A Sensor Network Test-bed for an Integrated Target Surveillance Experiment

Pratik K. Biswas and Shashi Phoha
Applied Research Laboratory
Penn State University
State College, PA 16804
E-mail: pkb3@psu.edu

***Abstract*—In this paper, we describe a distributed sensor network test-bed and a surveillance experiment to demonstrate the integration of distributed tracking algorithms with strategies for location estimation, energy management and mobility management of sensor nodes. The test-bed consists of real sensor nodes augmented with a simulated environment. Data from real world tracking is provided to the simulated environment, where it is used to self-organize the sensor network in an energy-efficient way. Results from the simulation are then fed back to the real world to enable the sensor network to reorganize for reinforced tracking.**

***Index Terms*—Sensor Network, Sensor Network Test-bed, Sensor Nodes, Integrated Target Surveillance Experiment**

1. INTRODUCTION

THE Emergent Surveillance Plexus (ESP) [1] is a Multi-disciplinary University Research Initiative (MURI), which has been funded by DARPA to advance the surveillance capabilities of sensor networks. It involves participants from universities like PSU, UCLA, Duke, Wisconsin, Cornell and LSU. One of its goals is to develop an infrastructure that can support applications, adaptable to dynamic environments.

We have set up a test-bed at PSU/ARL (Applied Research Laboratory) that provides a heterogeneous platform to support realistic surveillance applications, whose results can be independently validated. To demonstrate its applicability, we have constructed an experiment, which integrates some of the MURI participants' innovations, to provide insights into energy-efficient, self-organization of sensor networks for surveillance.

2. BACKGROUND

Our experiment consists of the Beamforming algorithm (for estimating direction-of-arrival) from UCLA [2], Dynamic Space Time Clustering (DSTC) algorithm (for tracking) from PSU/ARL [3], Location Estimation algorithm (for node localization) from Wisconsin [4], Self-configuration and Adaptive Reconfiguration algorithm (for state management) [5] and Lowest Energy Deadline First (LEDF) algorithm (for power aware RTOS) [7] from Duke and Distributed Annealing algorithm (for mobility strategy) from PSU/EE [6].

This research is sponsored by the Defense Advanced Research Projects Agency (DARPA) and managed by the Army Research Office under Emergent Surveillance Plexus MURI Award # DAAD19-01-1-0504. Any opinions, findings or recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of the DARPA or the ARO.

3. RESEARCH GOAL

Our goal is to construct a sensor network test-bed and then use it to develop an experiment, by integrating the aforesaid algorithms (from section 2).

4. SENSOR NETWORK TEST-BED

We have developed a test-bed for sensor network that integrates real world sensing with the simulated environment. It consists of static and mobile real sensor nodes, sensing and tracking processes as virtual sensor nodes (on Windows/Linux based workstations) and simulated nodes running in the simulator (NS2).

A. Sensor Node Characteristics

Sensor nodes, real, virtual and simulated, can have the following characteristics: (1) they need to cooperate to track a target completely, (2) some may have GPS units while others may not, (3) those without GPS estimate their locations using message passing, (4) they can ensure connectivity and coverage through token exchange mechanism, (5) three mobile robots act as real sensor nodes, (6) they can move on demand and (7) they can construct their own command structure.

B. Architecture

The following figure represents the proposed high-level architecture of the test-bed.

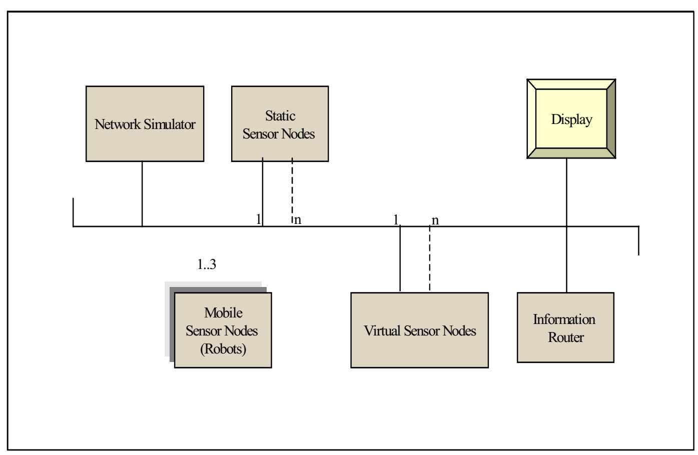

Figure 1: Conceptual Architecture of the test-bed

IEEE COMPUTER SOCIETY

5. INTEGRATED SURVEILLANCE EXPERIMENT

We have used this test-bed to conduct an integrated target surveillance experiment. We have tried to demonstrate that the proposed architecture of our test-bed can be used to track a target in real-time by an integration of the Beamforming algorithm [2] and DSTC algorithm [3] and such tracking can be reinforced by reorganizing nodes based on simulation results on location estimation, energy and mobility management of sensor nodes [4-6]. Accordingly, the experiment runs in 3 stages: (1) Real-time integrated tracking, (2) Self-organization simulation, and (3) Reinforced tracking in real-time.

A. Scenario

A simulated combat zone is under surveillance. One target enters the combat zone. Beamformers adjust their processing speeds, track the target and extract its acoustic signatures. These are used to determine the initial target position. Real and virtual sensor nodes (processes), running the DSTC algorithm, use the initial target position and further sensor inputs to track the rest of the path, as the target reaches its destination. This initial deployment configuration along with the tracking data are then fed to NS2 that simulates the real sensor network. The simulated sensor nodes (deployed as per the initial configuration) self-organize based on node localization, state reconfiguration and mobility strategy. NS2 feeds the Information Router with the self-organized configuration. The real sensor network reorganizes, using the resultant configuration, to track a second target traversing a similar path.

6. EXPERIMENTAL RESULTS AND EVALUATION

We define an evaluation metrics for our integrated surveillance experiment and present the relevant results.

A. Evaluation Metrics

We have used the following metrics for evaluating the results of our experiment - (1) *Variance*: This defines the point variance in x, y and t for all the points in a track versus the points on actual target path to which they correspond, (2) *Average Location Error*: This defines the average error between the actual location and the estimated location for each simulated sensor node, (3) *% of Active Nodes*: This defines the % of active nodes remaining due to self-reconfiguration, (4) *Power Usage for communication and mobility*: This defines the total power consumed by the active mobile nodes for communication and mobility, (5) *Average Movement*: This defines the average distance moved by a mobile node due to its mobility strategy.

B. Experimental Results

The results include statistics from all 3 stages.

1) Integrated Target Tracking

We track a single target in 30X30 (sq. ft) grid with 48 sensor nodes: 3 real, mobile sensor nodes (robots) and 45 virtual sensor nodes, using a combination of Beamforming and DSTC algorithms. Each node has a sensing and a communication range of 10 m (scaled). We can report a *variance* of 0.7911m^2.

2) Location Estimation, State Management & Mobility Strategy

We simulate the same initial deployment of 48 nodes, mapped to a 30X30 (sq. m) grid. We can report an *average location error* of 1.802288m. 31 (64.6%) nodes configure their states to be *active*, while the 3 mobile nodes move an *average distance* of 25.76m *per node* and consume a *total power* of 0.327W for *mobility* and 37.09W for *communication*.

3) Reinforced Target Tracking

We track a second target (following a similar path) in the original 30X30 grid (sq. ft) with the self-organized configuration, consisting of 31 nodes, running DSTC algorithm. We can report a *variance* of 3.7180m^2.

7. CONCLUSION AND FUTURE CHALLANGES

We have presented a test-bed that integrates real sensor nodes with processes that sense and track, as well as simulated sensor nodes. We have described an experiment that involves real-time tracking, reinforced by results from simulation for sensor network self-organization. Challenges remain in conducting experiments with larger number of sensor nodes in more complicated scenarios.

ACKNOWLEDGMENT

The authors would like to thank Dr. E. Keller, Mr. J. Douglas and Mr. J. Koch of PSU/ARL, Prof. G. Kesidis and his students from PSU/EE, Prof. K. Chakrabarty and Mr. Y. Zou from Duke and Prof. P. Ramanathan and his students from Wisconsin for contributing towards the implementation of the integrated surveillance experiment.

REFERENCES

[1] Emergent Surveillance Plexus MURI – ESP TR0201: *Experimental Plan and Validation (Winter 2003)*.

[2] J. C. Chen and K. Yao, “Beamforming,” In *Frontiers in Distributed Sensor Networks*, S. Iyengar and R. Brooks, eds., CRC Press, 2003.

[3] D. Friedlander, C. Griffin, N. Jacobson, S. Phoha and R. Brooks, “Dynamic Agent Classification and Tracking Using an Ad Hoc Mobile Acoustic Sensor Network,” *EURASIP Journal on Applied Signal Processing*, 2003:4, 371-377.

[4] N. Sundaram and P. Ramanathan, "Connectivity based location estimation scheme for wireless ad hoc networks," *Proceedings of Globecom*, vol. 1, pp.143-147, Nov. 2002.

[5] H. Sabbineni and K. Chakrabarty, “SCARE: A Scalable Self-configuration and Adaptive Reconfiguration Scheme for Dense Sensor Networks,” To appear in *Sensor Network Operations*, IEEE Press. S. Phoha et al. eds.

[6] R. Rao and G. Kesidis, “Purposeful mobility for relaying and surveillance in mobile ad-hoc sensor networks,” To appear in *IEEE Transactions on Mobile Computing*.

[7] V. Swaminathan, C. B. Schweizer, K. Chakrabarty and A. A. Patel, "Experiences in implementing an energy-driven task scheduler in RT-linux", *Proceedings of the Real-Time and Embedded Technology and Applications Symposium*, pp. 229-239, 2002.