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INPUT-TO-STATE STABILITY IN CONGESTION CONTROL PROBLEM OF COMPUTER NETWORKS WITH NONLINEAR LINKS

Ali Moarefianpour and Vahid Johari Majd*

Department of Electrical Engineering
Tarbiat Modares University
P.O. Box 14115-143, Tehran, Iran
moarefian@gmail.com; *Corresponding author: majd@modares.ac.ir

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Abstract. *In this paper, we address the stability of congestion control in Internet, considering all unmodeled flows as exogenous disturbances. In contrast with previous works, we suppose that both sets of senders and links in the network have nonlinear dynamics, and model the network based on fluid flow approximation. Each sender updates its sending rate to minimize its own cost function. The sending rate dynamics of each sender consist of a linear and a nonlinear subsystem in cascade form. The linear subsystem acts as dynamical pricing filter to improve the transients of the network congestion problem. For the obtained primal-dual algorithm, we first derive the existence conditions of the equilibrium point of the closed loop system; then we prove that the proposed control law guarantees input-to-state stability (ISS). The obtained general results are further simplified for two types of typical filters, namely, proportional and proportional plus approximate derivative filters. Using network simulator ns-2, we verify the performance of the proposed congestion control law for some network topologies.*
Keywords: Congestion control, Computer networks, Input-to-state stability, Nonlinear dynamics, Primal-dual algorithm.

1. Introduction.

An important issue in the design of a congestion control law is the proof of network stability for proposed algorithm. Proper mathematical representation of the problem is necessary for stability analysis. Game theory and optimization frameworks are proper tools for this purpose [1-3]. Primal algorithms that employ dynamic sender and static link models, or dual algorithms that consider static sender and dynamic link models are derived using optimization techniques [4]. Moreover, it is possible to describe different TCP/AQM algorithms in the primal-dual framework, where both sets of senders and links are assumed dynamical [4].

An early work on the global stability of congestion control problem was carried out by employing Lyapunov theory for primal and dual algorithms in the absence of propagation delay [3]. Local and global stability was further developed using different approaches such as Lyapunov [5], passivity [6], and game theoretic frameworks [7]. The first local asymptotic stability result for the congestion control problem in the presence of communication delay was developed in [8] by linearizing the model around the equilibrium point and applying Nyquist stability criteria. In that study, stability condition was derived for TCP connections with identical round trip delay neglecting the queuing delay compared to the propagation delay. Later, the stability for the continuous and discrete models of the senders and links, primal, dual, and primal-dual algorithms with identical or different round trip delay was discussed in the literature [9-14].

In addition to the effect of delay, exogenous disturbance is an effective source of instability for the systems especially nonlinear dynamical systems. In linear dynamical systems,