Decentralized and Dynamic Bandwidth Allocation in Networked Control Systems

Ahmad T. Al-Hammouri, Michael S. Branicky, Vincenzo Liberatore
Case Western Reserve University

Stephen M. Phillips
Arizona State University

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Paper Overview

- Control over Networks
  - NCSs, DCSs, SANETs, ...
- Control of Networks
  - Efficient BW allocation
    - Congestion control
  - Fairness
- We propose a “Cof N” scheme to better serve “Cover N”
Control over Networks

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Control over Networks

- Remote interaction (monitoring & control) with the physical world

- Applications:
  - Industrial automation & process control
  - Space exploration, e.g., telerobotics
  - Smart homes
  - Medical sensing & surgical simulations
  - Automatic asset mgmt. (RFID)

Control of Networks (Scope of the paper)

- A bandwidth allocation scheme

- Objectives:
  - Stability of control systems
  - Efficiency & fairness
  - Fully distributed, asynchronous, & scalable
  - Dynamic & self reconfigurable

- Formulating the scheme in CT
  - NCSs regulate $h$ based on congestion fed back from the network
Problem Formulation

- Define a utility fn $U(r)$ that is
  - Monotonically increasing
  - Strictly concave
  - Defined for $r \geq r_{\text{min}}$
- Optimization formulation

$$\max \sum_i U_i(r_i)$$
$$\text{s.t. } \sum_{i \in S(l)} r_i \leq C_l, l = 1, \ldots, L$$
$$\text{and } r_i \geq r_{\text{min}}, i$$
Distributed Implementation

- Two independent algorithms
  - End-systems (plants) algorithm
  - Router algorithm (later on)

\[ r(p_i) = 1/h = \left[U^{-1}(p_i)\right]_{r_{\min}}^{r_{\max}} \]

NCS-AQM Control Loop

Model Plant

\[ P(s) = \frac{B}{s} e^{-sd} \]

Queue Controller

\[ G(s) \]
Queue Controller $G(s)$

- Proportional (P) Controller
  
  $G_p(s) = k_p$

- Proportional-Integral (PI) Controller
  
  $G_{pi}(s) = k_p + \frac{k_i}{s}$

Determination of $k_p$ and $k_i$

- Stability region in the $k_i$–$k_p$ plane
  
  Stabilizes the NCS-AQM closed-loop system for delays less or equal $d$

- Analysis of quasi-polynomials, $f(s, e)$
Simulations & Results

50 NCS Plants:

\[ \frac{dx}{dt} = ax(t) + bu(t) \]

\[ U(r) = \frac{a - bK}{a} e^{ar} \]

\[ r_{\text{min}} = \frac{a}{\ln \left( \frac{bK + a}{bK - a} \right)} \]

- \[ u(t) = -K(R - x(t)) \]

- [Branicky et al. 2002]
- [Zhang et al. 2001]

Simulations & Results (cont.)

- [Branicky et al. 2002]
- [Zhang et al. 2001]
Thank You

- Questions
- Comments

- Probing further:
  http://start.case.edu/~vx111/NetBots