Energy Efficient Routing Protocol for Wireless Sensor and Actor Networks

Srinivasara Rao Dh[2], Ramesh Babu Battula[1], Srikanth Vemuru[1],
Rajasekhara rao Kurra[1], Pavan Kumar Tummala[1], and S.V. Rao[2]

[1] K L University, School of Computing
Vijayawada, Andhra Pradesh, India
[2] Indian Institute of Technology,
Guwahati, India
`d.rao@alumni.iitg.ernet.in`, `battula@alumni.iitg.ernet.in`,
`srikanth_ist@klce.ac.in`, `rajasekhar.kurra@klce.ac.in`,
`pavankumar_ist@klce.ac.in`, `svrao@iitg.ernet.in`
`http://www.kluniversity.in`, `http://www.iitg.ac.in`

Abstract. Wireless Sensor and Actor Networks (WSANs) are composed of heterogeneous nodes referred to as sensors and actors. Sensors are low-cost, low-power, multi-functional devices that communicate untethered in short distances. Actors collect and process sensor data and perform appropriate actions on the environment. Hence,actors are resource-rich devices equipped with higher processing and transmission capabilities, and longer battery life.In WSANs, the collaborative operation of the sensors enables the distributed sensing of a physical phenomenon. After sensors detect an event in the deployment field, the event data is distributively processed and transmitted to the actors, which gather, process, and eventually reconstruct the event data. WSANs can be considered a distributed control system designed to react to sensor information with an effective and timely action. For this reason, in WSANs it is important to provide real-time coordination and communication to guarantee timely execution of the right actions and energy efficiency of the networking protocols is also a major concern, since sensors are resource-constrained devices. We propose an energy efficient routing protocol for wireless sensor and actor networks to cope with these challenges keeping in mind the resource constraints of the network and the early response by the actor nodes for delay sensitive applications with number of transmissions as less as possible. Our protocol is based on clustering (virtual grid) and Voronoi region concept.

Keywords: Sensor, Actor, Voronoi diagram, Virtual Grid.

1 Introduction

A Wireless Sensor and Actor Network(WSAN)[2] can be considered as a specialized WSN with the addition of resource-rich actor nodes that have better processing capabilities, higher transmission power, and longer battery life. Since

N. Meghanathan et al. (Eds.): NeCoM, WiMoN, and WeST 2010, CCIS 90, pp. 114–123, 2010.

actors have higher capabilities and can action large areas, they are fewer in number compared to the number of sensor nodes in an environment. The actor is present in the network to take action based on the sensed information received from the sensor nodes. WSANs will be an integral part of systems such as battlefield surveillance, nuclear, biological or chemical attack detection, home automation, and environmental monitoring[7]. Figure - 1 represents a simple WSAN with a sink that is present to take care of overall communication and coordination.

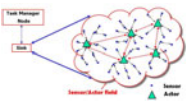

Fig. 1. Wireless Sensor and Actor Networks Architecture

One of the major challenges of WSAN for efficient communication is the coordination among sensor and actor nodes. Sensor-Actor coordination is for quick event reporting to appropriate actor node. Actor-actor coordination is to avoid redundant action in overlapped action area and a reliable action.

2 Realted Work

2.1 Static Actors in WSAN Area

A Distributed Coordination Framework for WSAN. A coordination protocol framework for WSAN is addressed with a proposed sensor-actor coordination model based on event driven clustering paradigm, where cluster formation is triggered by an event so that clusters are created on the fly to optimally react to the event and to provides reliability with minimum energy consumption[5]. This way, only the event area is clustered,and each cluster consists of those sensor nodes that send their data to the same actor. **A Coordination Protocol for WSAN** - A sensor-sensor coordination protocol for WSAN based on clustering and Voronoi region concept is proposed in [6]. This protocol creates clusters consisting of sensors detecting the same event and forwards to the nearest actor. **ELRS: An Energy-Efficient Layered Routing Scheme for WSAN** An energy efficient layered routing scheme is described in[9] for semiautomated architecture, where the network field is divided into different sized (overlapped) actor fields, which covers all the sensor nodes. **Delay-Energy Aware Routing Protocol for Sensor and Actor Networks** - Delay energy aware routing protocol(DEAP)[10] mainly consists of two components- Routing based on Forwarding Sets and the Random wakeup Scheme. **Resource-Aware and Link Quality Based Routing Metric for WSAN** - This paper presents a resource-aware and link quality based(RLQ)[11] routing metric to address energy limitations, link quality variations, and node heterogeneity in WSAN.

2.2 Mobile Actors in WSAN Area

A Communication Architecture for Mobile WSAN. The coordination and communication problem has been studied and a hybrid location management scheme has been proposed to handle the mobility of actors along with a geographical routing algorithm for sensor-actor communication [7]. The sensor-actor communication uses forwarding rules based on geographical position in the presence of Rayleigh fading channels. **Real-time Coordination and Routing in Wireless Sensor and Actor Networks** Mobile actors proposes a real-time coordination and routing framework for sensor-actor coordination to achieve energy-efficient and reliable communication [12]. **Intelligent actor mobility in wireless sensor and actor networks** - A inherent clustering algorithm is introduced to connect sensor nodes and cluster's are formed by using the sensor node locations, sensor nodes transmission range. Sensor node locations can be obtained using localization techniques such as angle-of-arrival measurements, distance related measurements, and received signal strength profiling techniques [21]. The main goal is to develop intelligent mobility models for an actor node in a wireless sensor and actor network to maximize timely detection of events. Random mobility models are unsuitable for sparsely connected networks[22], 100% event detection by single actor is possible. These mobility models are not studied for fully connected network and actor mobility cost is not considered. This mobility models good for the applications where the actor collect event inform from sparsely connected network. **A Real-time Communication Framework for Wireless Sensor-Actuator Networks** - This paper[23] main objective is to provide a low latency event reporting algorithm for sensor-to-actor communication and an effective coordination algorithm among the actors.

2.3 System Model and Assumptions

This protocol considers few assumptions for simplicity in building system model:

a) The network is composed of N_s sensors and N_a actors, and they are deployed uniformly in the network area with high density of sensor nodes and low density of actor nodes i.e, $N_s >> N_a$. Every sensor node associates itself to one of the actor nodes to which it is nearest, which leads to the construction of Voronoi regions around actor nodes. It is also assumed that all the nodes (both sensor and actor) are equipped with GPS enabled devices and hence each node is aware of its own location information.
b) Sensors are homogeneous and wireless channels are bi-directional, symmetric and error-free and equipped with a low data rate radio interface. This interface is used to communicate with other sensor(s) and actor(s) if they are in the communication range of sensor.
c) Sensors nodes are assumed to be immobile. Data transmission and reception are major energy consuming activities. Each sensor node sends the information about events in multi-hop communication to actor.

d) Actor nodes are mobile, and these are equipped with two radio transmitters, i.e., a low data rate transmitter to communicate with the sensors, and a high rate wireless interface for actor actor communication. From the perspective of sensors, actors are equivalent recipients of information.
e) Actor nodes have much more efficiency in terms of energy level and transmission power compared to sensor nodes. Sensor nodes communicate with the actors by sending data via multiple hops and actor to actor communication is through actors.

2.4 Voronoi Diagram

Voronoi diagram is a most fundamental data structure in computational geometry [25]. Voronoi diagram can be used in finding a partition of the given set of points into subsets whose members are similar. Let S be the set of N nodes on a plane. For two nodes P and Q of S the dominance of P over Q is defined as the subset of the nodes being at least as close to P as to Q. Dominance of P and Q is a closed half plane bounded by the perpendicular bisector of P and Q. The bisector separates all nodes of the plane closer to P from those closer to Q and will be termed as the separator of P and Q. The region of a node P is the portion of the plane lying on all the dominance of P over the remaining nodes in S. They form a polygonal partition of the plane. These partitions are called Voronoi regions and combination of such regions for a plane is referred as Voronoi diagram. As we know that the set A=$\{a_1, a_2, a_3, ...a_n\}$ of actor nodes are sparsely deployed. It is advisable for each sensor node to report sensed events to the closest actor node in order to reduce latency and communication cost. All the sensors which are closer to an actor a_i than any other actor in the region called Voronoi region at a_i, denoted by V(a_i). The Voronoi region V(a_i) is a set of points closer to a_i than any other actor a_j, where i $\neq$ j. Union of all Voronoi regions of A is called Voronoi diagram. In other words Voronoi diagram of a set of actors is a partitioning the plane into regions such that each actor node is associated to a region in which all points of that region is closest to it than any other actor node. Formal definition of Voronoi diagram of a set $A = \{a_1, a_2, a_3, ...a_n\}$ of actors is defined as follows: We denote the set of points closer to a site a_i than the site a_j is denoted by $B(a_i, a_j)$. Voronoi region $V(a_i)$ of a site a_i is

$$\cap_{i=1,j\neq 1}^{n} = B(a_i, a_j) \tag{1}$$

Voronoi diagram of the set of points

$$\cup_{i=1}^{n} V(a_i) \tag{2}$$

3 The Procedure

The protocol has three different phases. Before we discuss details of the procedure we will take a look at overview of procedure

3.1 Initialization Phase

Sensor and actor nodes are deployed uniformly throughout the network area under consideration. Each node uses location and grid size to determine the grid ID. The estimation of Grid size is also important for reliable connectivity and we have to ensure that the active member in adjacent grids are within transmission range. Active member in adjacent grids must communicate with each other provided they are within their transmission range. If the grid size is too large some active member in adjacent grids may be out of transmission range. This must be avoided so as not to experience early network partition. The upper bound for a square grid with width r is calculated as follows:

$$r \leq \frac{R_c}{2\sqrt{2}} \tag{3}$$

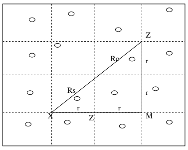

Fig. 2. Grid size computation

This Figure - 2 shows that if the grid size is less than or equal to r, where R_c is the maximum transmit distance, the active member in adjacent grids are within their transmission ranges. **Node Scheduling** - Sensor nodes within a grid coordinate and the node having highest energy level becomes active. Each sensor node calculates an expected life time considering maximum utilization of its energy level. After some predefined time interval, every other sensor node of that grid wakes up to receive a message broadcasted by current active sensor node. The broadcasted message contains the nodes remaining life and the next wakeup time for other sensor nodes of that grid. At this moment, if the current active sensor node expected life value is less than a threshold value, the awake sensor nodes remain awake until the next sensor node having highest energy level becomes active and broadcasts its expected life along with the next wake-up time for other sensor nodes. **Neighbor Discovery** - Once node scheduling is formed among grid members, the active member in the grid sends HELLO message to one-hop grid neighbors. This hello message including location id, grid-id, rate of energy consumption, fraction of energy consumption. The last two parameters are useful in selecting next hop neighbors while forwarding data to actor. **Actors Association** - Each actor node periodically broadcast it's location id, actor-id within it's communication range.

3.2 Event Detection and Reporting Phase

When an event occurs it is detected by the active sensor node inside the grid(s) and forwards towards nearest actors by energy-aware greedy forwarding. If the

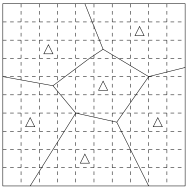

Fig. 3. Network area divided into grids and Voronoi regions

Actor is in communication range of the sensor then directly forwards to actor. If it is not in the communication range, the sensor node selects the next hop grid active member based on the cost computing parameter. Each sensor node periodically broadcast it's hello message to one hop neighbor, it contains rate of energy consumption and fraction of energy consumption. **Rate of Energy Consumption -** Rate of energy consumption is the energy consumption per unit time. It is calculated after each hello period, H_p. Each grid active node keeps the track of number of hello periods occurred. We now calculate the rate of energy consumption of a node at the start of n^{th} periodic interval. Let E_{in} be the energy at the start of the n^{th} periodic interval and E_{i0} be the initial energy of the node i. Energy consumption of the node i till the start of n_{th} periodic interval is given by (E_{i0} - E_{in}). Number of periodic intervals that elapsed till the start of n_{th} periodic interval is (n-1). Therefore, total time elapsed is (n-1) $\times$ H_p. Thus, the rate of energy consumption after n^{th} periodic interval, R_{in}, is given by

$$R_{in} = \frac{E_{i0} - E_{in}}{(n-1) \times H_p}. \tag{4}$$

Fraction of Energy Consumption: Fraction of energy consumption is defined as the total energy consumption per unit initial energy of node. Like rate of energy consumption, fraction of energy consumption is also calculated after each H_p. It is assumed in the proposed scheme that for n_{th} periodic interval, value of fraction of energy consumed is F_{in} till the start of $(n+1)^{th}$ periodic interval. Fraction of energy consumption of node i, F_{in}, is calculated using below equation

$$F_{in} = \frac{E_{i0} - E_{in}}{F_{i0}} \tag{5}$$

Cost Computation Parameter: When sensor node A needs to forward the packet to actor node B, and the distance of sensor node A to actor node B is D and distance of its neighbors (which are in the radio range of A) to B is d_1, d_2, d_3, . . . , d_k, then reasonable fairness of energy at nodes can be achieved if the packet is forwarded to the node, which has least fraction of energy consumption (F_{in}). Further, reasonable fairness of number of hops traveled can also be achieved if the packet is forwarded to the node which is at the minimum distance from the destination. We aim at a scheme so that a packet should be forwarded to

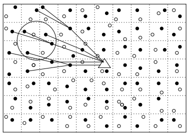

Fig. 4. Data aggregation along forwarding path within a Voronoi region

a Actor which also has minimum rate of energy consumption. We propose the cost metric as

$$C_{in} = R_{in} \times \left(\frac{d_i}{D} + F_{in} \right) \tag{6}$$

3.3 Actor Coordination and Reaction

The objective of this phase is to select best actor(s) to form the actor team, and to control their motion toward the action area. The position of the sensors that generate readings defines event area. The action area represents the area where the actors should act, and is identified by processing the event data. In general, the event area and the action areas may be different, although they may coincide in several applications.

4 Simulation and Results

4.1 Performance Metrics

We use the following performance metrics to analyze the performance of our protocol in terms of throughput, packet delivery ratio, average delay and normalized routing overhead. *Throughput:* Throughput is considered as one of the significant performance metric for any routing protocol. It is computed as the amount of data transferred (in bits) divided by the simulated data transfer time (the time interval from sending the first CBR packet to receiving the last CBR packet). *Packet Delivery Ratio:* It is measured as the ratio of the number of packets delivered to destination and the number of packets sent by source. *Average Delay:* Average delay is the ratio of sum total of delay for each packet and the total number of received packets. *Average Energy Consumption*:The metric is measured as the percent of energy consumed by a node with respect to its initial energy.

4.2 Simulation Environment

We simulate our idea in NS-2 with simulation parameters as shown in the table 1.

The topology of the network is generated by dividing the network area into square size grids of fifteen meters length and placing two nodes in each grid randomly.

Table 1. Simulation parameters

1	Simulator	NS-2
2	Simulation time	200sec
3	Simulation Area	200×200
4.	Number of Nodes	200
4	Transmission Range	50 meters/sec
5	Grid size	15 meters
6	Traffic Type	CBR
7	Data Payload	128 bytes
8	Mac Layer	802.11
9	Propagation Model	Two-RayGround
10	Antenna	Omni-directional

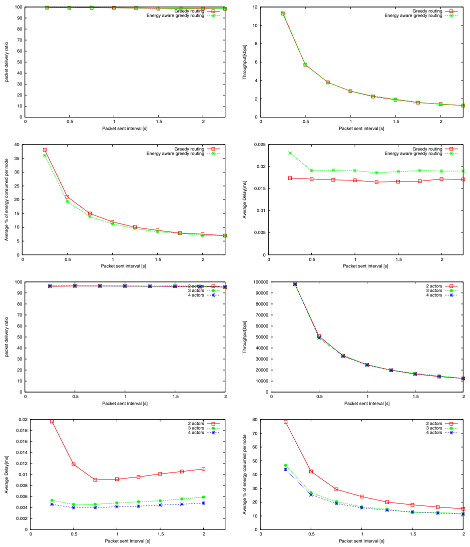

Fig. 5. Simulation Results

4.3 Results and Analysis

During the simulation process we have closely observed the different performance metrics for various CBR intervals ranging from 0.25 seconds up to 2.0 seconds with a step of 0.25 seconds. This is basically the variation of traffic load in the network. Graphs for CBR intervals (traffic load) against all the performance metrics(as mentioned in the above section) were constructed which clearly depicts that our protocol outperforms in all respects. First four graphs are comparing the greedy forwarding vs energy aware greedy forwarding against all performance metrics. Rest graphs are comparing all performance metrics by considering two actors, three actors, four actors. For the all simulation results are taken with initial energy of each sensor node is considered as 25 units and transmission power is 0.6w, receiving power is 0.3w.

5 Conclusion

The protocol emphasizes on coordination among sensor and actor nodes for WSAN based on Voronoi region and virtual grid and reduce congestion and redundancy in the network. The protocol divides the network area into grids and in each grid only one sensor node remains active. Sensor nodes gather event information and send it to nearest actor node based on Voronoi region. The important characteristics like real-time requirements and efficient utilization of available node energy are also taken into consideration. The advantage is that as for each sensor node there is only one closest actor node based on the Voronoi region, there will be no problem of deciding the actor node to which data needs to be transmitted upon detecting an event which is a major challenge in WSAN.

References

1. Akyildiz, I.F., Su, W., Sankarasubramaniam, Y., Cayirci, E.: Wireless sensor networks: A survey. Computer Networks 38, 392–422 (2002)
2. Akyildiz, I.F., Kasimoglu, I.H.: Wireless sensor and actor networks:Research challenges. In: Ad Hoc Networks, October 2004, vol. 2, pp. 351–367. Elsevier, Amsterdam (2004)
3. Heinzelman, W.R., Chandrakasan, A., Balakrishnan, H.: Energyefficient communication protocol for wireless microsensor networks(leach). In: Proceedings of 33rd Hawail International Conference on System Sciences (2000)
4. Intanagonwiwat, C., Govindan, R., Estrin, D.: Directed diffusion: a scalable and robust communication paradigm for sensor networks. In: Proceedings of the sixth annual international conference on Mobile computing and networking, Boston, MA USA, pp. 56–67 (2000)
5. Melodia, T., Pompili, D., Gungor, V.C., Akyildiz, I.F.: A Distributed Coordination Framework for Wireless Sensor and Actor Networks. In: Proceedings of 6th ACM international Symposium on Mobile Ad-hoc Networking and Computing (May 2005)
6. Bouhafs, F., Merabti, M., Mokhtar, H.: A Coordination Protocol for Wireless Sensor and Actor Networks, PGP Net (2006)
7. Melodia, T., Pompili, D., Akyildiz, I.F.: A Communication Architecture for Mobile Wireless Sensor and Actor Networks. In: Proceedings of IEEE SECON (2006)
8. Yuan, H., Ma, H., Liao, H.: Coordination Mechanism in Wireless Sensor and Actor Networks. In: Proceedings of the First International Multi-Symposiums on Computational Sciences, IMSCCS 2006 (2006)
9. Peng, H., Huafeng, W., Dilin, M., Chuanshan, G.: Elrs:An Energyefficient Layered Routing Scheme for Wireless Sensor and Actor Networks. In: Procedings of the 20th IEEE International Conference on Advanced Information Networking and Applications, AINA 2006 (2006)
10. Durresi, A., Paruchuri, V., Barolli, L.: Delay-Energy Aware Routing Protocol for Sensor and Actor Networks. In: Proceedings of the 11th International Conference on parallel and Distributed Systems, ICPDDS 2005 (2005)

11. Cargi Gungor, V., Sastry, C., Song, Z., Integlia, R.: Resource-Aware and Link-Quality-Based Routing in Wireless Sensor and Actor Networks. In: Proceedings of IEEE ICC (June 2007)
12. Shah, G.A., Bozyigit, M., Akan, O.B., Baykal, B.: Real-time Coordination and Routing in Wireless Sensor and Actor Networks. In: 6th International Conference, NEW2AN 2006, St. Petersburg, Russia (2006)
13. Xu, Y., Heidermann, J., Estrin, D.: Geography-Informed Energy Conservation for Ad-hoc Routing(GAF). In: Proceedings of 7th annual ACM International conference on Mobile Computing and Networking (July 2001)
14. Mitton, N., Busson, A., Fleury, E.: Self-Organization in Large Scale Ad-Hoc Networks. In: The Third Annual MED-HOC-NET Workshop (June 2004)
15. Wang, Y.C.R.P.X., Xing, G., Gill, C.: Integrated Coverage and Connectivity Cconfiguration in Wireless Sensor Networks. In: Proceedings of Sen-Sys 2003, Los Angeles, USA, pp. 7–14 (2003)
16. Aurenhammer, F.: Voronoi diagrams: A Survey of a Fundamental Geometric Data Structure. ACM 23, 345–405 (1991)
17. Bouhafs, F., Merabti, M., Mokhtar, H.: A Semantic Clustering Routing Protocol for Wireless Sensor Networks. In: Proceedings of IEEE CCNC (2006)
18. Heinzelman, W.R., Chandrakasan, A., Balakrishnan, H.: Energyefficient Communication Protocol for Wireless Microsensor Networks (LEACH). In: Proceedings of 33rd Hawail International Conference on System Sciences (2000)
19. Bouhafs, F., Merabti, M., Mokhtar, H.: A Semantic Clustering Routing Protocol for Wireless Sensor Networks. In: Proceedings of IEEE CCNC (2006)
20. Yu, Y., Govindan, R., Estrin, D.: Geographical and Energy Aware Routing: A Recursive Data Dissemination Protocol for Wireless Sensor Networks (2001)
21. Mao, G., Fidan, B., Anderson, B.D.O.: Wireless Sensor Network Localization Techniques. Comput. Netw. 51(10), 2529–2553 (2007), `http://dx.doi.org/10.1016/j.comnet.2006.11.018` Issn - 1389-1286
22. Camp, T., Boleng, J., Davies, V.: A Survey of Mobility Models for Ad Hoc Network Research. Wireless Communications and Mobile Computing (WCMC): Special issue on Mobile Ad Hoc Networking: Research, Trends and Applications 2, 483–502 (2002)
23. Ngai, E.C.-H., Lyu, M.R., Liu, J.: A Real-time Communication Framework for Wireless Sensor-Actuator Networks. In: IEEE Aerospace Conference (2004)
24. Mc Neff, J.G.: The global positioning system. IEEE Transactions on Microwave Theory and Techniques 50, 645–652 (2002)
25. Aurenhammer, F.: Voronoi Diagrams: A Survey of a Fundamental Geometric Data Structure. ACM 23, 345–405 (1991)