A Self-Organizing Agent-Based Sensor Network for Power Plant Condition Monitoring

Hanieh Agharazi, Richard M. Kolacinski and Kenneth A. Loparo

Department of Electrical Engineering and Computer Science, Case Western Reserve University

INTRODUCTION

The objective of this work is to develop algorithms and software systems that enable a sensor network for condition monitoring of power generation plants to be adaptive, resilient, and self-healing. This sensor network should dynamically discover the intrinsic communication topology of power generation systems, associate sensor data streams with operational objectives and reconfigure itself to degrade sensing and communication capabilities. The challenges and opportunities in developing the sensor network are listed in Table 1 below.

Table 1. Challenges and Opportunities

<table>
<thead>
<tr>
<th>Challenges</th>
<th>Opportunities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scalability</td>
<td>Ubiquitous computational and wireless communication infrastructure</td>
</tr>
<tr>
<td>Complexity</td>
<td>No unified technology strategy</td>
</tr>
<tr>
<td>Data transmission (BIT, QoS), Computation factor</td>
<td>Self-organizing properties on-the-fly</td>
</tr>
<tr>
<td>Accommodate existing infrastructure</td>
<td>Substantial constrains in sensor deployment</td>
</tr>
<tr>
<td>Lack of a prior understanding of relevant systems</td>
<td>Scalability and robustness</td>
</tr>
<tr>
<td>Wide variation in operational conditions</td>
<td>Widely distributed computational resources</td>
</tr>
<tr>
<td>System permeability</td>
<td>High degree of communication redundancy</td>
</tr>
</tbody>
</table>

These constraints and opportunities mandate a distributed and agent-based approach and strongly suggest the use of biologically inspired algorithms.

• Distributed: Scalability, accommodate new instrumentation and reorganizing existing infrastructure.
• Agent-Based: Flexible, provide a basis for bottom-up application, minimize communication requirements and distribute processing.
• Biologically Inspired: Capture emergent phenomena (provide basis for accommodating unforeseen challenges).

TECHNICAL APPROACH

TOPOLOGY DISCOVERY

The intrinsic communication between elements of the system manifests in the mutual information between the sensing performed at disparate locations of the network and thus can be used to extract the system’s intrinsic topology.

Biologically inspired methods, e.g., swarm intelligence algorithms, are well suited to addressing this problem in an adaptive and distributed manner.

SWARM INTELLIGENCE

Agent-Based:

• Self-organization (Balancing)
• Feedback (Amplification)
• Many Interactions

Distributed:

• Positive feedback (Amplification)
• Negative feedback (Balancing)
• Amplification of fluctuation

• Indirect communication between elements via interaction with environment

LOCAL BEHAVIORS

• Local behaviors are not specified in a deterministic manner, agents have limited autonomy.

FOREGAGING BEHAVIOR

Foraging behaviors provide a basis for searching and optimization:

• Not trials emerge “shortest path” solutions.
• Arms lay a pheromone trail as they move.
• Pheromone increase with traffic but dissipates over time.
• Pheromone marking reinforced on frequently used trails but fades on infrequently used trails.
• Recombinable “trail fronts” offer tunable exploration behaviors.

FORAGING BEHAVIOR

Self-organization: Stigmergy

S c a l a b i l i t y , a c c o m m o d a t e n e w i n s t r u m e n t a t i o n a n d

NETWORK DISCOVERY

An agent’s foraging moves are described as:

• Food defined as mutual information – agent carries information with it looking for data containing the “same information.”
• Pheromone defined as correlation between the “same information.”

Generalized Swarm Algorithms:

• Multiple interacting swarms (super swarms) can manage disparate information streams.

GENERAL FORAGING BEHAVIORS

CORRENTROPY

Let $X$ and $Y$ be two RVs, define the estimated correntropy as:

$$C(X,Y) = \sum_{x,y} P(x,y) \kappa(x,y)$$

where $\kappa(x,y)$ is the set of observations and $\kappa$ is a non-negative definite function (e.g., mutual information).

• Generalization of correlation to entropic measures.
• Can define a correntropy function to capture time shifted correlation.

• Correlation: Restricted to capturing linear relationships between RVs.
• Provides useful proxy for investigating window size needed for agent-based estimation of correntropy (i.e. provides lower bound).

Exemplary linear system:

$$X_{1,2} = A X_{1,2} + D \kappa_{1,2}$$

$$\kappa_{1,2} = N(0,1)$$

• Window size = [50, 200, 1000]

RESULTS:

- 7.4766 - 0.5311
- 5.4841 - 0.0772
- 1.4681 - 6.2307
- 0.3876 - 7.6766
- 5.4841 - 0.0772
- 1.4681 - 6.2307
- 0.3876 - 7.6766
- 9.3388 - 1.4681
- 1.8371 - 0.0772
- 0.0935 - 1.5962
- 0.0935 - 1.5962
- 0.0935 - 1.5962
- 0.0935 - 1.5962

Figure 4. Examination of window size and lag on correlation estimation

CONCLUSIONS AND FUTURE WORK

• Propose method to derive the intrinsic topology of the physical network by looking at the mutual information between system elements.
• Value of information measure provides basis for determining interconnection strength.
• Entropy defined as mutual information.
• Mutual information is a useful tool for investigating window size needed for agent-based estimation of entropies (i.e. provides lower bound).
• Correlation: Restricted to capturing linear relationships between RVs.
• Provides useful proxy for investigating window size needed for agent-based estimation of correntropy (i.e. provides lower bound).
• Can define a correntropy function to capture time shifted correlation.

• Window size = [50, 200, 1000]

Figure 1. Generating Data to Operational Needs and Objectives

Figure 2. Adjusting the Parameters in Foraging

Figure 3. Observation of Physical System fierce forging perspective

Figure 4. Examination of window size and lag on correlation estimation

Figure 5. Adjusting the Parameters in Foraging

Figure 6. Observation of Physical System fierce forging perspective