Center for Embedded Systems
An NSF Industry/University Cooperative Research Center

Center for Embedded Systems (CES)
Request for Proposals Template – YEAR 6

DUE: Monday, March 31, 2014, by 5 p.m.

TITLE:	**Synchronizing Finite State Machine Controllers for Distribution Systems**				
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DEPT:	ECE	**SCHOOL:**	SOUTHERN ILLINOIS UNIVERSITYCARBONDALE		

ABSTRACT: (250 OR FEWER WORDS)

We consider a distribution system in which a set of suppliers (or "generators") are connected to a set of consumers (or "loads") through a network of switches. Each of the generators and switches is controlled by a Finite State Machine (FSM) that specifies the allowed states and the transitions among them. For fault tolerance and/or load balancing purposes, the network has to be occasionally reconfigured so that the supply to the consumers continues uninterrupted. The trivial approach is to view the local FSMs as one global FSM that responds accordingly to the event requiring the reconfiguration. The problem with this centralized approach is that the complexity becomes unmanageable as the size of the system scales up. In this project we propose a decentralized scheme where the individual FSMs are synchronized through message passing in a distributed manner in order to arrive at a consensus on how to respond safely to each reconfiguration triggering event. The scheme is to be implemented and validated in OPNET using as a case study a power supply system for avionics.

PROBLEM:

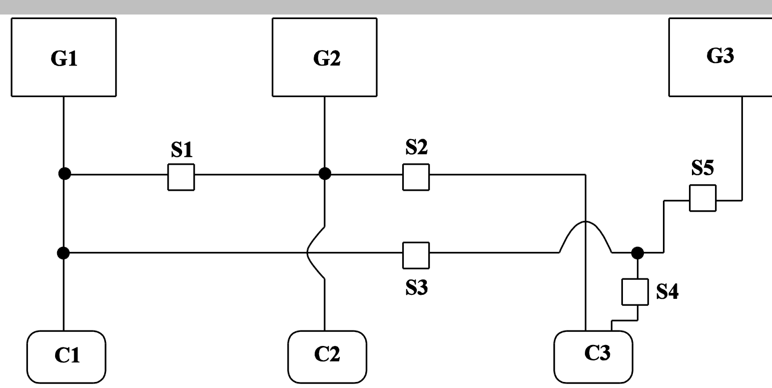

Fig. 1: An example topology of Suppliers (Generators), Consumers (Loads) and Switches.

We consider an abstract model of a distribution system in which a set of suppliers (or "generators") are connected to a set of consumers (or "loads") through a network of switches. Each of the generators and switches is controlled by a Finite State Machine (FSM) that specifies the allowed states and the transitions among them. As an example, consider the setup shown in Fig. 1. In this setup, generators G1, G2, G3 are connected to consumers C1, C2, C3 through a network of switches. Generator G1 in Fig. 1 can be in any of the following states: OFF, Standby, Supply_C1, Supply_C1&C2, Supply_C1&C3, Supply_C1&C2&C3. Similarly, the possible (allowed) states for Generator G2 are OFF, Standby, Supply_C2, Supply_ C2&C1, Supply_C2 & C3, Supply_C2&C3&C1, while the possible states for Generator G3 are OFF, Standby, Supply_C3, Supply_ C3&C1, Supply_C1. Each of these states corresponds to a particular configuration of the switches. For example, when Generator G1 is in state Supply_C1, then switches S1and S3 must be OFF, because if S1 was ON then G1 would be in state Supply_C1&C2, whereas if

S3 was on, an invalid situation would occur (namely, G1 and G3 driving the same load). The states of each individual FSM controller are not independent (orthogonal), but there are dependencies among them. For example, if G1 is in state Supply_S1, then G2 cannot be in state Supply_ C2&C1 or state Supply_C2&C3&C1, and G3 cannot be in state Supply_C1 or Supply_ C3&C1. The local FSM controllers can be informed of each other's state by exchanging messages carried out by an underlying communication network (in addition to the switched distribution network).

Such a system needs to be reconfigured for a variety of reasons such as load balancing (generators should normally drive approximately the same number of loads), or fault tolerance (if a generator fails, the loads it supplied must be supplied from other generators). We want to be able to do such reconfigurations dynamically in a distributed/decentralized/asynchronous manner. In a trivial centralized/monolithic approach, the system is treated as a single FSM with an exponentially large number of global states that quickly grows out of control as the system gets bigger. In contrast by allowing each of the local FSM controllers to operate asynchronously through message passing, the complexity of the problem becomes manageable.

RATIONALE:

The local FSM controllers must be able to respond to each reconfiguration triggering event in a decentralized/asynchronous manner through message passing. The complexity of a centralized global FSM is impractical even for moderately large (30 nodes) distribution systems. The proposed work aims to provide such a decentralized solution using as a case study a power supply system for avionics.

APPROACH:

In the proposed approach, we plan to establish synchronization, consensus, and reconfiguration procedures among neighboring FSM controllers so that (i) state transitions occur when state/status information messages are received asynchronously from neighboring nodes; (ii) a consensus on the action (reaction) to a failure is reached among all relevant nodes; and (iii) the reconfiguration of the switches is done in the appropriate order so that no transient forbidden states are ever created.

For example in Fig. 1, consider the case where G1 is in state Supply_C1, G2 is in state Supply_C2 & C3, and G3 is in state Standby and assume that G2 fail. Then once the notification of this event reaches G1 and G3, the following scenarios are possible: (a) G1 transitions from state Supply_C1 to state Supply_C1&C2&C3, while G3 remains at Standby, or (b) G1 transitions from state Supply_C1 to state Supply_C1&C2, while G3 transitions from state Standby to Supply_C3. Depending on pre-specified system settings, alternative (b) may well be preferable (higher priority) in order not to overload G1 under alternative (a). The two FSM controllers of G1 and G3 must come to a consensus about the final action (that is, alternative (b)). Then the reconfiguration must be done in the proper order, which in this case is setting S2=OFF, followed by S4=ON and S5=ON (assuming switches S1 and S3 are maintained to OFF as in the previous state).

We will use as a case study a power supply system for avionics. The synchronization, consensus, and reconfiguration procedures will all be simulated in OPNET.

NOVELTY:

There is a lot of work on the fault-tolerance in Distributed Asynchronous Systems [see, e.g., [1 -3]) and also there is a lot of mathematical theory developed for the decentralized control and coordination of Discrete-Event Systems (DES) (see, e.g., [4-14]). However, the results remain at the theoretical/generic level and may not even be directly applicable as -within our knowledge- no experimental verification has been given in the literature for specific systems. The proposed work will develop a practical methodology for a real-world industrial problem, namely the control/reconfiguration of the power supply system of an aircraft.

POTENTIAL BENEFITS TO INDUSTRY MEMBERS:

The studied model of a distribution system with a set of suppliers (or "generators") connected to a set of consumers (or "loads") through a network of switches is general enough that it can be useful in many situations. Also the reconfiguration triggering events considered are general enough to model different requirements such as reconfiguration due to a failure or reconfiguration due to load balancing. The specifics of network topology, valid and forbidden states, requirements for consensus, and timing deadlines are all case specific but the modelling/formulations obtained for the specific study on the avionics power supply system are expected to be easily carried to other domains.

DELIVERABLES:

The project deliverables will be as follows:

1. Comprehensive report on the DS modelling and synchronization, consensus, and reconfiguration procedures for the avionics power supply system.
2. Software prototype tool in OPNET of the model developed in 1.

TIMELINE/MILESTONES: (PER QUARTER)

The timeline for the proposed project activities is as follows:

Quarter 1

Development of the Distribution System (DS) and the FSM for each controller and the consensus and reconfiguration order strategies.

Quarter 2

Implementation of OPNET models to simulate the DS.

Quarter 3

Simulation of different scenarios and efficiency evaluation.

Quarter 4

Refinement of the DS formulation and simulation package and writing of the comprehensive project report.

TECHNOLOGY TRANSFER:

Technology transfer will be performed in the form of the evaluation tool and comprehensive reports.

BUDGET:

Funds in the amount of $25,000 are requested for:

1. Yearlong support of one PhD student and one MS student.
2. PI summer salary
3. Travel to Industrial Advisory Board (IAB) meetings and member company locations for in-person meetings as required

BIBLIOGRAPHY: (ATTACH IN IEEE CONFERENCE OR JOURNAL FORMAT)

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PI INFORMATION: (ATTACH 2-PAGE CV)

Short Curriculum Vitae

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Dimitri Kagaris received the Diploma degree in Computer Engineering and Informatics from the University of Patras, Greece, in 1988, and the M.S. and Ph.D. degrees in Computer Science from Dartmouth College, Hanover, New Hampshire, USA, in 1991 and 1994, respectively.
He is currently a full professor in the Electrical & Computer Engineering Department, Southern Illinois University, Carbondale, Illinois, USA. His research interests include multicore systems, digital design automation and test, VLSI synthesis, computer networks.
He has over 80 publications in peer-reviewed journals and conferences and has contributed chapters in scientific encyclopedias. He has been active in the area of Built-in Self-Test and Design for Testability since 1992. Part of his research has been supported by National Science Foundation (NSF). He has received twice the Outstanding Paper Award from the IEEE International Conference on Computer Design. He has served as a reviewer in major journals and conferences and has participated three times in NSF panels for the review and funding of Design Automation proposals. He is currently serving as Associate Editor of the IEEE Transactions on Computers.

RECENT RELEVANT JOURNAL PUBLICATIONS

1. D. Kagaris, ``Maximizing the Lifetime of a Wireless Sensor Network with Fixed Targets,'' **Ad Hoc and Sensor Wireless Networks**, v. 17, n. 3-4, pp. 253 - 268, 2013.

2. D. Nikolos, D. Kagaris, S. Sudireddy, S. Gidaros, ``An Improved Search Method for Accumulator-Based Test Set Embedding,'' **IEEE Transactions on Computers**, v. 58, n. 1, pp. 132 - 138, Jan. 2009.

3. J. Kakade, D. Kagaris, D.K. Pradhan, ``Evaluation of Generalized LFSRs as Test Pattern Generators in Two-Dimensional Scan Designs,'' **IEEE Transactions on Computer-Aided Design of Integrated Circuits and Systems**, v. 27, n. 9, pp. 1689 - 1692, Sept. 2008.

4. J. Kakade, D. Kagaris, "Minimization of Linear Dependencies through the Use of Phase Shifters," **IEEE Transactions on Computer-Aided Design of Integrated Circuits and Systems,** v. 26, n. 10, pp. 1877-1882, Oct. 2007.

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6. D. Kagaris, ``Improved TDM Switching Assignments for Variable and Fixed Burst Length,'' **International Journal of Satellite Communications and Networking**, v. 25, pp. 93-107, 2007.

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I/UCRC Executive Summary - Project Synopsis		**Date: 03/31/14**
Project Title: Synchronizing Finite State Machine Controllers for Fault Tolerance.		
Center/Site: CES/SOUTHERN ILLINOIS UNIVERSITYCARBONDALE		
Principle Investigator: DIMITRI KAGARIS		**Type: (New or Continuing)** NEW
Tracking No.: (CES office to input)	**Phone : 618 453 7973**	**E-mail : kagaris@engr.siu.edu**
		Proposed Budget: $25,000

Abstract: We consider a distribution system in which a set of suppliers (or "generators") are connected to a set of consumers (or "loads") through a network of switches. Each of the generators and switches is controlled by a Finite State Machine (FSM) that specifies the allowed states and the transitions among them. For fault tolerance and/or load balancing purposes, the network has to be occasionally reconfigured so that the supply to the consumers continues uninterrupted. The trivial approach is to view the local FSMs as one global FSM that responds accordingly to the event requiring the reconfiguration. The problem with this centralized approach is that the complexity becomes unmanageable as the size of the system scales up. In this project we propose a decentralized scheme where the individual FSMs are synchronized through message passing in a distributed manner in order to arrive at a consensus on how to respond safely to each reconfiguration triggering event. The scheme is to be implemented and validated in OPNET using as a case study a power supply system for avionics.

Problem: We consider an abstract model of a distribution system in which a set of suppliers (or "generators") are connected to a set of consumers (or "loads") through a network of switches. Each of the generators and switches is controlled by a Finite State Machine (FSM) that specifies the allowed states and the transitions among them. Such a system needs to be reconfigured for a variety of reasons such as load balancing (generators should normally drive approximately the same number of loads), or fault tolerance (if a generator fails, the loads it supplied must be supplied from other generators). We want to be able to do such reconfigurations dynamically in a distributed/decentralized/asynchronous manner.

Rationale / Approach: The local FSM controllers must be able to respond to each reconfiguration triggering event in a decentralized/asynchronous manner through message passing. The complexity of a centralized global FSM is impractical even for moderately large (30 nodes) distribution systems. The proposed work aims to provide such a decentralized solution using as a case study a power supply system for avionics. We will develop synchronization, consensus, and reconfiguration procedures which will all be simulated in OPNET.

Novelty: Existing results remain at the theoretical/generic level and may not even be directly applicable as - within our knowledge- no experimental verification has been given in the literature for specific systems. The proposed work will develop a practical methodology for a real-world industrial problem, namely the control/reconfiguration of the power supply system of an aircraft.

Potential Member Company Benefits: The studied model of a distribution system with a set of suppliers (or "generators") connected to a set of consumers (or "loads") through a network of switches is general enough that it can be useful in many situations. Also the reconfiguration triggering events considered are general enough to model different requirements such as reconfiguration due to a failure or reconfiguration due to load balancing.

Deliverables for the proposed year: (1).Comprehensive report on the DS modelling and synchronization, consensus, and reconfiguration procedures for the avionics power supply system. (2) Software prototype tool in OPNET of the developed model.

Milestones for the proposed year: (1) Development of the Distribution System (DS) and the FSM for each controller and the consensus and reconfiguration order strategies. (2) Implementation of OPNET models to simulate the DS. (3)Simulation of different scenarios and efficiency evaluation.
(4) Refinement of the DS formulation and simulation package and writing of the comprehensive project report.

Progress to Date: THIS SECTION TO BE UPDATED IN JANUARY

Estimated Start Date: 08/15/2014	**Estimated Knowledge Transfer Date**: 08/31/2015