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# A Multiobjective Coverage and Connectivity Strategy for Improving the Performance of Wireless Sensor Networks

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***Abstract— The demand for Wireless Sensor Networks (WSN) has motivated the researchers to obtain energy optimized solutions, because of the constraint on the limited use of energy in these networks. In WSN, apart from energy optimization there are many other areas such as, coverage of the target area and the connectivity of the network for data routing, which attract the attention of researchers for optimization so that the performance of WSN can be improved significantly. These areas provide large scope for optimization to enhance the lifetime of WSNs. This paper provides a multiobjective approach for the optimization of problems of target area coverage and network connectivity for data routing in WSN.***

***Keywords— Energy Efficient Routing, Energy Balance, Network Coverage, Network Lifetime, Genetic Algorithm***

## I. INTRODUCTION

A Wireless sensor network consists of randomly/manually deployed sensors that sense the physical or environmental events and send the collected data to the base station. A large number of inexpensive, small and autonomous sensors are generally deployed in an ad hoc manner at remote areas. Sensor nodes in a WSN are constrained in storage capacity, computation power; bandwidth and power supply [1-4]. The routing protocols in WSN aim at reducing the energy consumption and thus prolong the network lifetime. The development of multifunctional low cost and power, sensors is the need of today. Sensor nodes are smaller in size and capable of sensing the events, collecting data and processing it. They also communicate with other sensors in the network, via radio frequency (RF) channel. The application areas of WSNs are in the field of civil, health, military and environment [4]. Different routing schemes have been addressed by researchers for static problems. The network can be setup with different possible configurations. In each possible configuration a sensor can be either in active state or inactive state. A node which is active can transmit the data or receive the data from some of the other nodes that are inside its communicating radius. Whereas an inactive node remains in an energy saving state consuming very low energy during this period and it can be activated whenever necessary.

## II. REVIEW WORK

The research in Wireless Sensor Network has explored many optimization areas. A data centric approach using the existing routing schemes and performance analysis of these schemes is done in [5]. Evolutionary Algorithms can be used effectively to find the energy efficient path in wireless sensor networks [6]. A simple approach to minimize the average path length is proposed in [7] where they considered the wireless network of sensor nodes having known spatial distribution using a GA approach. Each of the nodes consists of a relatively simple transceiver (antennas, a receiver and a transmitter). The goal of the optimization is to minimize the average path length from source to destination to minimize the transmitted power. Further, a method proposed in [8] has used a multipath routing protocol for WSNs to improve the reliability. The technique uses many paths and sends through them the same sub-packets. This increases the network traffic (not energy aware), but the reliability of the network is increased but this may reduce the lifetime of the sensor network. The energy awareness in multi path routing is done in [9-12] with consideration of maximizing the lifetime of the network. This protocol uses the idea of routing the packets through path where the nodes have the maximum residual energy. The path is changed whenever a better path is found. By using this approach, the nodes in the primary path will not get their energy exhausted by the continuously using the same path, thus longer lifetime is achieved.

Because of the random deployment of nodes in WSN, the selection of active node set from all the nodes is an NP-complete problem. The evolutionary algorithms which are heuristic based, provide an efficient methodology find the solution to this kind of problems. A protocol called PEAS has been proposed by [13]. Here some nodes are made redundant and not activated so long as there are other nodes available to cover the target area. The centralized and distributed algorithms using greedy approach based on randomization are being proposed that can maximize the coverage [14]. The lifetime of the WSN is prolonged by changing the state of nodes alternately active and inactive [15]. In [16] a linear programming approach has been used to get a minimized active node set for the coverage. A protocol called pCover is proposed by [17]. It uses only the local information and does not need time synchronization. Evolutionary computing has been extensively applied to wireless sensor networks. Elitist GA is used in [18] that have inherent advantage whereby it keeps the elite solutions in the next generation so as to quickly converge towards the global optima.

 

Considering the distance between the transmitter and receiver and the remaining energy of the nodes to find the energy efficient route is a better approach [19]. Alternate node selection from the neighborhood is used along with hybrid GA in [20] so that the nodes do not deplete of energy and the network lifetime is extended. The rest of paper is organized as follows: Section 3 is the describes the problem which includes network model used and mathematical description of the problem, section 4 describes the genetic multiobjective approach applied to network coverage and energy load balancing, in section 5 the simulation results are discussed and section 6 is the conclusion.

## III. PROBLEM DESCRIPTION

In order to get enhanced coverage the target area of the wireless sensor network should be densely deployed. Due to random method of deployment redundant nodes are present that are sensing the same area. Allowing all the nodes to simultaneously, will result in interference and collision, also the same data will be sensed by many sensors which will result in wastage of energy. As the target area is densely deployed and thus has more sensor nodes than required, to completely cover the target area, an energy efficient strategy is desired for efficiently utilizing the available power. The proposed strategy in this paper describes two states for every node: active or sleep. The sensing operation can only be performed in active state. Those nodes which are currently sensing are in active state. Nodes in the active state consume more energy as compared to those in the sleep state. Using efficient coverage control strategy significant energy saving can be achieved. If a certain target region is covered by a node, then other node(s) which are in the sensing range of that node, are redundant nodes and can be in sleep mode. Thus a significant amount of energy can be saved in this way. To find the effective coverage is a problem which needs attention in wireless sensor networks and can be defined by the node set that are able to cover the target area completely. In the initial phase complete coverage of the target area is ensured by a reasonable selection of nodes. Also the energy balance of the network should be maintained to ensure proper connectivity and to prolong the lifetime of the network. The energy balance of the network makes sure that some nodes are not over-utilized thus quickly depleting their energy while other nodes can still perform data transmission. This may result in energy imbalance and the network connectivity may fail. To maintain energy balance the nodes in data routing selected in such a manner that the net energy dissipation of the network is kept minimum as in equation (8).

### A. *Network Model*

A two-dimensional rectangular region is assumed as target area having k sensor nodes deployed in random fashion. The sensor model used is shown below [21, 23]:

$$Þ(i,j) = \begin{cases} 1 & if\ d_{ij} < d_0 \\ 0 & otherwise \end{cases} \qquad (1)$$

$$d_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \qquad (2)$$

Equation (1), shows coverage *Þ(i, j)* of the point *j* on the grid which is covered by the $i^{th}$ sensor node, the sensor node *i* is placed at deployment point (*xi*, *yi*). All the points having distance $d_{ij} < d_0$ are covered by the sensor *i* and it is denoted by a value 1 and the value *0* otherwise. Equation (2) gives the Euclidean distance between sensors *i* and *j* placed at (*xi*, *yi*) and (*xj* , *yj* ). A sensor *i* coveres a point (*xj*, *yj*) if it falls in the circle having radius less than $d_0$ i.e. $d_0$ is the detection range. If a node in the set covers the point *k(x,y)*, then it is covered by the node set. The probability of the point *k*(*x*, *y*) being covered by the node set is denoted by $P_k$:

$$P_k = 1 - \prod_{i=1}^{N} (1 - Þ(i,k)) \qquad (3)$$

The network model realizes a powerful Base Station which has adequate energy supply source and it is located away from the sink. The sensor nodes in the network have limited energy and therefore some limited number of sensor nodes is kept active while others are inactive, to save energy. All the nodes are initialized with a same level of initial energy. The radio energy model described by equations (4) and (5) is used [22] in this paper for energy dissipation. Two channel models, free space (fs) and the multipath (mp) fading are used. The choice of the either model depends upon the distance between the transmitter and receivers. The free space model is used when the distance between the two nodes in the link *(i, j)* is less than a circle radius (detection range) $d_0$, otherwise, the multipath fading model is used. $E_{elec}$ is the energy dissipated per bit to run the radio electronics. Thus, for transmitting a *k*-bit packet for a distance *d*, the energy expended by a radio is:

$$\mathrm{ETX_{k,d}} = \begin{cases} \sum_{i=1}^{N-1} \left(\mathrm{kE_{elec}} + \mathrm{k}\xi_{fs} * \mathrm{d}^2\right) & \mathrm{d} < \mathrm{d_0} \\ \sum_{i=1}^{N-1} \left(\mathrm{kE_{elec}} + \mathrm{k}\xi_{mp} * \mathrm{d}^4\right) & \mathrm{d} \geq \mathrm{d_0} \end{cases} \qquad (4)$$

To receive a *k*-bit message, the radio expends:

$$\mathrm{ETX_k} = \mathrm{E_{elec}} * \mathrm{k} \qquad (5)$$

### B. *Mathematical Description*

The strategy for coverage and energy balance is being described in this section. *A* is the target region area. The total number of nodes available in the target area (active and inactive) are *N*. For the active node set S, the sense areas of the active nodes are denoted by $s_i$. The active nodes are given by *l*, where $0<=l<=N$. The target area covered by the set *S* (set of active nodes), is given by $A_s$ and defined as union of all active nodes $s_i$ $1 \le i \le l$ in the active node set *S*:

$$A_s = \bigcup_{i=1}^{l} s_i \qquad (6)$$

Node utilization $\rho$ in WSN is defined as the ratio of number of active nodes and total number of nodes in the network:

$$\rho = \frac{l}{N} \qquad (7)$$

As in [20], the Energy balance of the network is computed as

$$E_{net} = \frac{E_{\max} - E_{min}}{E_{max}} \ (8)$$

Where $E_{net}$ is the Energy balance of the network. $E_{max}$ is the maximum remaining energy of a node in the network; $E_{min}$ is the minimum residual energy of a node in the network. The lower value of $E_{net}$ is good to prolong the lifetime of the network and higher value of $E_{net}$ is not desirable as it indicates uneven energy dissipation.

## IV. Multiobjective Optimization Search to WSN Coverage Control and Connecivity

The dynamic coverage and network connectivity for data routing problem which is described in the section 3.2 is represented as a multiobjective optimization problem and the multiobjective genetic algorithm is used to solve the problem. The network coverage has to be maximized which is given by the ratio of target area covered $A_s$ and the total target area $A$.

*Objective function 1.* Assuming that the target region point can be sensed by the network coverage, the maximized network coverage can be given by:

$$Max\ f_A(x) = \frac{A_s}{A} \qquad (9)$$

*Objective function 2.* The energy consumption of the network is to be minimized. Considering the node utilization and balanced energy consumption it is given by:

$$Min\ f_2(x) = \omega_1\rho + \omega_2 Enet \quad (10)$$

where $\omega_1$ is the weight of energy consumption, and $\omega_2$ is the weight of balanced energy consumption.

The purpose of the above function is to minimize the total energy consumption in the WSN so that the network lifetime can be improved. This function uses the node utilization energy balance parameters for prolonging the network lifetime. For the purpose of simultaneously minimizing both the objective functions, $Max\ f_A(x)$ function is changed as

$$Min\ f_1(x) = 1 - f_A(x). \qquad (11)$$

Thus the multi-objective coverage control and connectivity model thus discussed can be shown as minimization of:

$$Min\ (f_x(x), f_2(x)) \qquad (12)$$
$$subject\ to\ 0 \le l \le N,$$
$$x_i \in \{0,1\},$$

The above model presents a multiobjective algorithm for optimizing the coverage control and connectivity of the network for data routing in WSNs. The problem is modeled as a multiobjective optimization, in which the design criteria are set as minimizing the energy consumption during data collection and maximizing the coverage while keeping the network connectivity. The proposed strategy consists of multiobjective approach, which uses Nondominated Sorting Genetic Algorithm 2 (NSGA-II) [24] for providing the solution to the multiobjective coverage control and network connectivity problem. Considering the WSN network model given in (12), encoding method has been improved so that the proposed methodology of the multi-objective optimization algorithm can be accommodated.

Here, it is necessary to mention that the optimization strategy is executed at the base station. This architecture is chosen for the network because of its suitability in reduction of consumption of energy in the network: as the sensor nodes in have limited battery life as well as processing capabilities. They are mainly performing the tasks of sensing, transmitting and receiving data and hence it does not need any extra power for the processing of the optimization search algorithms. Whereas this architecture has the drawback in that it causes a delay time (latency). This latency time is needed by the sensor to detect node failure in the network and ask the base station to provide a solution for this (the signal of which particular sensor is to be activated for getting the coverage) [25]. This latency is not zero, but it is not considered for the cases discussed in this paper. It is assumed that this latency time dose not remain relevant when it is compared to the dynamic process of measuring physical quantities (pressure, temperature, humidity etc.). This latency may be ignored in cases where there is not much variation in quantities within short time periods but it must be considered when there is considerable variation in the quantities in short time periods.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 0 | 1 | 0 | 0 | 1 | 1 | 1 | 0 |

(a)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |

(b)

**Figure 1: Binary encoding structure of WSN**

### A. *Encoding Rules.*

In the proposed methodology, each individual is represented as a sequence of genes for the individual. The Figure 1 shows the encoding scheme used in this paper where each individual consists of a bit string *N*. Each bit in the encoding represents an individual sensor node. Each bit describes the state of a node (active or inactive) in the network. A *1* in the bit position indicates that the sensor node is active, otherwise it is inactive which is represented by a *0*. The encoding form of the *N*-bit string is $x=(x_1, x_2, \ldots x_i, \ldots x_N)$.

 

$$x_i = \begin{cases} 1 & \text{sensor i is selected} \\ 0 & \text{else} \end{cases}$$

Two examples of encoding bit strings for an individual are shown in figure 1. The length of the binary string is *N*=8. Figure 1 (a) shows that the sensor nodes (2, 5, 6, and 7) are in active state and the rest of the sensor nodes are in inactive or in sleep state. Figure 1(b) shows that all the sensor nodes are active nodes and none of the nodes are in sleep state.

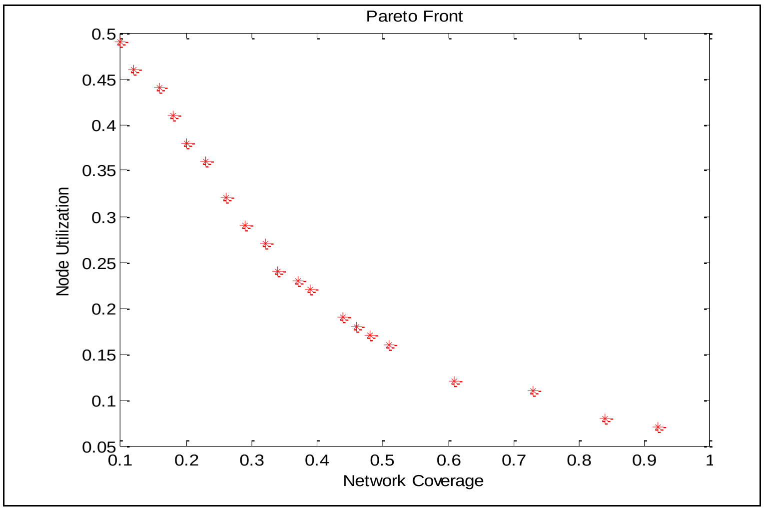


Figure 2: Pareto front - Network Coverage and Node Utilization

## V. RESULTS AND SIMULATION

This section describes the performance of the proposed multi-objective coverage control and connectivity strategy for the WSN. The study of the parameters is performed by writing the custom code in MATLAB for simulating the strategy. In this paper, the radio energy model described in (4) and (5) is used. The free space(fs) and the multipath(mp) fading are the two channel models. They alter depending on the distance between the transmitter and receivers. When the distance is less than a the connecting radius $d_0$, the free space model is used, otherwise, the multipath model is used. $E_{elec}$ is the energy dissipated per bit to run the transmitter or the receiver circuit. For the simulations described in this paper, the communication energy parameters are set as: $E_{elec}$ =50nJ/bit, $\xi_{fs}$ =10pJ/bit/m$^2$, $\xi_{mp}$ =0.0013pJ/bit/m4, connecting radius $d_0$ =50m.

A rectangular region 100m x 100m is selected as the target area. The target region was deployed with 195 sensor nodes. All the nodes used were of same type.

**TABLE 1: NETWORK COVERAGE ACHIEVED WITH NUMBER OF ACTIVE NODES ANALYSIS**

| Coverage thresholds | | | | | | |
|---|---|---|---|---|---|---|
| | | 80% | 85% | 90% | 95% | 100% |
| ω1=0.5, ω2=0.5 | Network Coverage % | 80.19 | 84.47 | 90.23 | 93.61 | 99.74 |
| | Active Nodes nos | 63 | 64 | 70 | 75 | 150 |
| | Network Lifetime:rounds | 241 | 241 | 241 | 241 | 152 |
| ω1=0.7, ω2=0.3 | Network Coverage % | 78.43 | 83.21 | 90.04 | 92.56 | 98.71 |
| | Active Nodes nos | 43 | 53 | 72 | 80 | 130 |
| | Network Lifetime | 301 | 289 | 282 | 271 | 227 |
| ω1=0.1, ω2=0.0 | Network Coverage % | 79.49 | 83.89 | 89.72 | 93.23 | 97.42 |
| | Active Nodes | 42 | 48 | 63 | 73 | 118 |
| | Network Lifetime rounds | 242 | 239 | 235 | 219 | 151 |

The coverage area or the communicating radius of each node is 10m. The Pareto front for Network coverage and node utilization parameters is shown in Figure 2. The node utilization ρ given by (7) is the ratio of active node set and total number of nodes in the target area. The number of active nodes and the coverage obtained from the algorithm are shown in Table 1. The analysis in Table 1 is based on different values for the weight of energy consumption and the weight of energy balance at different coverage threshold values.

The weight ratio defines the compromise levels for energy consumption and energy balance. $\omega 1$ = 1 and $\omega 2$ = 0 means that only node utilization is used as the fitness function and but balance of energy consumption is not taken into account. As is evident from the third row in the table the number of nodes used is minimum in this case for the above weights.

If $\omega 2$ is increased means much attention is given to balance of energy consumption and importance of node utilization factor is being ignored. This results in increase on the number of nodes as shown in the first row in Table 1 and thus the network lifetime is reduced as shown in the Figure 3. The middle row with $\omega 1$ = 0.7 and $\omega 2$ = 0.3 are better weight selections to achieve better coverage and optimum node utilization. This also increases the network lifetime as expected as shown in Figure 3.

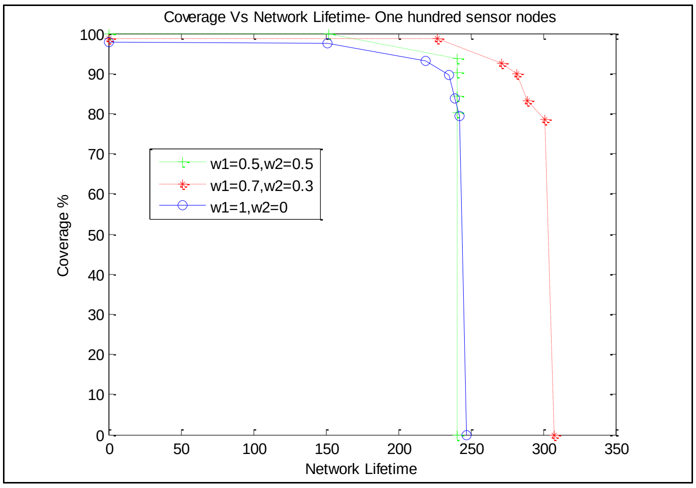


Figure 3: Coverage Vs Network Lifetime

## VI. CONCLUSION

In this paper the genetic multiobjective optimization techniques is used for optimizing the contradictory problems of energy load balancing and network coverage. The strategy used provides a compromise at the network coverage, network energy load balancing and network connectivity. This strategy can adjust the weights to energy consumption and energy load balance to achieve the optimum performance of the WSN. It is clear from the simulation results that the proposed strategy has wide applicability and it can significantly enhance the performance of WSN.

## REFERENCES

[1] Goldberg D. E., "Genetic Algorithms in Search, Optimization, and Machine Learning" Reading, MA: Addison-*Wesley*, 1989.

[2] Akyildiz I. F., Su W., Sankarasubramaniam Y., Cayirci E., "A Survey On Sensor Networks," *IEEE Communications Magazine*, Vol. 40, Issue 8, 2002.

[3] Raghavendra V. K., Förster A. , Venayagamoorthy G. K., "Computational Intelligence in Wireless Sensor Networks: A Survey," *IEEE Communications Surveys & Tutorials*, Vol. 13, No. 1, pp. 68-96, 2011.

[4] Heikalabad S. R., Ghaffari A., Hadian A., Rasouli H., "DPCC: Dynamic Predictive Congestion Control in Wireless Sensor Networks," *IJCSI International Journal of Computer Science Issues*, Vol. 8, Issue 1, pp.472-477, 2011.

[5] Azni A. H., Saudi M. M., Azman A., Johari A. S., "Performance Analysis of Routing Protocol for WSN using Data Centric Approach," *World Academy of Science, Engineering and Technology*, Issue 53, 2009

[6] Singh V. K., Sharma V.,"On the Hybridization of Evolutionary Algorithms and Optimization Techniques," *Conference on Advancements in Communication, Computing & Signal Processing (COMMUNE CACCS 2011)*, 2011.

[7] Johnson J. M., Samii Y. R., "Genetic Algorithm Optimization of Wireless Communication Networks," *Proceedings for Antennas and Propagation Society International Symposium*, AP-S. Digest, 1995.

[8] Li Q., Aslam J. Rus D., "Hierarchical Power-Aware Routing in Sensor Networks," *Proceedings of DIMACS Workshop on Pervasive Networking*, 2011.

[9] Murthy S., Garcia-Luna-Aceves J. J., "An Efficient Routing Protocol for Wireless Networks," *ACM Mobile Networks Applications*, Vol. 1, Issue 2, pp.183-197, 1996.

[10] Singh S., Woo M., Mghavendra C.S., "Power-Aware Routing in Mobile Ad Hoc Networks," *ACM SIGMOBILE Mobile Computing and Communications Review*,, pp. 181-190, 1998.

[11] Heinzelman W. R., Chandrakasan A., Balakrishnan H., "Energy-Efficient Communication Protocol for Wireless Microsensor Networks," *Proceedings for the Hawaii International Conference on System Sciences, (IEEE)*, January 4-7, pp.876–882, 2000.

[12] Chang J.H., Tassiulas L. , "Maximum Lifetime Routing in Wireless Sensor Networks," *Journal IEEE/ACM Transactions on Networking (TON)*, Vol. 12 Issue 4, 2004.

[13] F. Ye, G. Zhong, J. Cheng, S. Lu, and L. Zhang, "PEAS: a robust energy conserving protocol for long-lived sensor networks," in *Proceedings of the International Conference on Distributed Computing Systems*, pp. 28–37, Providence, RI, USA, 2003.

 

[14] Z. Abrams, A. Goel, and S. Plotkin, "Set K-cover algorithms for energy efficientmonitoring in wireless sensor networks," in *Proceedings of the 3rd International Symposium on Information Processing in Sensor Networks (IPSN '04)*, pp. 424–432, Berkeley, Calif, USA, 2004.
[15] D. Tian and N. D. Georganas, "A node scheduling scheme for energy conservation in large wireless sensor networks," *Wireless Communications and Mobile Computing*, vol. 3, no. 2, pp. 271–290, 2003.
[16] K. Chakrabarty, S. S. Iyengar, H. Qi, and E. Cho, "Grid coverage for surveillance and target location in distributed sensor networks," *IEEE Transactions on Computers*, vol. 51, no. 12, pp. 1448–1453, 2002.
[17] L. Wang and S. S. Kulkarni, "Sacrificing a little coverage can substantially increase network lifetime," *Ad Hoc Networks*, vol. 6, no. 8, pp. 1281–1300, 2008.
[18] Singh Vinay. K., Sharma Vidushi., "Elitist Genetic Algorithm Based Energy Efficient Routing Scheme For Wireless Sensor Networks", International Journal of Advanced Smart Sensor Network Systems (IJASSN), Volume 2, Number 2, April 2012.
[19] Singh Vinay. K., Sharma Vidushi., "Extending Wireless Sensor Network Lifetime Through Effective Genetic Algorithm Based Approach" COMMUNE Conference on Advancements in Communication, Computing & Signal Processing, March 2012.
[20] Singh Vinay. K., Sharma Vidushi, "Lifetime Maximization of Wireless Sensor Networks using Improved Genetic Algorithm based Approach,"International Journal of Computer Applications (0975 – 8887) Volume 57– No.14, November 2012
[21] W. R. Heinzelman, A. Chandrakasan, and H. Balakrishnan, "Energy-efficient communication protocol for wireless microsensor networks," in *Proceedings of the 33rd Hawaii International Conference on System Sciences (HICSS '00)*, p. 223, Maui, Hawaii, USA, 2000.
[22] Hui, X., Zhi-gang, Z., and Feng, N. 2010 A Novel Routing Protocol in Wireless Sensor Networks based on Ant Colony Optimization International Journal of Intelligent Information Technology Application, Vol. 3 Issue (1), 1-5.
[23] Hui Zhou, Tian Liang, Chen Xu, & Jing Xie1, "Multiobjective Coverage Control Strategy for Energy-Efficient Wireless Sensor Networks" Hindawi Publishing Corporation-International Journal of Distributed Sensor Networks, Volume 2012, Article ID 720734, 10 pages.
[24] K. Deb, A. Pratap, S. Agarwal, and T. Meyarivan, "A fast and elitist multiobjective genetic algorithm: NSGA II," IEEE Trans. Evol. Comput., vol. 6, pp. 182–197, 2002.
[25] Flávio V. C. Martins, Eduardo G. Carrano, Elizabeth F. Wanner, Ricardo H. C. Takahashi, "A Hybrid Multiobjective Evolutionary Approach for Improving the Performance of Wireless Sensor Networks" IEEE Sensors Journal, vol. 11, NO. 3, March 2011

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