Optimized Forwarding for Wireless Sensor Networks by Fuzzy Inference System

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Abstract

For the flat wireless sensor networks, we investigate the optimization problem of the routing path based on the metrics: distance, power and link usage to maximize the lifetime of the sensor networks. We employ the well known fuzzy inference systems (FIS) for the selection of the best node, from the candidate nodes, in order to forward packet to the sink. Simulation results show that network lifetime can be improved by employing the optimized routing protocol.

1. Introduction

Wireless sensor network (WSN) is composed of cheap and tiny unreliable sensors with limited resources, where the sensors possess sensing, computing and communicating capabilities [1]. Due to the advancement of the micro electro mechanical system (MEMS) technology and sensor networks prospective diversified applications (such as home automation, industrial monitoring, military, environmental and many more) WSN is expecting a huge growth in near future and also experiencing an intense research interest.

Sensor networks are generally considered as composed of randomly and densely deployed large number of nodes. Based on the underlying network structure WSN can be flat or hierarchical. In the flat networks all the sensor nodes perform the same functions, on the other hand in the hierarchical networks the higher energy nodes known as cluster heads maintain the cluster, aggregate data from the non-cluster head sensor node and transmit the conglomerated data to the sink.

Depending on how source finds a route to the destination, routing protocols in sensor networks could be either proactive or reactive. In proactive routing, routes are computed before they are needed; on the other hand a reactive routing calculates the route only when it is needed.

The design constituent of the routing protocol depends mainly on the application because of the application's traffic demand and pattern may vary enormously. Power consumption, mobility, scalability and QoS are the other most significant issues in designing routing protocols in WSN.

Today's main challenge for the designers and developers of protocols and applications for WSN is the resource scarcity of nodes, most importantly its power availability, since in sensor networks the battery life is considered as the network life.

To extend the sensor network lifetime, we utilize the fuzzy inference system (FIS) that optimizes the routing path (depending on the metrics: distance, remaining battery power and link usage) in a distributed fashion.

The remaining paper is organized as follows. Section II, describes some related works considers the metrics: distance, energy and load distribution. Section III states the problem statement. In section IV, we present our protocol, its advantages and drawbacks. In Section V, we present our simulation results and finally in Section VI, the key conclusions and the future works are stated.

2. Background

A number of protocols have been proposed in the area of sensor routing. Reference [2] proposes low energy adaptive clustering hierarchy (LEACH) a cluster based hierarchical network routing protocol, where the sensor nodes transmit to the cluster head directly. Cluster heads then transmit the data to the sink. In [3], authors propose a variant of hierarchical algorithm where, the sensor nodes forward the data by several hops, optimized by the Dijkstra's [4] algorithm.

Reference [5] stochastically distributes the load by choosing a random node from the forwarding path. Alternatively, [6] proposes the algorithm where a probability is assign to each node for load distribution. Here, the probability is inversely proportional to the cost function of the particular path and the data is forwarded based on the designated probability. Reference [7] proposes a protocol that combines both stochastic and cost based schemes introduces in [5] and [6].

Reference [8] proposes the routing protocol that selects the highest energy node from the forwarding table to forward data.

In an improved version of LEACH, a recent paper proposes, hierarchical battery aware routing (H-BAR) [9]. Protocol selects the highest battery powered node as the CH. H-BAR shows a favorable improvement in the performance. Reference [10] proposes geographical multipath routing protocol (GMR) based on the location information. In [11], energy and mobility is considered in addition to GMR. They optimize all the metrics by FIS for their improved routing protocol, energy and mobility aware geographic routing protocol (EM-GMR).

3. Problem Statement

From the aforementioned literatures we find some very simple criterion to lengthen the lifetime of the sensor networks. These include:

- Small multiple hops: As the energy consumed for the transmission is proportional to the square of the distance from sender to receiver, multiple short hops is preferable instead of a single large hop.
- Shortest path: Shortest path from the sender to receiver is the straight line connecting the nodes. Forwarding packets along this line is more efficient than a detour.
- Load distribution: In case, concentration of events in some particular areas is more than that of other areas, using shortest path will cause implosion along the path. So uniform distribution of traffic is needed.
- Highest remaining energy: Nodes having greater remaining energy participates more than the nodes having small amount of power can extent the network lifetime.

This paper presents a solution that optimizes the routing path according to all the abovementioned criteria by a single distributed algorithm.

4. Proposed Routing Protocol

4.1. Assumptions

The proposed protocol assumes that the nodes can access their own battery level and transmit power can be adjusted depending on the distance of the destination. Protocol also assumes that the sensors know their location information. Sensors shipped with the GPS receivers, can readily sense its location information. Alternatively, location information can also be acquired through a localization algorithm. In fact location information is important when an event occurs. Most of the applications will probably need the information to monitor an interested area, at least in a course grain. So, this is very much justifiable to infer that location information is available to the nodes. Localization itself is an ongoing area of research and is not within the scope of our research.

4.2. Goals

Our main objective of designing the protocol is to find an optimal path from the available metrics; shortest path, minimum distance, battery usage and number of packets forwarded previously by the same link. Optimizing the path will result in maximizing the life of the network.

4.3. Protocol Operation

Nodes collect the routing metrics through the localization algorithms, accessing their own battery level and keeping track of the link usage.

The protocol has the potential to be implemented in both the reactive and proactive manner. In reactive routing, when a node needs to transfer data it generates routing query and asks for its single hop neighbor's information, in order to calculate the routing path. On the other hand, proactive routing, updates the neighboring nodes by periodical broadcasting.

When a data is needed to be sent the protocol selects the optimal path through the FIS. Finally, it adjust the transmit power according to the distance of the receiver node and forward the data. By using the FIS [12] we can integrate the different types of metrics (distance, battery power and link usages in our case) even when the correlation between the metrics is difficult to model mathematically. Each node can make distributed forwarding decisions. This eliminates the necessity of hierarchical networks.

Fig. 1shows an example network where a source node needs to send a data packet to the destination sink. The shortest path and the radio ranges are shown in the figure too. To eliminate the burden on the FIS algorithm it simply discards some of the nodes as a potential candidate. Light shaded nodes are discarded, as they are not in the forward direction. In this case n_1, n_2 and

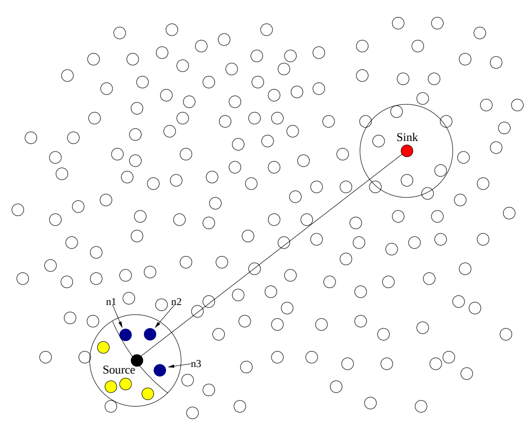

Fig. 1. Sensor Networks.

n_3 are the potential candidates.

4.3.1. Routing Matrices

The routing metrics are shown in the table above. Here, *d* is the distance of candidate nodes from the source, *ds* is the distance of the candidate nodes from the shortest path, while *p* and *l* denote the power and the link usage respectively. Here, all the metrics are assumed to be normalized in order to implement the fuzzy rules.

Table 1: Routing Table.

Node	Distance (*d*)	Distance (*ds*)	Power (*p*)	Link Usage (*l*)
n_1	d_1	ds_1	p_1	l_1
n_2	d_2	ds_2	p_2	l_2
n_3	d_3	ds_3	p_3	l_3

4.3.2. Optimum Selection by Fuzzy Logic in our case

The first step of designing fuzzy optimization requires characterizing the membership function (MF), which gives the input output relations. MFs are different for the different metrics. The input parameters are the routing metrics (x-axis) with respect to the corresponding cost (y-axis) of the MF and the outputs are projected to form the trapezoids as shown in figure 2(a-d). For a particular node all different trapezoids are added up and finally finding the centroid makes decision. We will see the algorithm step by step for the case of WSN routing.

4.3.3.Membership functions (Costs)

A. Distance from the node: As the power is proportional to the square of the distance, in case of the first order radio model, the MF of the distance (from the node) is the curve as shown in Fig. 2(a). The distances d_1, d_2 *and* d_3 are the inputs of the MF (Fig. 2(a)). Let, $d_1 < d_3 < d_2$. Outputs, the projected trapezoids are the weights for the corresponding nodes. The height of the trapezoids for the i^{th} node are defined as $hd_i = k_{dist}.d_i^2$ .... (1) where k_{dist} is a constant for all values of $d_i = 0....1$.

B. Distance from the shortest path: The MF, in this case, is the same as the previous one because it is also a distance. Inputs $ds_3 < ds_2 < ds_1$. The outputs are the corresponding trapezoids (Fig. 2(b)). Similarly as equation (1) the heights are given as $hds_i = k_{dist}.ds_i^2$ for $d_i = 0....1$.

C. Battery Used: For the battery usage the MF is set in such a way that, up to 30% there is little effect of the usage. When the usage goes higher 30%-70% it shows moderate resistance to forwarding. But when it is at 70%-100% it shows the highest resistance to forwarding a packet. Let, $p_3 < p_2 < p_1$. Therefore,

$$hp_i = \begin{cases} 0.333.k_{power}.p_i \\ 0.75.k_{power}.p_i \\ 2.k_{power}.p_i - 1 \end{cases} if \begin{cases} 0 < p_i <= 0.3 \\ 0.3 < p_i <= 0.7 \\ 0.7 < p_i <= 1 \end{cases}$$

where hp_i and k_{power} are the height of the i^{th} node and the co-efficient respectively (derived from the Fig 2(c)).

D. Link Usage: We use a linear function as a link usage MF. The more the path is used the more it becomes reluctant to forward the packet. Here we assume $l_2 < l_1 < l_3$. The heights become $hl_i = k_{link}.l_i$ where k_{link} is the corresponding coefficient.

Decision (based on A, B, C & D): All the four types of outputs are added and the weighted average is taken (black circles in Fig. 2(e)). The area of the trapezoids, are calculated by the following expressions.

$$A_{i,j} = \frac{(1-(1-h_{i,j})^2)}{2}$$

where *A* denotes the area of the trapezoid and *j* is the j^{th} membership function. In this case $j = 1,2,3,4$. As the total number of parameter considered is 4. Therefore, the weighted averages are calculated as.

$$Av_i = \frac{\sum_{j=1}^{4} A_{i,j}}{4}$$

Let Av_1, Av_2 and Av_3 be the respective weighted average of the nodes *n1, n2 and n3*. As, $Av_1 > Av_2 > Av_3$, n_3 is the optimal node that the source will forward to due to its minimum cost.

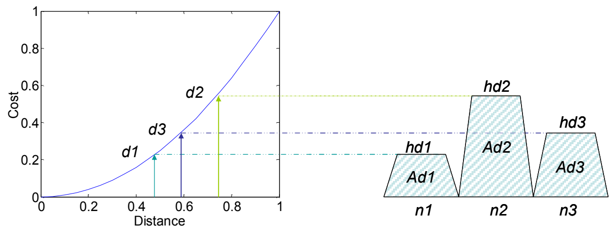

Fig. 2(a) Membership Function (Distance from the Node).

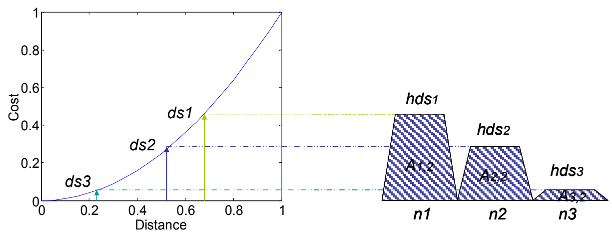

Fig. 2(b) Membership Function (Distance form the Shortest Path).

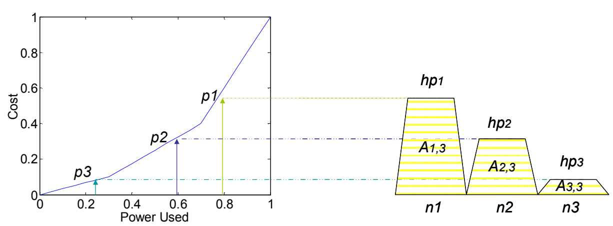

Fig. 2(c) Membership Function (Power).

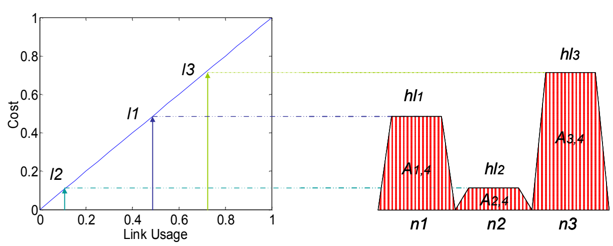

Fig. 2(d) Membership Function (Link).

4.4. Discussion

4.4.1. Protocol Advantages

- As sensor networks could be composed of a large number of sensors, it is not desirable that sensor networks will have a global addressing scheme because of its huge maintenance overhead. Our protocol does not need to maintain the ID, hence the cost of global addressing mechanism is saved and makes the network scalable.

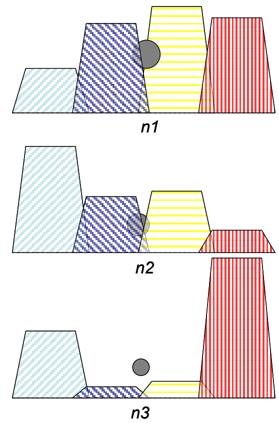

Fig. 2(e) Weighted Average.

- Nodes need to maintain a small table because it needs only to maintain the cost metrics for the neighboring nodes. Thereby, the protocol saves the storage cost to store the routing table. It also saves communication cost such as transmit-receive energy and bandwidth.
- In case of reactive implementation the protocol is fast in responding to the network dynamics because of its minimum discovery overhead.
- Optimal selection of the node saves data transfer cost. Transmission energy is considered the primary consumer of the energy usage for wireless sensor networks.
- Nodes having more remaining energy contribute more to the forwarding of packets.
- The protocol is fair as it distributes the workload of forwarding data evenly.
- For the cluster based sensor networks, the failure of a cluster head may cause the whole cluster to become non- operational. Moreover, for maintaining the clusters, (selection or election of the cluster heads, and nodes joining to the clusters) requires control message exchange. This overhead may be considered as an extra burden to the resource critical sensor nodes. By using a flat architecture this protocol eliminates both the aforementioned issues.

4.4.2. Limitations

- *Failure reaching the sink:* The protocol will fail to converge in the presence of voids or dead ends even when there exists a routing path through farther nodes. The solution to the failure is to locally flood the network to find a path. In the worst case scenario, when the local flooding also fails then flooding the whole network becomes an option. Perimeter routing [13] can also be used where message traverse through the face of intersecting line between source and destination thereby guiding the packets out of the local minima.

- *Processing cost:* To run the fuzzy algorithm instructions, nodes require some amount of battery power because of the algorithm complexity. However, the processor within the sensor node consumes significantly less energy than the transmitter. The amount of power requires to transmit 1-bit to 100m distance is equivalent to the amount of power requires to run millions of instructions [1]. The protocol exploits the relation and uses it favorably i.e. uses calculation to optimize transmission

5. Performance Evaluation

To evaluate the performance of the protocol, we simulate the protocol in MATLAB. We apply the same radio model introduced in [2] and used by several papers [9]. In this radio model, the transmission and receive cost is defined as $EnT(k) = Elec.k + Eamp.k.d^2$ and $EnR(k) = Elec.k$ respectively, where, *k* is the number of bit per packet, *d* is the distance, *Elec* and *Eamp* are 50*nj/bit* and 100*pj/bit/m^2* respectively.

For the simulation, we randomly deploy 100 static sensor nodes in 100*m* x 100*m* field, with the sensors transmitting over a radius of 20m (Fig.3). The sink is moving randomly as shown in Fig. 4. Each sensor generates packet randomly, checks whether the sink is within its direct radio range. If yes, the node directly transmits the data to the sink otherwise via the intermediate nodes according to the proposed protocol.

The network will become partitioned and communications will degrade drastically when too many nodes die. For the reason we only evaluate the first 32 deaths. We observe the performance of the optimizations using different combinations of the metric parameters. As shown in Fig. 5 the highest performance is found when all the four metrics are considered and optimized.

In real world, the generating packets could be non-uniform. We expect that the protocol will perform even better is such a case.

6. Conclusions

Motivated by the sensor lifetime elongation problem, we optimized the distances, energy and link usage to disseminate data for a static sensor bed where the only mobile entity is the sink. Simulation results show that the networks lifetime could be extended by the scheme.

In this work we only investigated the evenly distributed traffic pattern. We will extend our work to include hot spots in the networks. We also intend to integrate mobility as an additional metric in the routing protocol for mobile sensors.

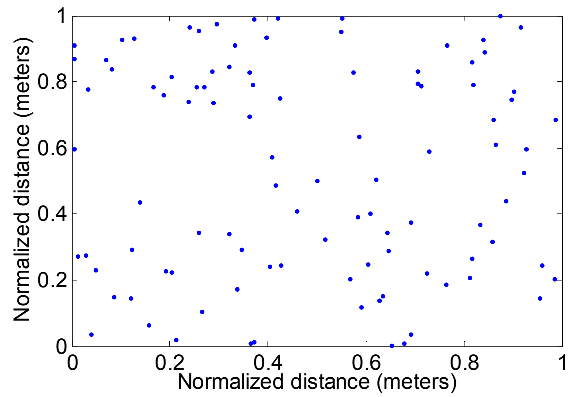

Fig. 3. Randomly deployed Sensor Nodes.

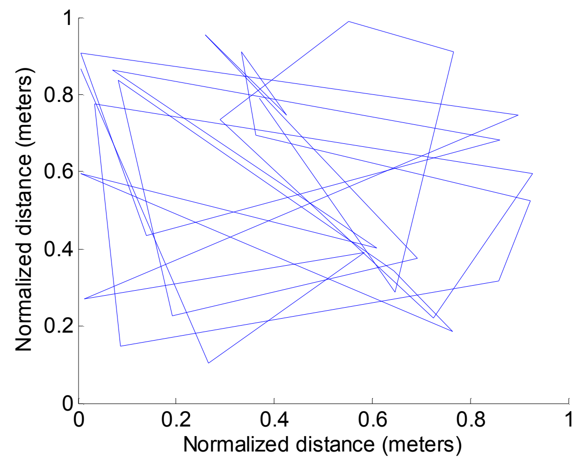

Fig. 4. Sink Mobility Model.

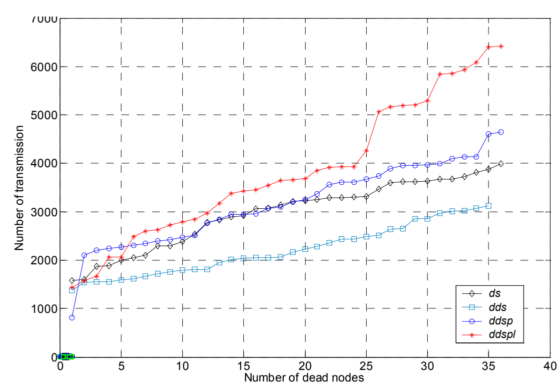

Fig. 5. Performance (Number of Transmission vs. dead nodes).

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