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Multi Criteria Routing in Wireless Sensor Network using Weighted Product Model and Relative Rating

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***Abstract*—Nowadays WSNs are expected to be an integral part of the extensive computing environment. But because of limited resource of the sensor nodes, it requires to manage an ever-increasing need for efficient energy and resource management for both the sensor nodes as well as the overall sensor network. In sensor network, to provide the energy efficiency across all the sensor nodes, finding of efficient route is very important. Our algorithm proposes an efficient and multi-hop routing algorithm which is able to choose an efficient route between available routes by considering multiple important criteria for taking routing decision and at the same time to provide balanced energy consumption across all the sensor nodes.**

***Keywords*—WSN, Routing, Multi criteria decision analysis, Relative Rating.**

I. Introduction

Wireless sensor network is a self-organizing wireless network system which enables densely deployment of nodes. WSN is a prominent technology in collecting data from remote locations by interacting with the physical phenomena and depend on the collaborative effort by huge numbers of low cost sensor nodes [1].

These sensor nodes collect, process and send the data to a base station. Basically these sensor nodes gather the environmental data. These data are collected and routed to the destination via other intermediate nodes. The data packets are received and passed from the data source to the base station. In case of multi-hop, route finding is the key support for network transmission technology. In a WSN, an efficient routing algorithm is very important. But the realization of the same is not so easy because of many routing parameters of the network and the limited resources of the sensor node. The various constraints of the WSNs lead to set optimization problem in designing energy-efficient routing algorithms. There are some routing protocols in WSN which select the next hop by considering only one criterion i.e. either energy [2], [3] or distance [4]. But they cannot balance the energy consumption. Thus, for most of the existing routing algorithms, next hop is selected randomly or based on residual energy, node density or distance from the sink node. If next hop is selected based on residual energy, other important performance metrics may be from the sink node compared to other neighboring nodes. In this case end-to-end delay will increase as the path length (i.e. hop count) increases. Similarly, if next hop node is selected based on the shortest path (i.e. minimum hop count), then similar type of problem arises. A node near to sink node, but with low residual energy may get selected as the next hop. Hence single criterion does not always provide efficient routing decisions. So an ideal next hop selection is made based on the multiple criteria. Handling of multiple criteria to select the next hop is solved by multi-criteria decision analysis method [5].

In this paper, an algorithm is proposed which maintains balanced energy consumption among the nodes with consideration of minimum hop count using multiple criteria together. The multi criteria decision analysis (MCDA) method is used to solve decision problems with multiple criteria. In our proposed scheme, Weighted Product Model (WPM) is applied for solving the routing decision making problem. To dynamically assign the weight on every criterion, this proposed scheme considers Relative Rating method.

Rest of the paper is organized as follows. In Section II, weighted product model is discussed. Subsequently, routing scheme using a multi criteria decision model is proposed in Section III and calculation of weights is discussed in Section IV. The implementation effort on TinyOS is briefed in Section V and evaluation of the scheme is presented in Section VI. In Section VII, related work is discussed. Finally, we conclude the paper with a direction for future work in Section VIII.

II. Multi-criteria Decision Analysis

Multi criteria decision analysis (MCDA) is a set of techniques as well as an approach of *Operations Research* [6]. It is also referred as multi-criteria decision making (MCDM). Here the decisions are made by considering multiple criteria, instead of considering only a single criterion. Criteria may be classified into *(i) benefit criteria* and *(ii) cost criteria*. A criterion is assumed to be *benefit criterion* when the higher the values are, the better it is. But a *cost criterion* is one which is better when its values are lower. Main aim of this MCDA is, to form an overall ordering of available options. The options are ordered from the most preferred to the least preferred. No option is there which achieves the entire objective. So the options are ordered from the best to the worst based on the number of achieving objectives.

A. Weighted product model (WPM)

The weighted product model (WPM) is a popular multi-criteria decision analysis (MCDA) method [7]. In the proposed

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	C_1	C_2	C_3
Alts.	w_1	w_2	w_3
A_1	x_{11}	x_{12}	x_{13}
A_2	x_{21}	x_{22}	x_{23}
A_3	x_{31}	x_{32}	x_{33}

Fig. 1. Decision Matrix

routing scheme, this method is used for solving the decision problem. Instead of addition, this method uses multiplication to rank the alternatives. Each alternative is compared with others by multiplying a number of ratios, one for each criterion. Each ratio is raised to the power equivalent to the relative weight of the corresponding criterion. Basically in order to compare two alternatives by using WPM, following calculation has to be done.

Suppose there are *n* number of criteria and *m* number of alternatives or options. Each alternative is denoted by A_1, A_2 and so on. Furthermore, let us assume that all the criteria are benefit criteria. Next suppose that w_j denotes the relative weight of importance of the criterion C_j and a_{ij} is the performance value of alternative A_i when it is evaluated in terms of criterion C_j. For cost criteria, relative weight is denoted by (-w_j). Thus we calculate a ratio as follows:

$$P(A_K/A_L) = \Pi_{j=1}^{n}(a_K j/a_L j)^{w_j}, \tag{1}$$

$where\ K \neq L\ and\ K, L = 1, 2, 3....m$

If the ratio $P(A_K/A_L)$ is greater than or equal to the value 1, then it is concluded that A_K is more desirable than A_L .

The WPM may be illustrated in the following decision matrix in Figure 1. In this matrix, there are three alternatives (A_1,A_2,A_3) and three criteria (C_1, C_2, C_3). These criteria are assigned with three different weights (w_1, w_2, w_3). x_{11} to x_{33} are different values.

For example, if using the above decision matrix, $P(A_1/A_2)$ and $P(A_2/A_3)$ are calculated as follows:

$$P(A_1/A_2) = (x_{11}/x_{21})^{w_1} \times (x_{12}/x_{22})^{w_2} \times (x_{13}/x_{23})^{w_3} > 1 \tag{2}$$

$$P(A_2/A_3) = (x_{21}/x_{31})^{w_1} \times (x_{22}/x_{32})^{w_2} \times (x_{23}/x_{33})^{w_3} > 1 \tag{3}$$

then the ranking index is: $A_1 > A_2 > A_3$

1) Advantage of WPM : : In the proposed routing scheme, weighted product model is used for selecting best alternative because:

- WPM can be used in multi-dimensional decision process, as it is dimensionless. Here three different criteria are considered. Each of the criterion has different dimension. Thus, WPM is appropriate to combine these values.
- It can accommodate benefit criteria as well as cost criteria simultaneously during decision making.

III. Proposed Routing Scheme

In this scheme, it is assumed that deployment of the sensor nodes are random and static. All the nodes know the position

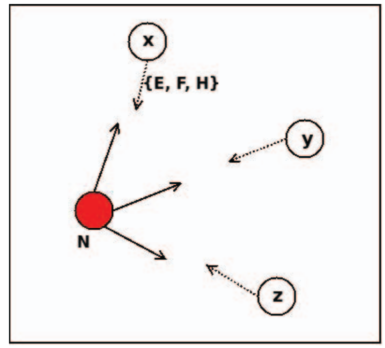

Fig. 2. A scenario for routing

of the sink node. Every node is capable of receiving and then forwarding the data to the next hop node until the data reaches its desired destination.

A scenario is presented in Figure 2, where a routing scheme is required to be applied. Node N has to select one of its neighbor nodes **x, y, z** as next hop node in order to forward the data towards destination ie. sink node.

As discussed earlier, selection of the next hop node based on one single criterion may actually hamper the performance of the network. So, a routing scheme is presented which implements WPM model of MCDA based on three criteria. We have considered three different criteria i.e. residual energy, frequency of packet transmission and hop count to determine the product value applying WPM. Here, first one is the benefit criterion and other two are cost criteria. One particular node cannot always remain the next hop node. Next hop node is changed dynamically based on this product value. It implies that dissipation of battery power is balanced across various nodes. Thus, network lifetime is enhanced in this proposed algorithm. A neighbor table is maintained by every node. It contains following four fields :*(i) Neighbor node, (ii) Residual energy, (iii) Frequency, (iv) Hop count*. Information in the neighbor table is used to make the routing decision. Here, the routing decision depends on the above said multiple parameters or criteria. The following few steps are taken to make routing decision.

Step 1: WPM is applied for each neighbor available in the *neighbor table* of node N. For each neighbor node, index value or product value $P(A_i)$ is calculated using WPM. The three parameters or criteria for each of the neighbor nodes are taken into consideration while doing the calculation. The three criteria are residual energy (*E*), frequency of packet transmission (*F*) and hop count from sink node (*H*). These three criteria are assigned with weights w_1, w_2 and w_3 respectively. Thus, the product value of each neighbor may be calculated as :

$$P(A_i) = (E)^{w_1} \times (F)^{w_2} \times (H)^{w_3} \tag{4}$$

Step 2: Now the product values of the neighbor nodes are compared. The node with highest product value $P(A_i^*)$ is selected as the next hop node.

Step 3: Source node forwards the data packet to the selected next hop node.

Section IV describes the calculation of weights (w_1, w_2 and w_3) for different criteria .

IV. Calculation of Weights

In this proposed routing algorithm, weights are not assigned arbitarily. Instead weights are assigned based on the requirement of particular application. *Relative Rating* method is applied to assign the weighted value on each criterion .

A. Relative Rating

In MCDA, several methods are used to assign the weight on multiple decision criteria. Among these methods, relative rating is the simplest one. In relative rating method, the decision criteria are ordered according to a rating value. Because practically it is not possible for a single decision maker to assign a numerical weight for multiple decision criteria. So in this method the weight of every criterion is calculated based on the rating value of the criterion as the decision maker is more comfortable to arrange the multi criteria based on rating order.

This method is used to compare the different decision criteria during assignment of the rating of each criterion. Here the highest weight is given to the first-rating criterion and vice-versa. That means this method is a combination of weight-rating relation.

Here rating depends on how our objective performance has been improved. As our proposed scheme considers three different criteria i.e. Residual energy, frequency and hop count. Among these, Residual energy is the benefit criteria that means more residual energy is preferred and frequency and hop count are the cost criteria that means low value of these criteria are preferred. The properties of this cost and benefit criteria improves the network performance : (i) minimum hop count ensures minimum delay, (ii) minimum frequency ensures minimum energy consumption and (iii) maximum residual energy increases network lifetime.

Our proposed algorithm considers Relative Rating method because this method rating the criteria based on the properties of the cost and benefit criteria, which improves the network performance.

B. Derivation of weight from rating value

In our proposed scheme obtaining the rating value of each criterion is application specific. Each criterion is rated relative to the others in satisfying a particular interest and arranged accordingly. The three criteria is rated 1, 2, 3 depending on which satisfy the interest: the best is 1, second best is 2 and third best is 3. Different weights are pre-defined for each of the rank. An example of rating-weight mapping may be like Table I. The mapping is defined by decision maker according to requirement of a particular application. For example, here the rating of the criteria may vary depending on the network deployment i.e. Dense deployment and sparse deployment.

TABLE I. Rating & Weight mapping

Rating	Weights
1	0.5
2	0.3
3	0.2

1) Dense deployment: In dense deployment a huge number of sensor nodes are deployed per unit area. That means one sensor node can have many number of neighbour nodes. So it will not be the best solution to choose the next hop node by giving the best priority to residual energy or frequency. As nodes are very congested so almost the energy resource is very high per each node. So we cannot separate a few nodes based on the residual energy. Frequency number may vary per each node but this change is very small so we can separate less number of nodes based on the frequency compare to the energy. But frequency is not given as the best crietrion because in the case of dense deployment the topology generally shows the uniform distribution; so only a few numbers of nodes have the different hop count and this number is less than others. So hop count is considered as the best. Frequency criterion has been given the second best priority as many numbers of node can have approximately the same residual energy.

So, in dense deployment the criterion may be ranked as hop count is best, frequency is second best and residual energy is the third best.

2) Sparse deployment: In sparse deployment very small numbers of node are deployed per unit area. That means each sensor node can have very small number of neighbour nodes. Total energy resource is not so much with compared to the dense deployment so considering energy resource is the highest priority. As energy is the important property of the sensor node. As here energy resource is considered as the best criterion then we have considered frequency is the second best criterion because after assigning the first priority we have to check which node has the highest residual energy after receiving the highest number of packets.

Here, the criteria may be ordered as energy is best, frequency is second best and hop count is third best.

V. Implementation

Open-source TinyOS[8] and TelosB motes[9] from Crossbow are used in order to test applicability and study the proposed routing scheme. As packet sniffing tool, we have installed Wireshark on Ubuntu. The routing scheme is installed on all the nodes which are deployed in such a manner so that multi-hop communication may achieve. 10 nodes are deployed apart from the sink node.

In this proposed scheme, residual energy is calculated on real-time. No static mathematical derivation or model is followed for this calculation. Every time to calculate the residual energy, we have called an event, voltage.readDone() in nesC language. A counter value is incremented after each packet transmission to keep track of the packet frequency. Hop count is retrieved from the HopsLeft field during the neighbor discovery.

VI. Results and Discussion

In this section, evaluation of this proposed routing algorithm is presented. Results in terms of residual energy and delay, are discussed.

A. Residual energy

Residual energy represents the remaining battery power of each intermediate node. It is fetched from the nodes in real time. Intially, each node contains 3000 mV. 12 observations are performed for each node starting from node initiation. Very small amount of energy is consumed for each packet transmission. So, residual energy value is measured after transmitting 10 packets during each observation.

It can be observed from Figure 3, that residual energy in each node is gradually decreasing during packet transmission. But it is more important that all the nodes consume almost equal amount of energy. It happens because the packet loads are distributed across all the nodes. So, it may be concluded that this method ensures balanced energy consumption which consequently increases network lifetime.

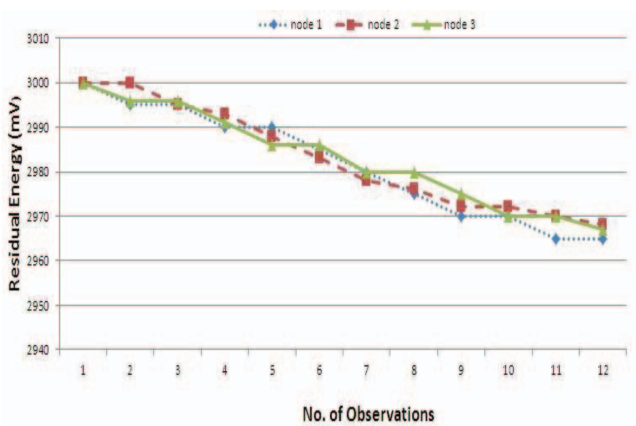

Fig. 3. Residual energy of intermediate nodes

B. Delay

Also end-to-end delay is measured from the source node to the destination node. In TinyOS, *Timestamps* are appended on the packets by the source node as well as the destination node. The delay is determined by considering the difference between these two *timestamps*. Alternatively, Wireshark may be used as a tool for delay calculation. To measure the delay, 11 observations are performed. In each observation, a packet is transmitted through multiple hops. Figure 4 represents the delay from the source to the sink node through multiple hops. In all the observations, delay is around 1 second which may be termed as very good performance.

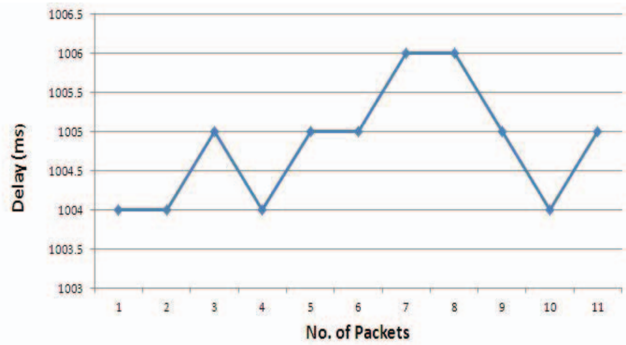

Fig. 4. Delay from source to destination through multiple hops

VII. Related Work

In this section, few research works are presented which have been carried out earlier in similar areas. In [10], a fast and reliable protocol is proposed for wireless sensor networks for critical condition monitoring applications. Here the next hop node is selected in every hop based on the hop count. In [11], the next hop node is selected based on the three parameters i.e. distance, angle between two nodes and residual energy. Here fuzzy logic reference system is applied to select the best alternative. The paper represents an algorithm which is developed to tackle the under-water problems like low communication bandwidth, large propagation delay, floating node mobility and high error probability. In [12], the next node is selected based on the three parameters serially, that means first some nodes are selected based on the highest prioritized metric, then the second prioritized metric and lastly lowest prioritized metric. All these papers use conventional methods for proposing routing algorithms.

Although many applications of multi criteria decision analysis (MCDA) are found in various other areas, to the best of our knowledge little application of this method has been made in the area of WSN routing. In [13], MCDA is applied in Geographical Information System (GIS) to overcome the limitation of GIS to make accurate spatial and policy decisions. Also, MCDA has found its application in content delivery networks [14]. In [15], an attempt is made for a routing scheme using multiple criteria but the various weights are set static. Still, reasons behind the particular weights are not explained.

In the present paper, we explored the implementation of a multiple criteria-based routing using Relative Rating method in weighted product model.

VIII. Conclusion

In this paper, a WSN routing algorithm is proposed using multi criteria decision analysis. The next hop is selected based on weighted product model and the weights are calculated using relative rating method. In this method weight assignment for each criterion based on the rating value is application specific. Different weights are pre-defined for each of the rating. Pre-defined weight assignment is fully dependent on the user. The multi-criteria include residual energy, packet transmission frequency and hop count. The main goal of this algorithm is to provide balanced energy consumption accross all the sensor nodes with minimum delay.

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