have been reported. In [25], a Kalman filter for networked systems with communication constraints was proposed where the measurements come from two different sensors. The channel accessing process of the two sensors is modeled by two independent Bernoulli random processes, and lower and upper bounds of the channel accessing probabilities of the two sensors are derived to ensure that the estimation error covariance is bounded. In [26], the robust optimum design problem for discrete-time systems with multiple sensor failures was studied where each sensor may fail at any sample time independently of the others. The sensor failures are expressed as Bernoulli random processes, and a robust and resilient minimum variance unbiased linear state estimator was presented. In [27], the H_∞ filtering problem for discrete-time networked systems with communication constraints was considered, and an H_∞ filters was obtained via the feasible solution of a set of linear matrix inequalities. More recently, a more general networked system model with communication constraints has been established in [28], where the model describes the channel accessing process of various transmission nodes and schedules various distributed network nodes. Optimal linear filters were designed by using the orthogonal projection principle and the innovation analysis approach. The aforementioned literatures have made some progress in the networked estimation with communication constraints, but, these studies

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