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Effective Implementation of AEPRA algorithm for Fault Recovery Mechanism in Wireless Sensor-Actor Networks

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Abstract

In wireless sensor-actor networks, sensors probe their surroundings and forward their data to actor nodes. Actors collaboratively respond to achieve predefined application mission. Since actors have to coordinate their operation, it is necessary to maintain a strongly connected network topology at all times. Moreover, the length of the inter-actor communication paths may be constrained to meet latency requirements. However, a failure of an actor may cause the network to partition into disjoint blocks and would, thus, violate such a connectivity goal. One of the effective recovery methodologies is to autonomously reposition a subset of the actor nodes to restore connectivity. Contemporary recovery schemes either impose high node relocation overhead or extend some of the inter-actor data paths. This paper overcomes these shortcomings and presents a Adaptive energy Efficient Protocol for fault Recovery Actors (AEPRA) algorithm. AEPRA relies on the local view of a node about the network to devise a recovery plan that relocates the least number of nodes and ensures that no path between any pair of nodes is extended. AEPRA is a localized and distributed algorithm that leverages existing route discovery activities in the network and imposes no additional prefailure communication overhead. AEPRA improves the network lifetime by adapting efficient energy consumption of the actors. The performance of AEPRA is analyzed mathematically and validated via extensive simulation experiments.

Index Terms: Fault tolerance, network recovery, topology management, wireless sensor-actor network (WSAN).

I. INTRODUCTION

Wireless Sensor and Actor Networks (WSAN) have attracted a lot of interest in recent years. Their potential applications include search-and-rescue, forest fire detection and containment, battlefield reconnaissance, under-water surveillance, etc. In WSAN, sensors which are small, densely-populated, and power-constrained devices probe their surroundings and send the collected data to more capable nodes (actors) for processing and putting forward an appropriate response [1]. For example, sensors can detect rising heat in some spots in a forest and inform mobile robots (actors) that correlate the reports from various sensors and conclude the eruption of a fire.

Given the collaborative nature of the WSAN operation, inter-actor connectivity is essential. Obviously, coordination among actors cannot be performed in a disconnected network topology. Therefore, actors strive to sustain communication links among them when they move. However, the failure of one or multiple actors may partition the network into disjoint sub-networks. This may happen while responding to a harsh event, e.g., a fire, and would require a rapid recovery so that the event would not get out of hand and lead to disastrous consequences. Since WSAN operate unattended and the deployment of spare actors may take time, the recovery should be performed through network self reconfiguration using existing resources

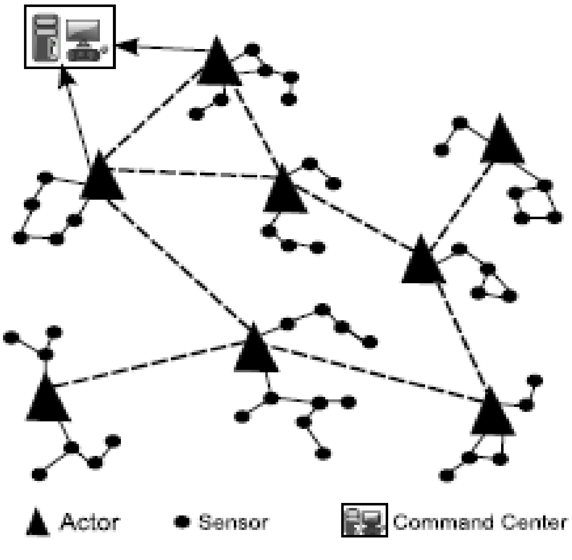


Fig. 1: A typical WSAN

This paper studies the tolerance of actor failure in WSAN. The mobility of actors is utilized to re-establish communication links among disconnected neighbours and at the same time minimize the coverage loss caused by the decreased actor count in the deployment area. Since the actor repositioning problem is hard, a restricted solution space is pursued where surviving nodes can only assume the positions of actors prior to the failure. The recovery problem is then modelled and forming a strongly connected inter-actor topology while minimizing the distance that the individual actors have to travel and minimizing the loss in coverage caused by the failure of some actors. The proposed solution handles the failure of one or multiple nodes and fits architectures in which the command center can develop the recovery plan. In addition, the proposed formulation provides a performance bound for existing schemes in the literature, e.g. [2] which tolerates a single node failure.

The paper is organized as follows. The next section discusses related work. The problem definition and the detailed description of the proposed approach can be found in section III. Section IV presents and discusses the simulation results. Finally, the paper is concluded in section V.

II. RELATEDWORK

Published schemes on tolerating node failure can be classified into two categories; provisioned and reactive solutions. Provisioned tolerance relies on the availability of redundant resources that can make up for the lost node(s). However, provisioned solutions for restoring connectivity are not suitable for WSAN since actors are typically more expensive and hard to deploy compared to sensors and thus assuming the presence of many actors is not practical. The second category pursues real-time restoration of severed connectivity. The main idea is to reposition the healthy actors so that a strongly connected inter-actor network topology can be established. For example, DARA [2] replaces the failed node with one of its neighbours. The approach requires every node to maintain 2-hop neighbour information so that the effect of the loss of a node can be assessed, i.e., whether the failed node is highly probable a cut-vertex or not. The candidate among the neighbours of the failed node is picked based on the node degree, distance from the failed node and the nodes ID respectively. The effect of moving a node triggers a cascaded relocation that ripples throughout the network to avoid breaking connectivity in another part in the network. The approach of [5] strives to limit the scope of cascaded relocation through the identification of dominators. Basically, the dominating set is determined and only cascaded relocation is pursued when a dominator moves. Meanwhile, Basu and J. Redi [3] assume the network is bi-connected prior to the failure and propose an algorithm that moves nodes in groups in order to restore the lost bi-connectivity when a node fails. However, deploying more actors to have a bi-connected network increases the cost of the application. In addition, having this feature cannot be guaranteed for random deployment. Unlike our approach, the focus of [3–5] has been on connectivity restoration without considering coverage. Most of published schemes that consider connectivity and coverage are geared for network planning and not to tolerate a node failure [6]. The only prior effort that factors in both connectivity and coverage, to the best of our knowledge, is reported in [7].

However, the approach is based on moving the neighbours of a failed node back and forth in order to minimize the effect of a node loss. In other words, connectivity cannot be guaranteed at all times.

III. ADAPTIVE ENERGY EFFICIENT PROTOCOL FOR FAULT RECOVERY ACTORS

A. Problem definition

In wireless sensor networks, it is critically important to save energy. Current research on routing in wireless sensor networks mostly focused on protocols that are energy aware to maximize the lifetime of the network, are scalable to accommodate a large number of sensor nodes, and are tolerant to sensor damage and battery exhaustion. Since such energy consideration has dominated most of the research in sensor networks, the concepts of delay was not primary concern in most of the published work on sensor networks. However in WSANs, depending on the application, there may be a need to rapidly respond to sensor input. Moreover, to provide right actions, sensor data must still be valid at the time of acting.

AEPRA mainly consists of two components - Routing based on Forwarding Sets and the Random Wakeup Scheme. The routing methodology in AEPRA is designed to take advantage of the fact that sensor networks are densely deployed. In conventional routing protocols, the shortest path between two nodes is computed proactively or reactively and a node forwards a packet only to the next node in the shortest path computed. A high node density results in the existence of several paths between two given nodes, whose path lengths are very close to the length of the shortest path.

These models are basically used in those simulating WSN. When a practical approach is required there are two main variables measured when defining received-power and link-quality: RSSI stands for Received Signal Strength Indicator. It is the measured power of a received radio signal. It is implemented and widely-used in 802.11 standards. Received power can be calculated from RSSI. LQI stands for Link Quality Indicator. LQI estimates how easily the received signal can be modulated when considering noise in the channel.

B. Received Sigal Strength Indicator(RSSI)

Even though RSSI meters are not built to this end, but rather to give information to the higher communication protocol layers about the status of the communication link, their usage is highly attractive, because the information they give is obtained almost “for free”. As a consequence, many studies exist which, analytically, through simulations or through real measurements, analyse how a receiver (mobile) can best use RSSI relative to multiple wireless transmitters to compute its position.

The availability of a Received Signal Strength Indicator (RSSI) in most of commercial off-the-shelf radio transceivers has promoted the design of several RSSI-based ranging techniques that, however, suffer two major drawbacks. On the one hand, inferring the transmitter-receiver distance from the received signal strength requires a rather accurate channel propagation model. On the other hand, the relation between distance and received signal power is very noisy due to the random attenuation phenomena that affect the radio signals, as multipath fading and shadowing.

C. Energy aware routing

Energy usage is an important issue in the design of WSANs which typically depends on portable energy sources like batteries for power .WSANs is large scale networks of small embedded devices, each with sensing, computation and communication capabilities. They have been widely discussed in recent years. In WSANs, sensor nodes have constrained in term of processing power, communication bandwidth, and storage space which required very efficient resource utilization. In WSANs the nodes are often grouped into individual disjoint sets called a cluster, clustering is used in WSANs, as it provides network scalability, resource sharing and efficient use of constrained resources that gives network topology stability and energy saving attributes. Clustering schemes offer reduced communication overheads, and efficient resource allocations thus decreasing the overall energy consumption and reducing the interferences among sensor nodes. A large number of clusters will congest the area with small size clusters and a very small number of clusters will exhaust the cluster head with large amount of messages transmitted from cluster members.

AEPRA protocol is hierarchical routing based on clustering and find the optimal number of clusters in WSANs in order to save energy and enhance network lifetime. A network infrastructure based on the use of controllably mobile elements was discussed, with the essential of reducing the communication energy consumption at the energy constrained nodes and thus, increasing useful network lifetime. Consumption at the energy constrained nodes and, thus, increase useful network lifetime. In particular, the infrastructure focuses on network protocols and motion control strategies. The significant issue to be noticed is that the controllably mobile infrastructure tests using a practical system and do not assume idealistic radio range models or operation in unobstructed environments.

A novel AEPRA routing for recovering the faulty actors has been proposed to address the issue that frequent location updates of actors may lead to both rapid energy consumption of the sensor nodes and increased collisions in wireless transmissions. The proposed scheme AEPRA takes advantage of the wireless broadcast transmission nature of wireless sensor nodes. When a actors moves, the new location information is propagated along the reverse geographic routing path to the source during data delivery.

D. Distributed implementation of AEPRA

The failure of a node may cause a part of the area to be left uncovered. The impact of a node failure can be even more serious when a node has multiple sensing capabilities. AEPRA performs some pre-failure planning without requiring passive spare nodes. The main idea is that every node ‘A’ will determine the list of its RSSI neighbor and share this list with its direct neighbors in order to orchestrate a recovery in case of failure of ‘A’.

Pre-Failure phase: AEPRA strives to prepare a recovery plan before a failure takes place. AEPRA enables every node ‘A’ to establish a RSSI list and share it with its direct neighbors. The entire process is distributed. As soon as a new network is formed or once the network topology has been changed, each node begins to collect the information about its RSSI neighbors to form its new RSSI. Nodes are chosen to be in RSSI based on the following criteria:

1) Criticality to network connectivity: A cut vertex in a graph links multiple connected components (sub-graphs). A cut vertex node thus is very crucial for network connectivity since its failure will leave the network partitioned into two or more isolated blocks in the RSSI of any of its neighbors.

2) Common sensing capability: The sensing capability of each node is defined as the set of ambient conditions that a node can measure. When a node does not have any of the sensing capabilities that 'A' possesses, such a node cannot serve as a backup for 'A' since it will not mitigate coverage loss.

Recovery Phase: In AEPRA, the RSSI neighbors of the failed node orchestrate the recovery in a distributed manner. Determining an effective recovery plan by each node in anticipation of its failure is not efficient since, (i) Identifying the set of backups using the RSSI is a costly operation in terms of computational overhead, which is proportional to the number of 1-hop and 2-hop neighbor, as shown in the next section. Therefore, as the network size grows, the node degree increases and the overhead tends to increase multifold, (ii) The topology changes dynamically after each failure and due to repositioning nodes for other purposes, e.g. to better serve an application task, which implies that updating the recovery plan becomes an inefficient choice. The recovery process begins when the one hop neighbors of 'A' miss heartbeat messages and each of them independently concludes that 'A' has failed. These neighbors will then reference the RSSI of 'A' to determine the most effective set of backup nodes.

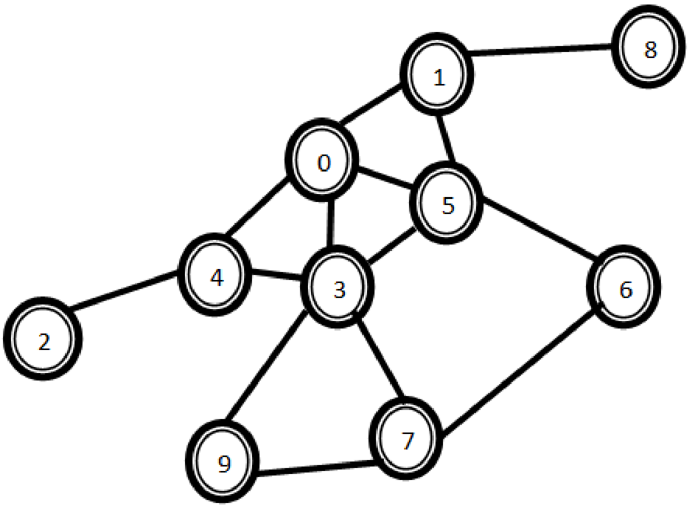


Fig. 2. Example one-connected inter-actor network. Nodes 3, 5, 6 and 7 are cut vertices whose failure leaves the network partitioned into two or multiple disjoint blocks.

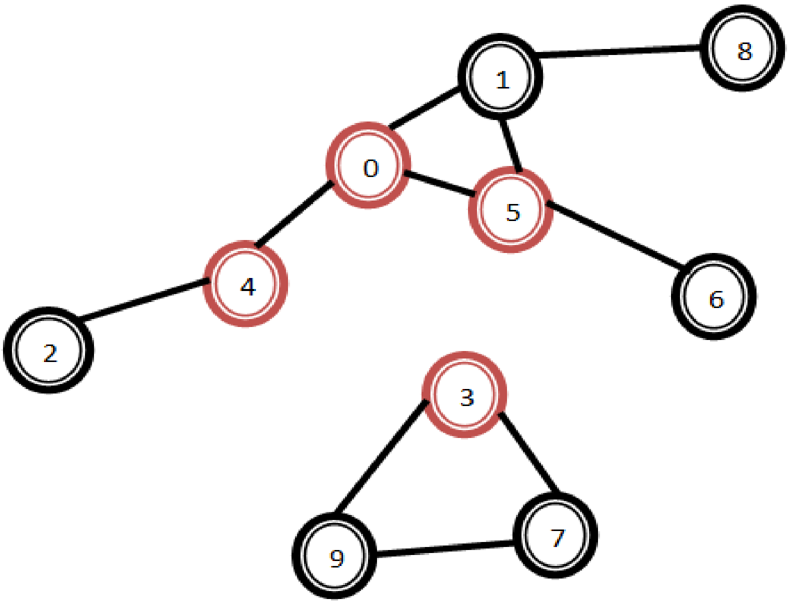


Fig. 3. Failure of actor node 3 which leads to disjoint the blocks and cause the network to partitioning.

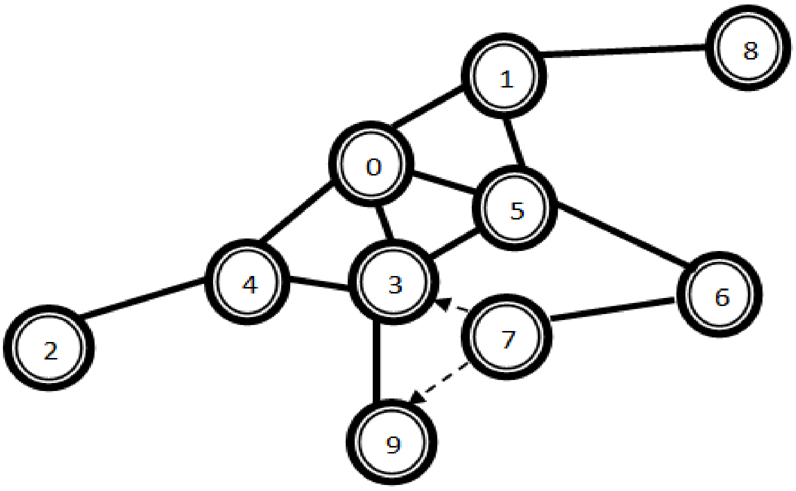


Fig. 4. Restoring the connectivity by replacing the position of node 3 by node 7.

Fig. 2,3,4 shows an example for how AEPRA restores connectivity after the failure of node3. Obviously, *node3* is a cut vertex, and *node7* becomes the one-hop neighbor that belongs to the smallest block [see Fig. 1]. In Fig. 3, *node7* notifies its neighbors and moves to the position of *node3* to restore connectivity. Disconnected children, i.e., *node6* and *node9*, follow through to maintain communication link with *node7*.

IV. SIMULATION RESULTS

AEPRA is validated through the simulation. This section discusses the simulation environment and experimental results. The experiments are performed on a NS2(Network Simulator 2). In the experiments, we have created connected topologies consisting of varying number of actors (1 to 10) with fixed transmission range (r = 100m). In addition, we run simulations with fixed nodes count (10 actors) while varying communication range (200m to 450m). The following parameters are used to vary the characteristics of the WSAN topology in the different experiments:

a) Communication range (r): All actors have the same communication range *r*. The value of *r* affects the initial WSAN topology. While a small *r* creates a sparse topology, a large *r* boosts the overall network connectivity.

b) Number of Deployed Actors (N): This parameter affects the node density and the WSAN connectivity. Increasing the value of *N* would affect the node density and thus WSAN topology would become highly-connected.

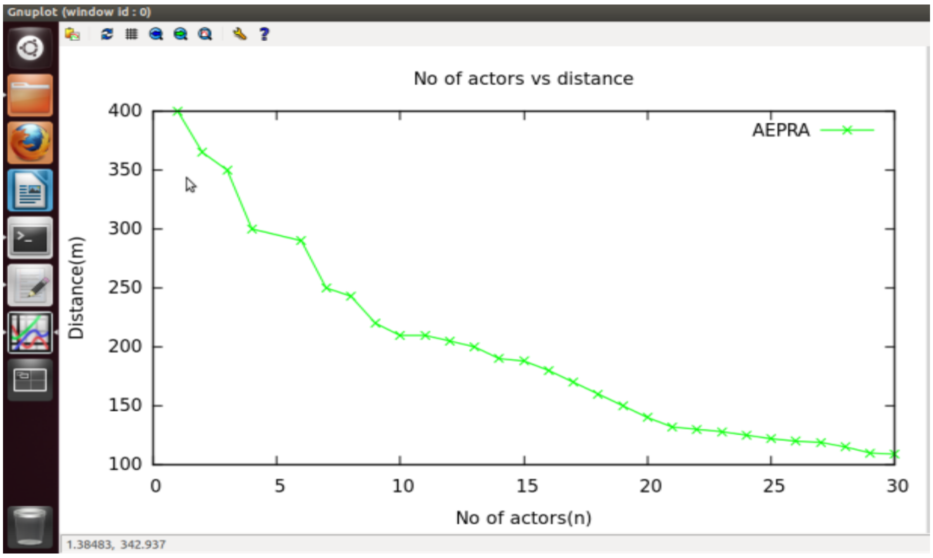
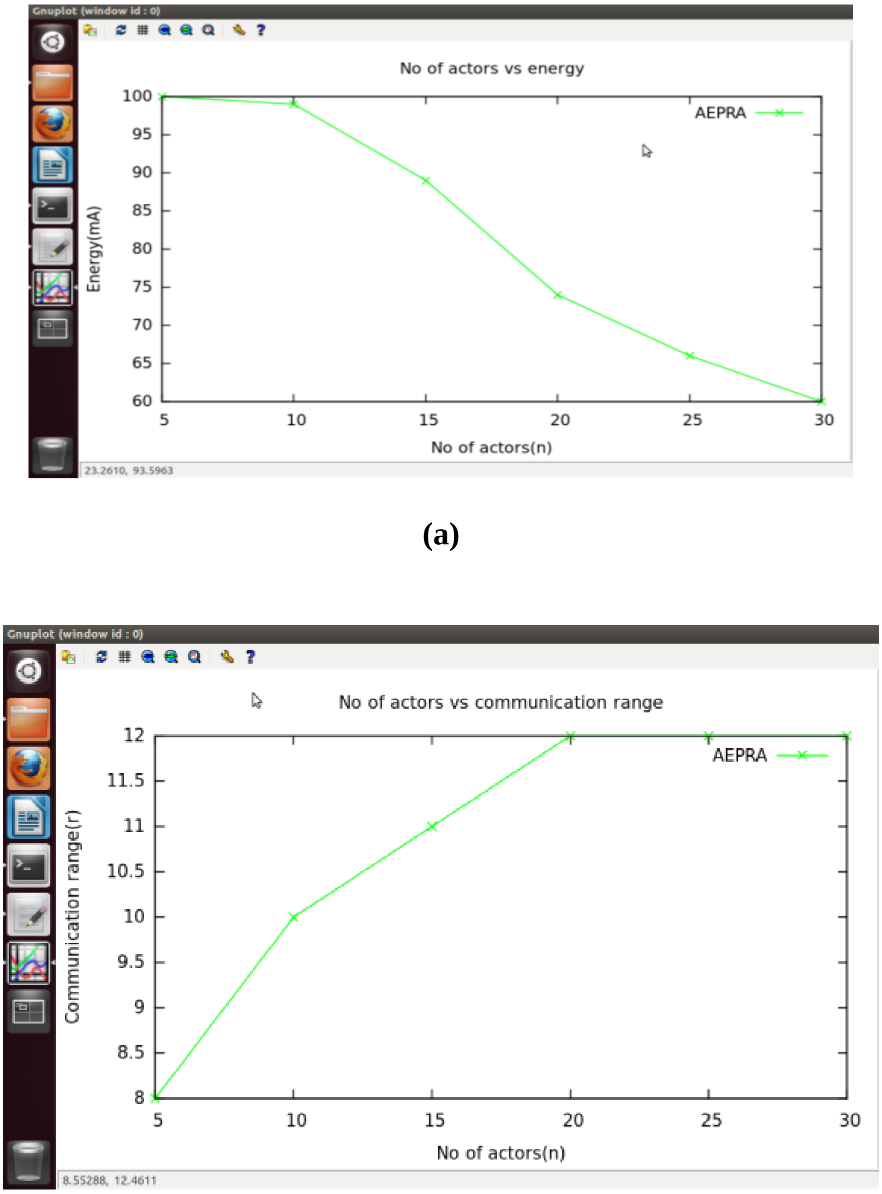


Fig. 5. The graph shows the number of actors are involved during recovery with respect to the distance involved.

Fig. 5 shows the number of actors is involved with respect to the distance during the recovery process. The distance gets decreased as the number of actors increased to save the energy of the actors and to minimize topology changes in the network with help of the AEPRA algorithm.



(a)

(b)

Fig. 6 (a) Effect of energy consumption decreases with increased number of actor under AEPRA. **(b)** Impact of increased actor's communication range on the relocation overhead for a network of 30 actors.

Fig. 6(a) shows that AEPRA scales well with dense topologies and outperforms AEPRA significantly. More specifically, in networks with a low degree of connectivity, most nodes have few neighbors, and RIM often yields a topology that has some longer paths between pairs of nodes compared to the prefailure topology. When the node count increases, AEPRA demonstrates distinct performance and dominates RIM even without considering the path length between nodes. Fig. 6(b) captures the impact of changing *r* for a network of 30 nodes. Obviously, AEPRA performs very well in highly connected networks and matches the performance of LeDiR for low ranges while meeting the internode path length goal.

V. CONCLUSION

This paper has tackled an important problem in mission critical WSANs; that is sustaining network connectivity without extending the length of data paths. We have proposed a new distributed Adaptive energy Efficient Protocol for fault Recovery Actors (AEPRA) algorithm that restores connectivity by careful repositioning of nodes. AEPRA relies only on the local view of the network and does not impose pre-failure overhead. The performance of AEPRA, in terms of the travelled distance and minimum number of actors has been validated through simulation. The results have demonstrated that AEPRA is almost insensitive to the variation in the commutations range. AEPRA also works very well in dense networks and yields closed to optimal performance even when nodes are partially aware of the network topology.

REFERENCES

[1] I. F. Akyildiz and I. H. Kasimoglu, “Wireless Sensor and actornetworks: Research Challenges,” Elsevier Ad hoc Network Journal, Vol. 2, pp. 351-367, 2004.

[2] M. Younis and K. Akkaya, “Strategies and techniques for node placement in wireless sensor networks: A survey,” J. Ad Hoc Netw., vol. 6, no. 4,pp. 621–655, Jun. 2008.

[3] A. Abbasi, M. Younis, and K. Akkaya, “Movement-assisted connectivity restoration in wireless sensor and actor networks,” IEEE Trans. Parallel Distrib. Syst., vol. 20, no. 9, pp. 1366–1379, Sep. 2009.

[4] M. Younis, S. Lee, S. Gupta, and K. Fisher, “A localized self-healing algorithm for networks of moveable sensor nodes,” in *Proc.* IEEE GLOBECOM, New Orleans, LA, Nov. 2008, pp. 1–5.

[5] K. Akkaya, F. Senel, A. Thimmapuram, and S. Uludag, “Distributed recovery from network partitioning in movable sensor/actor networks via controlled mobility,” IEEE Trans. Comput., vol. 59, no. 2, pp. 258–271, Feb. 2010.

[6] K. Akkaya and M. Younis, “COLA: A coverage and latency aware actor placement for wireless sensor and actor networks,” in Proc. IEEE VTC, Montreal, QC, Canada, Sep. 2006, pp. 1–5.

[7] A. Youssef, A. Agrawala, and M. Younis, “Accurate anchor-free localization in wireless sensor networks,” in Proc. 1st IEEE Workshop Inf. Assurance Wireless Sensor Netw., Phoenix, AZ, Apr. 2005.

[8] S. Yang, M. Li, and J.Wu, “Scan-based movement-assisted sensor deployment methods in wireless sensor networks,” IEEE Trans. Parallel Distrib. Syst., vol. 18, no. 8, pp. 1108–1121, Aug. 2007.