A Testbed for Networked Control Systems

Ahmad T. Al-Hammouri, Michael S. Branicky, and Vincenzo Liberatore

Department of Electrical Engineering and Computer Science

Case Western Reserve University

CASE SCHOOL OF ENGINEERING

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ABSTRACT

Advances in sensor, actuator, embedded system, and networking technologies have enabled the development of distributed control systems over communication networks. Such control systems, which are known as networked control systems (NCS), allow humans to extend their capabilities beyond their own physical reach. Potential applications include surveillance in remote and hazardous areas, space exploration, medical sensing and surgical simulations, and industrial plants monitoring. However, current network protocols and implementations introduce packet losses, long delays, and jitter that adversely influence stability and performance of networked control systems.

Our contention is to build middleware systems to compensate for lack of QoS in networks. To be able to validate and verify different systems, the systems need to be compared against benchmarks and testbed measurements. Therefore, we are building a testbed by marrying two existing and well-known simulators: *ns-2*, a simulator to simulate communication network dynamics and protocols, and *Ptolemy*, a simulator for concurrent and real-time systems.

In this poster, we present our experiences in the fields of Internet robotics and distributed interactive simulations, and we show the basis of building middleware systems to deal with network delays and unreliability.

INTRODUCTION

- NCS (Networked Control Systems): interconnection of sensors, actuators, and controllers by communication networks
- Advantages:
  - Reduced system wiring
  - Increased system flexibility and reconfigurablity
  - Ease of system diagnosis and maintenance
- The network introduces unreliable and time-dependant levels of service, such as delays, jitter, and losses
- Erratic levels of service are due to several independent factors, such as lack of or non-deterministic QoS, traffic burstiness, route changes, electromagnetic interferences (especially in wireless media), and failures
- Network vagaries can jeopardize the stability, safety, and performance of controlled units
- Our objective is to devise integrated control and communication algorithms to compensate for the vagaries of network service
- Strategies will be targeted toward the application or middleware layer

PROJECT URL: *http://home.cwru.edu/~vxl11/NetBots/*

NCS VISION

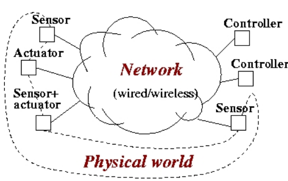


Figure 1: The vision of networked control systems.
Monitor and affect local and remote physical environments.

PREVIOUS PROJECTS

INTERNET ROBOTICS

- Use IP (Internet Protocol) networks to interact with *remote* intelligent systems, e.g., robots
- A non-real-time middleware to deal with data networks issues
- Based on mobile software components (agents) called "Virtual Robots"
- Advantages: Survivability and Fault-tolerance; Evolvablity and Re-programmability
- Sponsored by *NASA*
- Application: Conducting experiments on the International Space Station

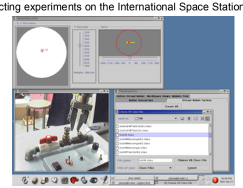


Figure 2: Internet Robotics.
Our current prototype: instructing ParaDex to manipulate switches, levers and valves.

DISTRIBUTED SIMULATIONS

- Explore the effectiveness of distributed simulations over the Internet
- Applications:
  - Networked games
  - Battlefield simulations
  - Surgical simulations
- Develop a demonstrative networked game based on client-server paradigm
- The game implements an application-layer delay compensation strategy
- Extrapolation of the game state is evaluated by dead-reckoning and is based on RTT active measurements
- To download and play, visit *http://home.cwru.edu/~vxl11/NetBots/*

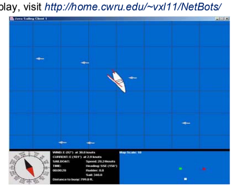


Figure 3: Distributed Simulations.
The sailing simulator: sailing a boat toward the target buoy as quickly as possible given the environmental conditions (wind and current).

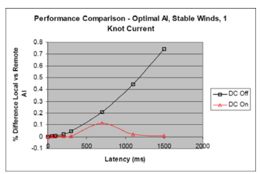


Figure 4: Distributed Simulations, Preliminary Results

CO-DESIGN

- Combine the study of networking with feedback control
- Network issues:
  - Reliability, delays, scalability, and bandwidth
- Controlled system issues:
  - Stability, performance, and fault tolerance
- *Co-design Goal*: Maximize the overall NCS performance subject to stability and network communication constraints
- NCSs pose novel challenges to the analysis and design of control systems and networks

CO-SIMULATION

- A framework to verify and evaluate various designs
- Combines dynamic system simulations and packet-level network simulations

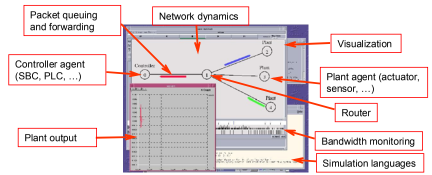


Figure 5: Co-simulation screenshot: interconnection of three plants, a controller, and a router

SIMULATION SOFTWARE

- Extension to *ns-2*, ***Agent/Plant***, represents the interface between the physical and the network dynamics
- An ***Agent/Plant*** can take the role of a sensor, controller interface, or actuator depending on its usage in the simulation script
- Pairs of plants are connected to each other and exchange sampled data and control instructions

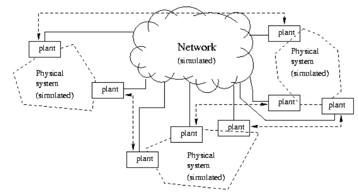


Figure 6: Usage of the ns-2 *Agent/Plant* extension for the co-simulation of networks and physical systems

FUTURE EXTENSIONS

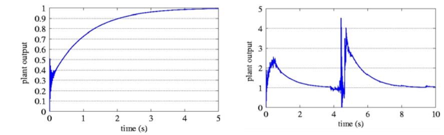
- Use *Ptolemy II* to model and simulate each of the plants (sensors, actuators, or controllers)
- Advantages:
  - Creation of more complex and physical systems
  - Improving the modularity of the co-simulation software
- A scenario: a Ptolemy's sensor model generates output data → ns-2 delivers the sampled data to a controller → the controller computes the control signal, inscribes it into a packet → ns-2 delivers the packet to simulated actuators

RESULTS

- Topology: *n* plants are connected to a controller sharing a bottleneck link (T1 line). A topology with three plants and a controller is shown in figure 5.
- Plants Model:

$$\frac{dx}{dt} = 100x(t) + u(t), \quad y(t) = x(t)$$

- Results:



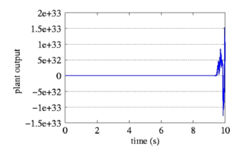


Figure 7: Plant 2 output.
Buff=inf., n=1 (left);
Buff=4, n=39 (up, right);
Buff=2, n=39 (down, right)

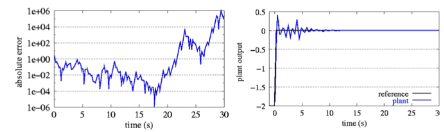


Figure 8: Contingency control: no contingency (left); contingency (right)

SPONSORS

- NSF Sensor and Sensor Networks Program
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