A Co-Simulation Platform for Actuator Networks

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http://vorlon.case.edu/~vxl11/NetBots/

INTRODUCTION & BACKGROUND

- A sensor-actuator network (SANET) consists of interconnected sensors, controllers, and actuators

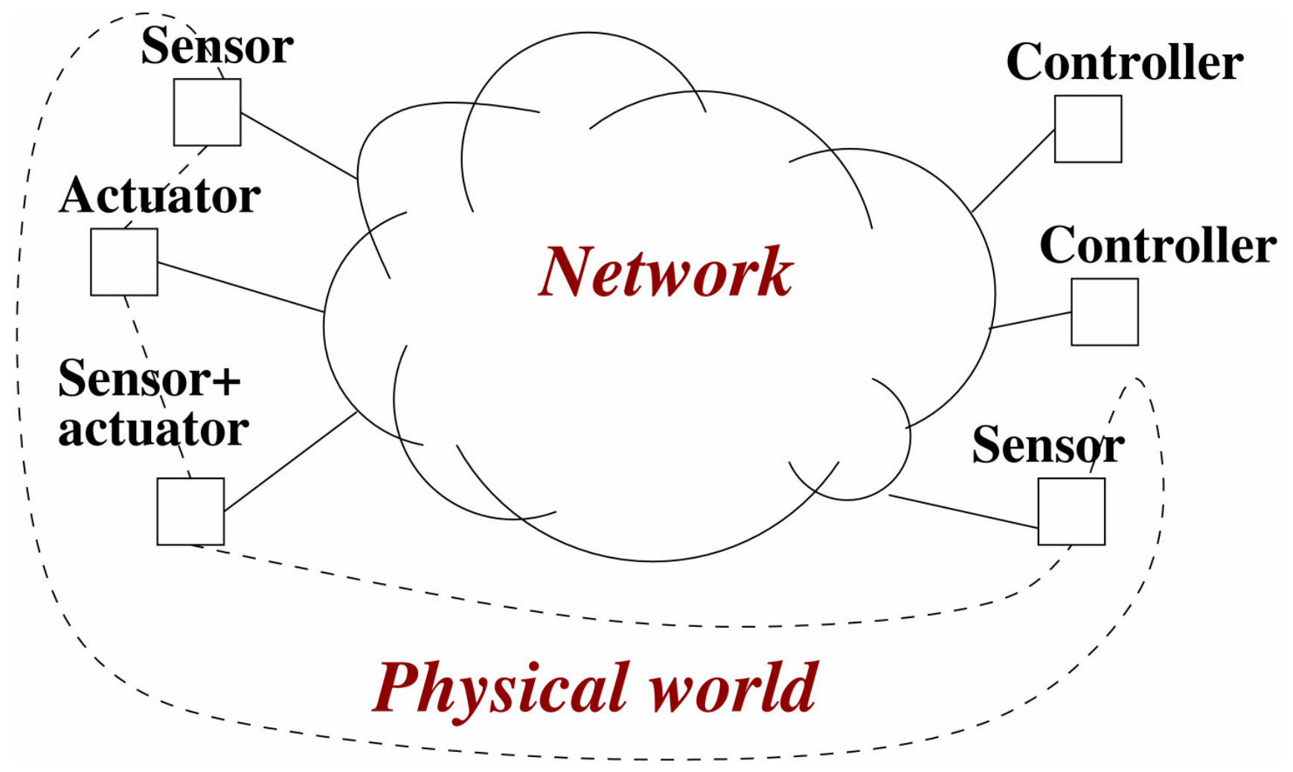

Fig. 1. SANETs consist of sensors, actuators, and controllers. Sensors sample the values of physical quantities and send them inside packets to controllers. Controllers examine received samples to compute control signals that are then sent to actuators. Actuators translate control signals into physical actions. All communications occur over the network [1].

- SANETs extend the distributed control of physical environments beyond physical barriers
- Potential applications include industrial automation, exploration of remote and hazardous environments, and the smart power grid [1]
- SANETs are *not* sensor networks, *not* necessarily energy and computation constrained, and their communications need *not* be wireless
- SANETs' effectiveness imposes stringent real-time constraints on the communication infrastructure:
  - Network performance affects the behavior, stability, and safety of the controlled physics
  - Demands of physics influence the design of a communication network
- Future progress in SANETs necessitates the existence of ***co-simulation*** tools that enable the joint and simultaneous simulation of both physical and communication networks dynamics
- Co-simulation will allow verification, validation, & evaluation of different control & network algorithms

RELATED & PREVIOUS WORK

- There exist separate simulation tools for dynamical systems & for communication networks
- SANETs can leverage such tools
  - First direction: extend dynamical systems simulators to also simulate the events and dynamics of communication networks. Example: TrueTime
  - Second direction: extend a network simulator to include capability for dynamical systems simulations. Example: Agent/Plant [2]
  - Third direction: marry a full-fledged network simulator with a full-fledged dynamical systems simulator. Examples:
    - ADEVS/ns-2 integrated tool
    - Modelica/ns-2 integrated tool

Modelica/ns-2 INTEGRATED TOOL

- Modelica [3]
  - A modeling language for large-scale physical systems
  - Supports model construction & reusability
  - Allows acausal modeling
  - Has several libraries (e.g., Standard, Power systems, Hydraulics, Pneumatics, Power train)
  - Has commercial and open source simulation environments
- ns-2 [4]
  - A widespread discrete-event networks simulator
  - Simulates routing, transport, & application protocols over wired, wireless, local- & wide-area networks

TECHNICAL APPROACH

- Integration via newly developed inter-process communication interfaces in both Modelica & ns-2
- IPC mechanics must guarantee synchronization between the two simulators
- Synchronization is achieved by *enslaving* each Modelica's module to a corresponding ns-2 agent

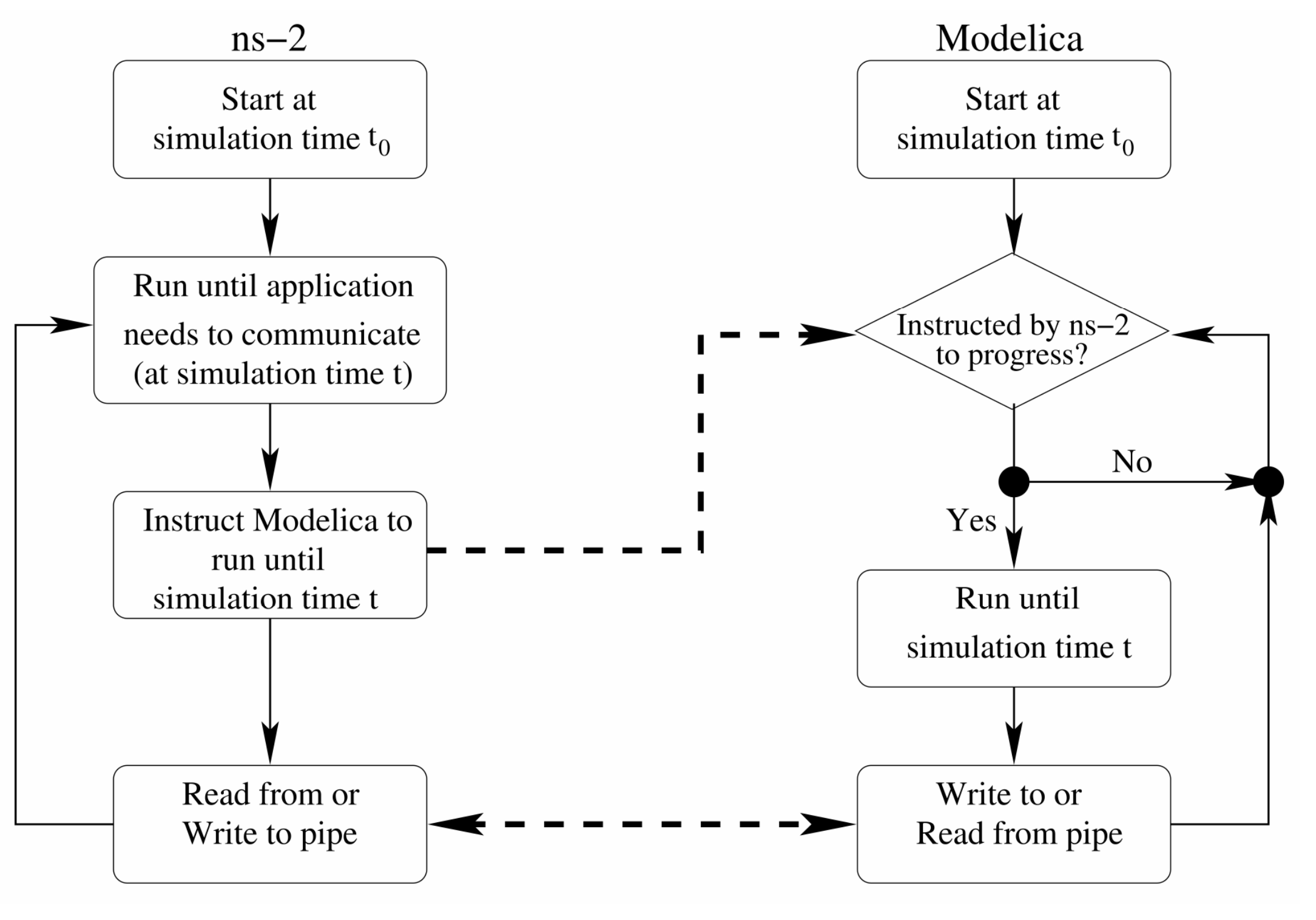

Fig. 2. The Modelica & ns-2 inter-simulator communication mechanics. ns-2 runs first and Modelica is paused. When the ns-2 application is slated by ns-2's event scheduler to receive (deliver) data from (to) a Modelica model at time *t*, it instructs Modelica to run until time *t*, and to exchange data at that point. After the data exchange, Modelica simulation time is suspended until the ns-2 application is scheduled again. Dashed lines represents communication via UNIX named pipes.

CASE STUDY: POWER SYSTEM CONTROL

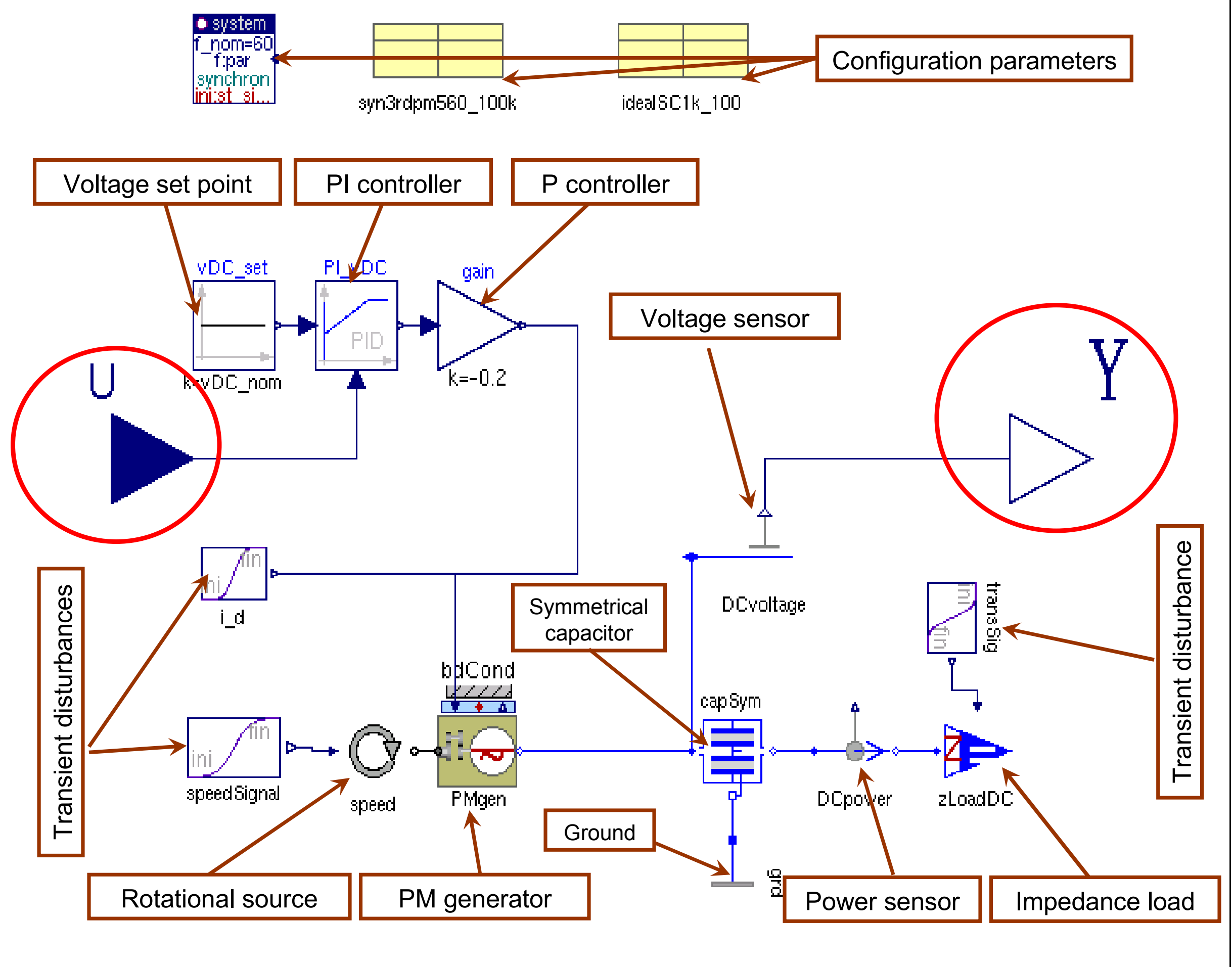

Fig. 3. A SANET consisting of a power transmission system that is controlled over a wide-area network. The power system involves typical power grid elements, including a permanent-magnet generator that supplies electrical power to a remote time-varying load. The voltage is measured by a sensor and is transported to a PID controller over the network (Fig. 4). The PID controller uses the voltage measurements to regulate the generator's output voltage under the varying load.

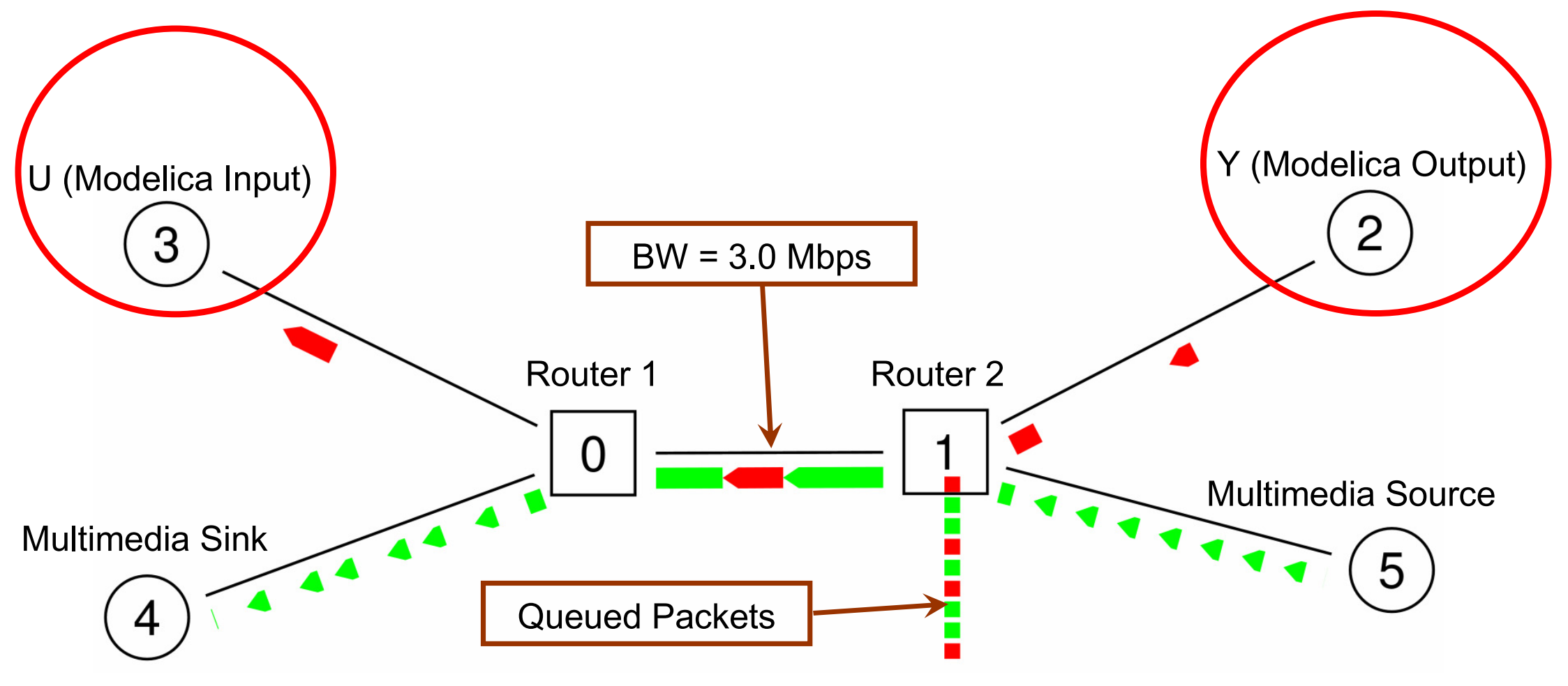

Fig. 4. The network topology over which voltage samples of Fig. 4 are communicated to the controller. The bottleneck link, which connects Router 1 and Router 2, has a capacity of 3.0Mbps and is shared by sensor data and multimedia cross-traffic that flows from node 5 to node 4.

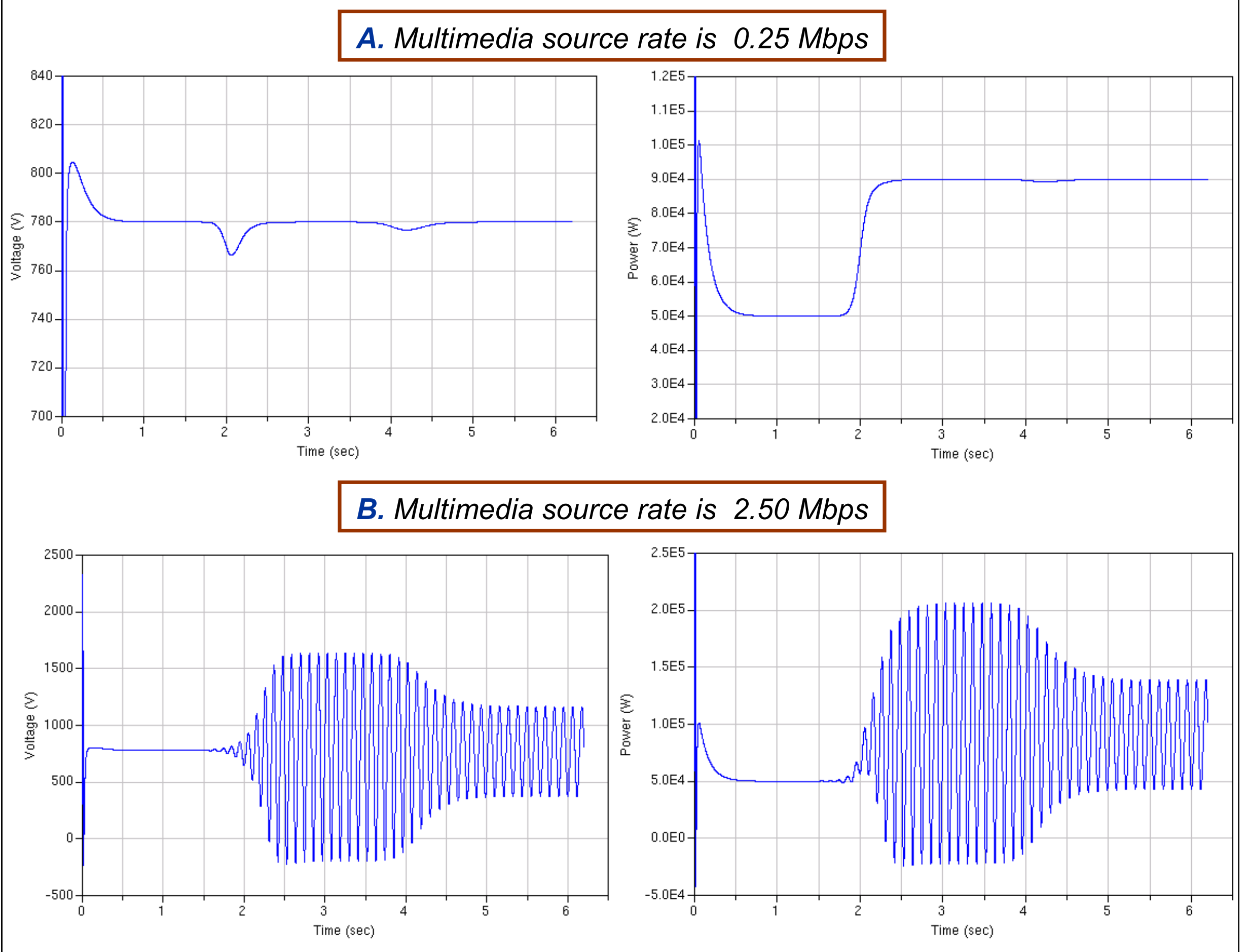

Fig. 5. The influence of the network cross-traffic on the ability of the SANET to stabilize the generator's voltage under the varying load. The plots show the line voltage and power for two cases of the multimedia transmission rate.

ACKNOWLEDGMENTS

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REFERENCES

1. A.T. Al-Hammouri, M.S. Branicky, V. Liberatore, and S.M. Phillips. Decentralized and dynamic bandwidth allocation in networked control systems. *WPDRTS'06*, Island of Rhodes, GREECE, 2006

2. M.S. Branicky, V. Liberatore, and S.M. Phillips. Networked control system co-simulation for co-design. *ACC'03*, Denver, 2003

3. Modelica. http://www.modelica.org/

4.The Network Simulator (ns-2). http://www.isi.edu/nsnam/ns/