An Efficient Energy Scheme of Wireless Sensor Node Dynamic Deployment

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Abstract: This text provides an efficient energy scheme of wireless sensor node dynamic deployment. A single sensor node communication model is defined initial. Sensors are co-working with their neighbors in their transmitting range. Suitable neighbor node number and sensing radius make sensors field more efficient. A value CAPR is defined in this text for power efficiency discriminating. A self-regulated sensing radius mechanism is proposed here that sensor can adjust its radius of sensing range for high efficient energy working.

Keywords: wireless sensor node, coverage area, neighbor node numbers, CAPR, self-regulated mechanism

1 Introduction

Wireless Sensor Network (WSN) has been proposed for many applications in which the sensors nodes are capable of sensing, computation, and communication [1]. In WSN, sensors deployment builds the network topology include distributed architecture and its heuristic algorithms. The topology of WSN will decide the performance of networks. Although most of the current WSNs consist of static sensor nodes, there are many applications where mobile nodes are involved [2]. Moreover, due the varying environment and the vulnerable of sensor nodes, the stationary deployment would suffer performance degradation in a long period. Therefore, the dynamic deployment with mobile nodes can adaptively optimize the network topology for WSNs [2-4]. Integrating multiple nodes deployment, the mainly focuses is how to deploy the sensors reasonably to guarantee a highly-effective on coverage for a Range of Interest (ROI), that is, how to construct a biggest coverage using minimum power consumption is the main goal in this paper. Many methods have been developed on the sensors placement and then to improve the coverage rate, such as force field based methods and virtual force algorithms (VFA) [5-7]. Recently, a Hybrid Virtual Force Algorithms (HVFA) has been proposed to improve the performance of coverage rate, connectivity and energy-efficient [8]. However, it need consider the moving path and power consumption for VFA scheme. Basically, WSN is a distributed topology. High node density and uniform node deployment is necessary. In this text, a single sensor node communication model is defined initial. A sensor node holds transmit-sensing communication ability. For coverage area maximized and power consumption minimized considering, we focus the selection of the radius of sensor node's transmitting and sensing according sensor node's local density. i.e. The radius of sensor node's transmitting is fixed. The radius of sensor node's transmitting is variable according its neighbor node density information it getting.

The rest of this paper is organized as follows. Section 2 describes a single wireless sensor node communication model and multiple sensors coverage area evaluating. A grid-based coverage area estimating algorithm is introduced there. Section 3 discusses neighbor node topology and sensor field power consumption. A critical term CAPR is defined to estimate power efficiency. Section 4 described a self-regulated sensing radius mechanism as an application example. Section 5 provides some conclusions.

2 Wireless Sensor Node Communication Model

2.1 Single Sensor Node Communication Model

A wireless sensor node is working with sensing and communication jobs simultaneous in WSN. Each sensor node sends its beacon through transmitting ability. It also can detect an event occurring within its sensing range then delving this message to its neighbors within communication range. Meanwhile, each sensor node can receive (listen) any information from other sensor node within sensing range. Figure 1 depicts a single sensor node's sensing and communication working scope with sensing radius r_s and communication radius r_c.

Transmitting distance r_c need larger than sensing distance r_s for information forward.

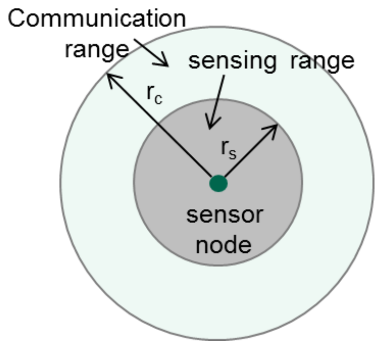

Fig. 1. Single sensor node communication model

2.2 Sensing Coverage Area

In real application, we need multiple sensor for sensing scope maximization in communication range. As figure 2 shown, two sensor nodes n_1, n_2 are separated a distance $d \le r_c$. It means n_1, n_2 can communicate each other. Each node has his own sensing scope. There are overlapping area exit between two sensor's sensing ranges. We call the total sensing area as coverage area CA of nodes n_1, n_2. The larger CA in ROI, the larger scope sensors can inspected.

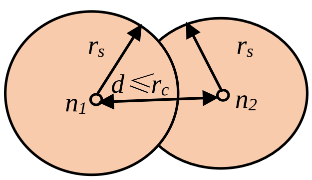

Fig. 2. Two closed sensors and their coverage area

2.3 Grid-based Coverage Area Evaluating Algorithm

The sensing coverage area evaluating is one of the core works for sensor deployment. A grid-based approach, we divided the specific scope into GP unit grids, then we can accumulate the content of grids for area evaluating. Applying this approach, the sensing coverage area (CA) in ROI can be express as

$$CA = \sum_{P=1}^{GP} A_P \qquad (1)$$

where GP is the total number of grid points in ROI, and

$$A_P = \begin{cases} 1 & P \text{ is in sensing scope} \\ 0 & P \text{ is not in sensing scope} \end{cases}.$$

A coverage area evaluating algorithm is shown here:

```
Begin
Initialized
  Parameter setting { r_s, r_c}
  Sensor node location setting{p_1(x_1, y_1), p_2(x_2, y_2),...,(x_i, y_i)}|(||p_2- p_1||) ≤r_c.

For k=1 to i
For r=0 to r_s
For ω = 0 to 2π

/* Every grid in circle setting */
  A_P(k,r,ω) = 1

End For
End For
End For

/* Calculate total coverage area */
  CA = Σ_{P=1}^{GP} A_P(r, ω)
End
```

An example in figure 3, we put two noes at (10, 10), (20, 10), and let r_s=6m. The coverage area is calculated as CA=217m^2.

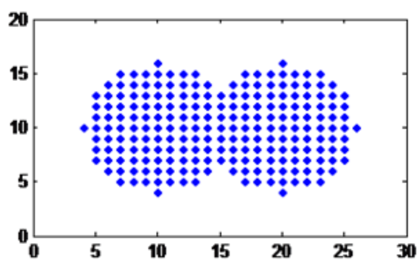

Fig. 3. Two nodes' coverage area calculation CA=217m^2

3 Sensor Field Power Consumption and Power Efficiency

3.1 Neighbor Node Topology

Neighbor-node topology control is one of important methods for distributed deployment in WSNs which rely on nodes' ability to determine the number and identity of neighbors within the maximum transmitting range [9]. In this section, we'll describe the meaning of neighbor node and its detection.

Let S be a set of all sensor nodes in ROI. The set of neighbor nodes of the ith node in AOI can be defined by $S_{ni}=\{n_j \in S, \mid d_{ij} \le r_c, j \ne i\}$, where d_{ij} is Euclidean distance between node n_i and n_j. The number of neighbor nodes of S_{ni} is denoted as n_b.

A simple way detection neighbor node, any sensor node n_i transmitted a beacon signal to its neighbor node with r_c

distance power in a period time T. If a sensor receives beacon signal, then it makes a record. Sensors do not transmitted beacon signal simultaneously. Figure 4 show sensors transmitted beacon signal protocol. If sensor has GPS ability, then beacon signal can include sensor's location information.

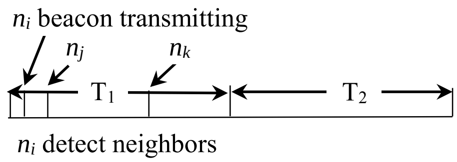

Fig. 4. Sensor beacon signal transmitting and neighbor's detection

3.2 Sensor Field Power Consumption

In front section, we had mentioned that a sensor node need join some another neighbor nodes in its communication range to achieve a maximum coverage area. In this section, we concern about how many neighbor nodes are need in a communication range and how much power energy are consumed. In a wireless sensor field, transmitting power P_T and sensing power P_S are two main parts of power consumptions P_C. They can be expressed as:

$$P_c = P_T + P_s \tag{2}$$

$$P_T = k_T r_c^2 \tag{3}$$

$$P_S = k_S r_s^2 \tag{4}$$

Let $r_c = r_s = 1$m, we simulate $P_T = 10$mW, $P_S = 3$mW. Then the parameter can be calculated as $k_T=10*10^{-3}$, $k_S=3*10^{-3}$. Next, we change r_c form 1m to 10m and deploy some sensor nodes at the edge of r_c circle for maximum coverage area getting. Then we adjust r_s to avoid coverage hole occurring. Figure 5 show a coverage hole case.

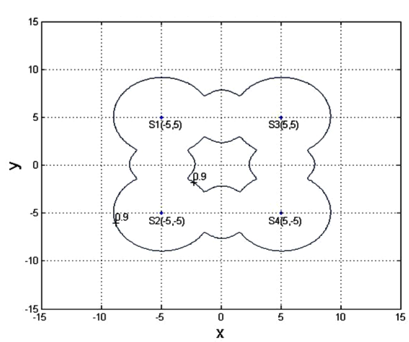

Fig. 5. A coverage hole case

Consider 3 various neighbor node numbers deployment cases as below. Here, we consider sensing power consumption is anytime, but transmitting power consumption is alternate.

Case 1: Deployment with neighbor node numbers=3, $r_c=r_s=10$m, in full coverage state that shown as figure 6. In this case, the total power consumption

$$P_C=P_T+4P_S=10*10^{-3}\text{x}10^2+4*3*10^{-3}*10^2=2.2\text{W}.$$

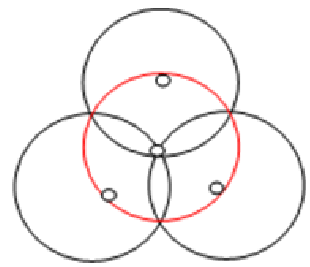

Fig. 6. Sensor deployment with neighbor node numbers=3, $r_s=r_c=10$m

Case 2: Deployment with node numbers=4, $r_c=10$m, $r_s=0.8r_c=8$m, in full coverage state that shown as figure 7. In this case, the total power consumption

$$P_C=P_T+5P_S=1+5*3*10^{-3}*8^2=1.96\text{W}$$

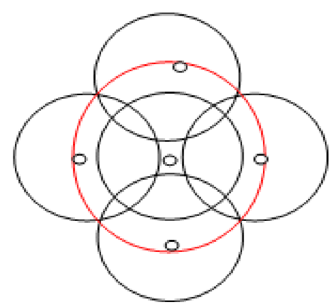

Fig. 7. Sensor deployment with neighbor node numbers=4, $r_s=0.8r_c=8$m

Case 3: Deployment with $n_e=6$, $r_c=10$m, $r_s=0.6r_c=6$m, in full coverage state that shown as figure 8. In this case, the total power consumption

$$P_C=P_T+7P_S=1+7*3*10^{-3}*6^2=1.76\text{W}$$

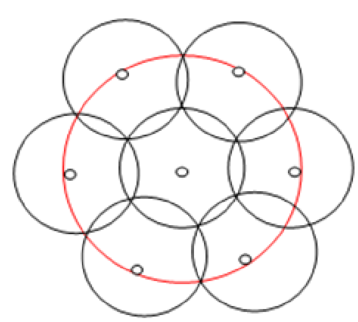

Fig. 8. Sensor deployment with neighbor node numbers=6, $r_s=0.6r_c=6$m

We summarize the results of three cases into table 1.

Table 1 Summary of three cases in full coverage state

Case	Neighbor numbers	r_c(m)	r_s(m)	P_C (W)
1	3	10	10	2.2
2	4	10	8	1.96
3	6	10	6	1.76

From this table shown, on condition neighbor numbers=6, r_c=10m, and r_c=6m is an optimal suggestion.

3.3 Coverage Power Efficiency and Simulation Results

Various neighbor node numbers construct various coverage area. Here, we define a discriminating value CAPR.

CAPR (Coverage Area to Power consumption Ratio) = coverage area/ power consumption

More high value of CAPR, more high efficient for wireless sensor network is. We select appropriate node position, then estimate the coverage area for each case. Results are shown in figure 9, 10, 11.

For case 1, neighbor node number n_b=3, CA=801m^2, CAPR=364m^2/w.

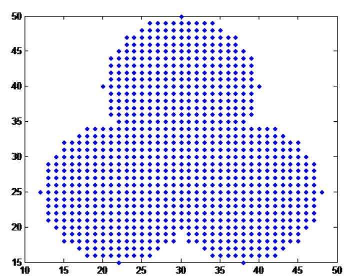

Fig. 9. Simulation result for case 1

For case 2, neighbor node number n_b=4, CA=723m^2, CAPR=368m^2/w.

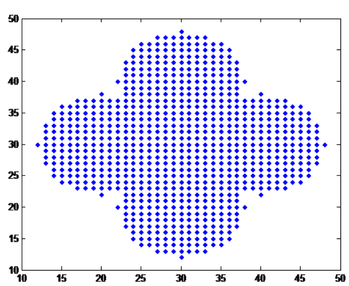

Fig. 10. Simulation result for case 2

For case 3, neighbor node number n_b=6, CA=673m^2, CAPR=382m^2/w.

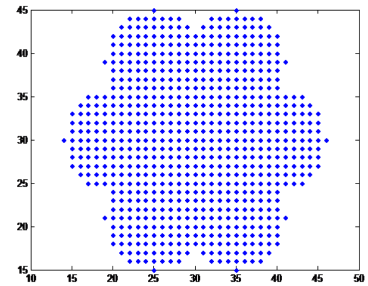

Fig. 11. Simulation result for case3

We summarize the results of three cases into table 2.

Table 2 Summary of three simulation cases

Case	n_b	$r_c : r_s$	CA (m^2)	P_C (W)	CAPR
1	3	1	801	2.2	364
2	4	0.8	723	1.96	368
3	6	0.6	673	1.76	382

From results, the network of n_b=6 is better than others. Another suggestion, we can utilize a suitable ratio of r_c:r_s when neighbor node numbers has been detected. Figure 12 shown a transfer graph of neighbor node number vs ratio of r_c:r_s and CAPR. For example, In a WSN environment, set sensor's r_c=10m, if a sensor detected its neighbor node numbers=3 then we can set sensor's r_s=10m×1=10m (at least), and result CAPR=364. If a sensor detected its neighbor node numbers=4 then we can set sensor's rs=10m×0.8=8m (at least), and result CAPR=368. If a sensor detected its neighbor node numbers=5 then we can set sensor's rs=10m×0.7=7m (at least), and result CAPR=379. If a sensor detected its neighbor node numbers=6 then we can set sensor's rs=10m×0.6=6m (at least), and result CAPR=382.

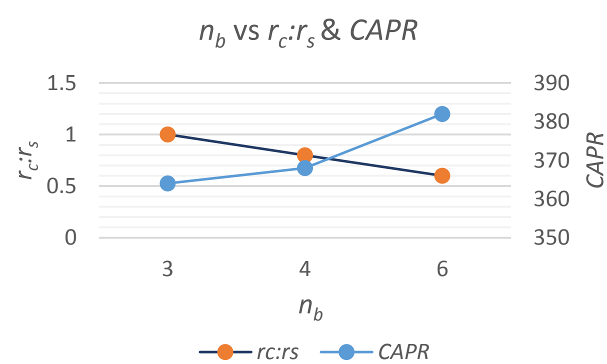

Fig. 12. Transfer graph of n_b vs ratio of r_c:r_s and $CAPR$

4 An Application Example: A Self-Regulated Sensing Radius Mechanism

Different from node moving scheme for sensor deployment, here we propose a self-regulated sensing radius mechanism shown as figure 13.

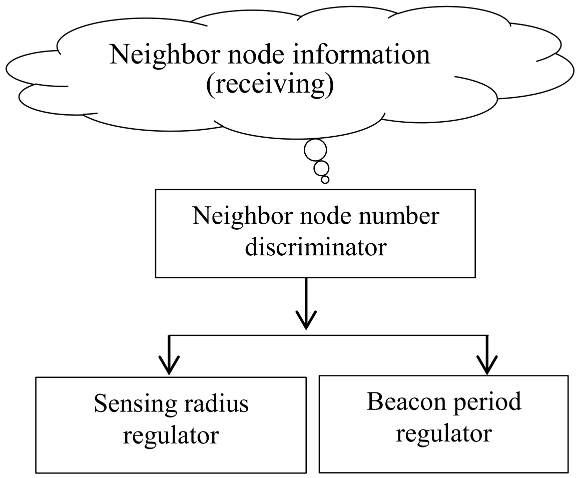

Fig. 13. A self-regulated sensing radius mechanism for sensor node

This mechanism include a neighbor node discriminator, sensor can adjust its sensing radius according neighbor node in a period time. An example explaining: A sensor node is working with other 4 neighbor nodes with r_c= 10m, r_s=8m initial. After a period time, this sensor discriminate its neighbor number changing to 6. Then this mechanism changes r_s from 8m to 6m.

5 Conclusions

Different from node moving scheme for sensor deployment, this text proposed a self-regulated scheme that sensor can adjust its radius of sensing range for high efficient power reaching in wireless sensor network. 6 neighbor nodes is an optimal selection for sensor working design.

Reference

[1] F. Akyildiz, S. Y. Sankarasubramaniam, and E. Cyirci, "Wireless Sensor Networks: A Survey," Computer Networks, Vol. 38, No. 4, pp. 393-422. , 2002

[2] A. Howard, M. J. Mataric and G. S. Sukhatme, "Mobile Sensor Network Deployment Using Potential Fields: A Distributed, Scalable Solution to the Area Coverage Problem," In Proceedings of 6th Int. Conf. Distributed Autonomous Robotic System, Fukuoka, Japan, pp. 299-308, 2002.

[3] N. Thangadurai, R. Dhanasekaran and R. D. Karthika, "Dynamic Energy Efficient Topology for Wireless Ad hoc Sensor Networks," WSEAS Transactions on Communications, Vol. 12, Issue 12, pp. 651-660, December 2013.

[4] D. G. Costa, L. A. Guedes, F. Vasques and P. Portugal, "Redundancy-Based Semi-Reliable Packet Transmission in Wireless Visual Sensor Networks Exploiting the Sensing Relevancies of Source Nodes," WSEAS Transactions on Communications, Vol. 12, Issue 9, pp. 468-478, September 2013.

[5] Y. Zou and K. Chakrabarty, "Sensor Deployment and Target Localization Based on Virtual Forces," In Proceedings of IEEE INFOCOM; pp. 1293– 1303, 2003.

[6] J. Li, B. Zhang, L. Cui, and S. Chai, "An Extended Virtual Force-based Approach to Distributed Self-Deployment in Mobile Sensor Networks," International Journal of Distributed Sensor Networks, 2012.

[7] N. Heo and V. P. Kumar, "A distributed self spreading algorithm for mobile wireless sensor networks," In Proceedings of IEEE WCNC , pp. 1597 – 1602, 2003.

[8] J. Wen, C. Yan, and Y. Huang, "Performance of Hybrid Virtual Force Algorithms on Mobile Deployment in Wireless Sensor Networks," WSEAS Transactions on Communications, Art. #61, Volume 13, pp. 558-566, 2014.

[9] J. Liu, and B. Li, "Mobilegrid: Capacity-Aware Topology Control in Mobile Ad Hoc Networks," In *Proceedings of IEEE International Conference on Computer Communications and Networks*, pp. 570–574, 2002.