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Energy Aware Optimal Routing for Wireless Sensor Networks

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Abstract: Wireless Sensor Network (WSN) is a collection of autonomous devices with computational, sensing, and wireless communication capabilities. The sensor nodes are low cost, multi-functional devices that are densely deployed either inside the phenomenon or very close to it and are often powered by independent power sources. The lifetime of such sensor nodes show a strong dependence on lifetime of the power source used. So, conservation of power and hence increase the lifetime becomes an important issue in WSNs. Routing in Wireless Sensor Networks, which consumes a considerable amount of energy, offers ample scope in increasing the life time of WSNs. To address this problem an Energy Aware Optimal Routing (EAOR) algorithm, which determines the path that consumes minimum power between the source node and the destination node, is proposed here. The proposed EAOR algorithm performs better in terms of conservation of power compared to the shortest path routing algorithm. This EAOR algorithm is also validated through extensive simulation in various scenarios, like increasing the number of sensor nodes and gateway nodes. The results show that EAOR algorithm performs well for all the scenarios.

Key words: Wireless sensor networks-energy management-routing

INTRODUCTION

The scattered sensor nodes which communicate among themselves form an integrated network. They have the capabilities to collect and route data back to the Monitoring Station. The position of the sensor nodes need not be engineered or pre-determined[1]. This allows random deployment in inaccessible terrains or disaster relief operations.

The features shown in fig. 1 ensure a wide range of applications for sensor networks. Some of the application areas are health, military, and security. For example, a doctor can monitor the physiological data about a patient remotely. While this is more convenient for the patient, it also allows the doctor to ascertain the patient's current condition from the place of work itself. Sensor networks can also be used to detect foreign chemical agents in the air and in the water. They can help to identify the type, concentration, and location of pollutants. In essence, sensor networks can provide the end user with intelligence and a better understanding of the environment[1]. It is envisioned that, in future, wireless sensor networks will be an integral part of our lives, more than the present-day personal computers.

The data collected by the scattered sensor nodes are routed back to the end user by a multi-hop infrastructure-less architecture through the sink as shown in Fig. 1. Basically, there are three types of

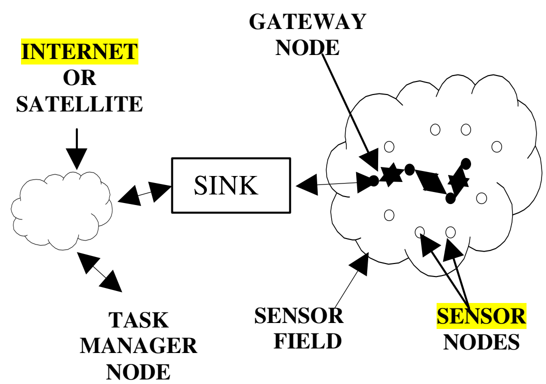

Fig.1. Sensor network

nodes: *Sensor nodes* responsible for sensing the data, *Sink nodes* or the *base station* nodes responsible for receiving, storing, and processing the data from sensor nodes. The Gateway *nodes* that connect sink nodes to external entities are called observers.

The nodes in a Sensor Network rely on batteries and other exhaustible means of energy sources for functioning. Advances during the last decade in integrated circuit technology have enabled the manufacturing of very powerful but inexpensive sensors, radios, and processors, allowing mass production of sophisticated systems connecting the

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physical world to computer networks. Such applications need to send sensor information to users or network entities using low-power transceivers since most nodes rely on batteries for their functioning. The sensor nodes in a sensor network are thus resource constrained. The power consumption must therefore be as low as possible, because replacing the battery of every node even once in a month would be a maintenance nightmare. Thus, the Power Management becomes an important issue to prolong the lifetime of battery powered wireless sensor networks.

Over the years, quite a few algorithms have been developed to take care of the power control issue. Martin Kubisch et al discussed their power control algorithms[2] based on the effective usage of the active time of the sensor nodes. This paper suggested that since the WSNs were powered by sources like batteries, transmission power control could improve the lifetime of the sensor nodes. Li and Hou[4] developed a power efficient broadcast algorithm for wireless sensor networks. It dealt with the conservative techniques for broadcasting the sensed messages so that power saving could be achieved. M. Younis. *et al.*[3] pointed out that an efficient energy-aware routing technique could improve the efficiency of the network. Several parameters such as the transmission distance, the number of hops and the delay have been taken into account for energy saving in the sensor networks.

An Energy Aware Optimal Routing (EAOR) algorithm, based on optimal routing, is proposed here to conserve energy and hence lengthen the lifetime of sensor nodes. This algorithm chooses the route that consumes minimum power as the optimum route for sending the information. This ensures that only minimum power is consumed from every node involved in this path.

The remaining portions of the paper are organized as follows: EAOR algorithm is explained in the next section, Gateway node discovery procedure follows that, and the next section deals with minimum power path determination. The results and conclusion are given in the last section.

ENERGY AWARE OPTIMAL ROUTING (EAOR) ALGORITHM

POWER CONTROL: A novel Power Control technique was used here for routing the sensed information to the base station. This algorithm has been named as EAOR (Energy Aware Optimal Routing). The flowchart of the EAOR algorithm is shown in Fig. 2.

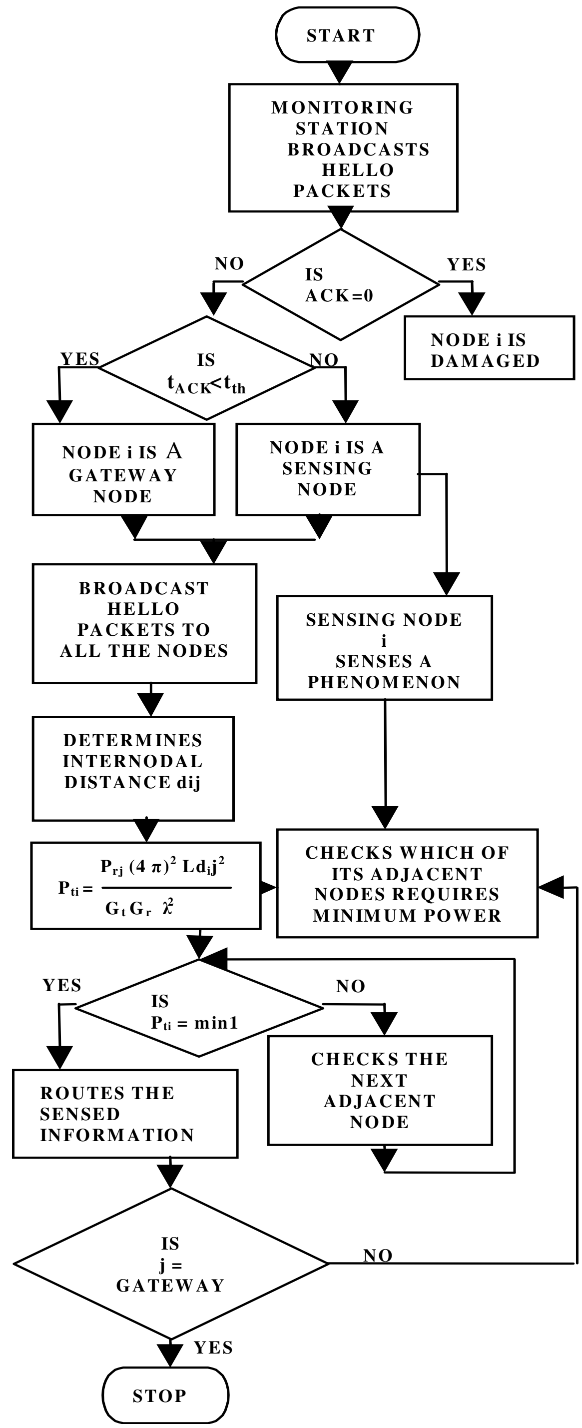

Fig. 2: Flowchart for Energy Aware Optimal routing (EAOR) algorithm

For simulating the wireless sensor environment, an area of size (280×290) m^2 was assumed. Totally seventy five (75) number of sensor nodes were taken into account for the study and all of them were generated randomly. Out of these, one of the nodes was assumed to be the *base station* or the *monitoring node*. The rest of the seventy-four nodes were assumed to be common sensor nodes. By transmitting the HELLO packets, the monitoring station determined the Gateway nodes as explained in the section Gateway node discovery. Out of the 75 nodes it was found that eight (8) nodes were Gateway nodes, 64 were common sensor nodes and three (3) were damaged nodes as shown in Appendix I. The time taken for acknowledgement to reach the base station, the Gateway nodes and the damaged nodes are given in Appendix I. Appendix II gives the path through each of the gateway node to the base station and the power consumed. The entire simulation was carried out in MATLAB 7.1.

GATEWAY NODE DISCOVERY

The gateway node was identified by the following procedure; The Monitoring Station first broadcast "HELLO" packets and found out which of the nodes were adjacent to it and which were not. It did this by measuring the time taken by each of the nodes to acknowledge the HELLO packet. The nodes that acknowledge the earliest were considered as Gateway Nodes. The other nodes that did not acknowledge at all were considered as damaged nodes. The remaining nodes, which acknowledged were regarded as common Sensing Nodes.

This process was repeated at regular intervals to check which of the nodes were functional and which were not functional[5].

TRANSMITTING POWER LEVEL MEASUREMENT

In WSNs, each of the nodes broadcast "HELLO" packets and thereby determined its distance from every other node with the aid of the acknowledgement times corresponding to these nodes.

The power required by any node 'i' to transmit the information to node 'j' which was at a distance of 'd_{ij}' could be calculated using the Friis equation[7] for free space propagation model assuming the ideal propagation condition.

The Friis equation is,

$$P_{ti} = k(d_{ij})^2 \quad (1)$$

where 'k' is proportionality constant given by,

$$k = \frac{P_r(4\pi)^2 L}{G_t G \lambda^2} \text{Watts} \quad (2)$$

P_{ti} = transmitted signal power (Watts)
P_r = received signal power (Watts)
G_t = transmitting antenna gain
G_r = receiving antenna gain
L = System loss (L = 1)
Λ = Wavelength (metres)

It is common to select $G_t = G_r = 1$ and L = 1. Thus, the power required to transmit from one node to other was directly proportional to the square of the distance between them.

$$P_t \propto d_{ij}^2 \quad \text{(Watts)}$$
$$P_t = kd_{ij}^2 \quad \text{(Watts)} \quad (3)$$

Thus, for each node in a sensor network the power required for transmission to every other node was computed and the values were stored in a table called 'Power Table'.

MINIMUM POWER PATH DETERMINATION

The minimum power determination of the proposed algorithm works as follows; whenever a node sensed a phenomenon, it temporarily stored the sensed information in its memory and looked up in its pre-determined Power Table to see which of its neighbors consumed minimum power for transmission. Now, the neighbour, which consumed the minimum power would become the working node which carried out the same process as its predecessor to determine its neighbor that required the minimum power. This process continued until a Gateway node was reached. Since there were a number of such Gateway nodes in a sensor field, the node which sensed the phenomenon then routed the sensed information to the base station through one of these Gateway nodes in such a way that minimum power was consumed in the entire path.

For example, suppose, sensor node four (4) is to transmit sensed information to the base station, it can send the data via different Gateway nodes. Now, it has to choose the best route such that the energy consumed is the minimum. This situation is simulated by inputting the source node and finding the energy consumed by all the possible routes and the minimum energy path is chosen for routing the sensed information.

Whenever a situation arose in which more than one path consumed the same minimum power, then, to avoid the conflict, the path that involved minimum number of hops was chosen for routing the sensed information.

In the worst case, there might be a situation in which multiple paths had the same minimum power consumption with the same number of hops to the base station. In such a case, EAOR chose the minimum power path that was encountered first. In this way a sensed phenomenon wasconveyed to the base station with minimum power consumption.

Fig. 3 shows the EAOR algorithm based routing of the sensed information from a sensing node to the base station through one of the available gateway '19' nodes. This routing is shown by dotted lines. This path was the minimum power path to the monitoring station via the gateway node '19'.

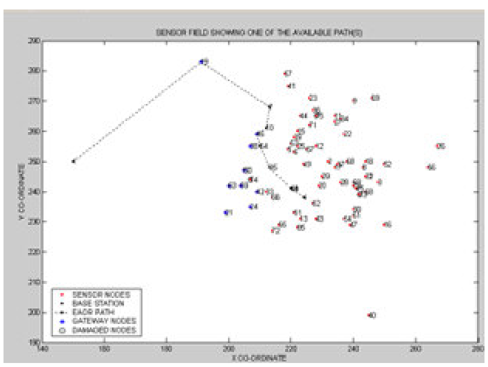

Fig.3: EAOR path 1

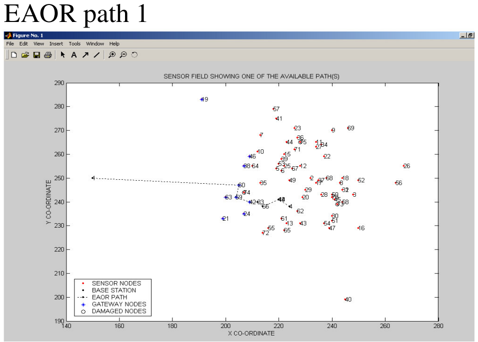

Fig.4: EAOR path 2

Fig. 4 portrays the routing of the sensed information from the same sensing node to the base station via another available gateway node '60' based on the EAOR algorithm.

Since there are 8 gateway nodes, the sensing node wouldl have 6 more minimum power paths to the base station, each via the other gateway nodes namely '42', '59', '21', '63', '64', '74' (Appendix I). The power consumed and the number of hops in each of the eight available paths using EAOR algorithm is tabulated in Table 1. It is seen that the 8th path (i.e. path via the gateway node 74) consumes minimum power (1.96mW) with 11 hops and so this path is chosen as the optimum path by the EAOR algorithm.

Table 1: Total Power consumed and number of hops (EAOR)

Path via Gateway Node	Power Consumed (mW)	Number of Hops
19	3.76	13
21	4.46	17
42	2.09	12
59	2.47	13
60	2.22	13
63	2.92	12
64	2.26	14
74	1.96	11

Table 2: Total Power consumed and number of Hops (Shortest Path algorithm)

Path via Gateway Node	Power consumed (mW)	Number of hops
19	4.90	12
21	6.56	14
42	2.76	10
59	3.72	12
60	3.32	11
63	4.06	11
64	3.14	10
74	3.00	8

Table 3: Comparison of power consumed using EAOR and Shortest path Algorithm.

Path via Gateway Node	Power consumed using shortest Path algorithm (mw)	Power consumed using eaor algorithm (mw)	% saving of power when eaor is used
19	4.90	3.76	23.26
21	6.56	4.46	32.01
42	2.76	2.09	22.82
59	3.72	2.47	33.60
60	3.32	2.22	33.13
63	4.06	2.92	28.07
64	3.14	2.26	28.02
74	3.00	1.96	34.66

For the same scenario, when shortest path algorithm was used, the power consumed and the number of hops in each of the 8 available paths were found out and are tabulated in Table 2. Table 3 shows the power saving in percentage when EAOR algorithm was used instead of shortest path algorithm. It is clear from the tables that the proposed EAOR algorithm performed better in terms of power management.

CONCLUSION

Power management is the prime concern of WSNs and is of utmost importance for the prolonged life-time of Sensor Networks because of the reliance of sensor nodes on batteries and other exhaustible means of energy. When the information is transmitted through a path that consumes minimum power, the sensor node life is increased. To increase the lifetime of a sensor node, an optimum route, which consumed minimum power was determined using EAOR algorithm. The proposed EAOR algorithm was compared with the shortest path routing algorithm and it was observed that EAOR algorithm performed better in terms of power consumption. The same is evident from table 3. By using EAOR algorithm it could be ensured that the WSN can be sustained for a longer time.

EAOR algorithm has been analyzed extensively by increasing the number of gateway nodes and sensor nodes and it was found to perform better. The results were so encouraging that the proposed method determined the optimum route that consumed minimum power for the entire process.

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