EBRP: Energy Band based Routing Protocol for Wireless Sensor Networks

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Abstract

Distributed sensor networks are large-scale, autonomous resource constrained systems used for gathering data in an intelligent manner. We study the concept of energy fairness in routing in Sensor Networks so as to increase the network lifetime. Our model aims to construct a nearly stateless routing protocol, which can be used to route data based on the residual energy of the nodes. This algorithm divides the network into different energy bands and then constructs routing paths. This type of architecture is novel and more suitable to wireless sensor networks that generate a lot of traffic as it achieves nearly uniform load distribution across all the nodes. This model has the advantage of eliminating the bottlenecks in the network, because the nodes will be expending their energies at a constant measured rate. This mechanism has another advantage wherein the paths need not be computed every time the data is sent. Simulations show that our model achieves fairness and load balancing across the network and increases the lifetime considerably.

1. INTRODUCTION

Wireless sensor networks, consists of large number of unattended devices capable of sensing, computation and communication. There has been a considerable amount of research in developing data centric routing in these networks as there is no concept of IP addresses in them. These networks owing to their severe resource constraints have to work in a coordinated manner to conserve the resources.

A typical sensor network has many nodes, which are scattered over a region of interest. The design goal is to make all the sensor nodes sense and gather information in a coordinated manner so as to minimize the energy consumption to increase the network lifetime. We take this fact into consideration and divide the network into energy bands i.e. each node falls into one of the energy bands depending on its residual energy. There is a direct correlation between the residual energy of the node and the band to which it belongs. The nodes with higher energies are in the higher energy bands and the nodes with lower energies fall into the lower energy bands.

Our protocol works well in networks with all kinds of data rates, as there is uniformity in the load distribution. The communication costs are really low as the protocol floods the network twice in the initial stages and then there is no need for any control packets after this. There is no need to exchange control packets or update the state of the network whenever data has to be routed from source to the destination. The process of flooding the network is repeated only when the network has achieved uniform state of energy distribution to recalculate the energy bands. This happens when most of the nodes in the network have similar energies.

The advantage of our model is the nearly stateless and highly localized approach to routing. This approach results in a network without bottlenecks as the load on each node is uniformly distributed in the entire network. Our model excels in protecting the weaker nodes and the level of protection offered to each node is inversely proportional to the energy level to which the node belongs. The protocol offers more protection to the weaker nodes thereby increasing their lifetime and in turn maximizing the network lifetime.

The fairness achieved by this protocol is very high as the low energy nodes are offered maximal protection. We measure the fairness in terms of energy distribution across the network and our simulation results show that the fairness is very close to being optimal in a network that handles a lot of traffic.

In essence our model stratifies the network into energy bands and routes data from the lower energy bands to the higher energy bands so that the traffic handled by the node is directly proportional to its energy band. Finally, this model could also be used to aggregate data along the path. The advantage of such a scheme is that the nodes belonging to the higher energy bands can handle less traffic as the data is aggregated along the path. Our paper has 5 sections. The section 2 discusses the related research in this field. Section 3 describes the model and its advantages. The section 4 is dedicated to the simulation parameters and results. Finally section 5 concludes the contributions of this paper.

2. RELATED WORK

There are many approaches to routing in sensor networks and most of them fall into four basic categories viz., stateless flat routing , hierarchical routing, geographic routing , energy aware routing. All the protocols use differernt global and local parameters to minimize the energy consumption in the network. Many of these schemes take either energy or disatnce as a parameter for routing. We believe that taking energy and distance into consideration will help to reduce the overall energy consumption. For example, [1] uses the concepts of clustering in sensor networks and then it takes the energy and distance as two parameters to come up with shortest paths.

The flat routing schemes do not have the concept of leader nodes and all the nodes in the network are peers. The routing in such schemes have pararmeters such as energy or distance. For example, [2] and [3] use totally localized statless routing schemes where the nodes flood the packets blindly to their neighbors. These protocols are robust but the traffic in the network is high as there is a lot of flooding involved.

Hierarchical routing deals with clusters and cluster heads for example, LEACH [4] and PEGASIS [5]. These schemes divide the network into regions and then route the traffic from one region to the other. Regions can be clusters as in [4] or can be in the form of zones as in the case of adhoc routing schemes. There are some protocols like GEAR [6] and GPSR [7] which try to minimize the energy consumed by taking energy and distance into consideration.

Geographic routing schemes use location information and the decisions can be local or global in nature depending on the specifics of the protocol. Geographic routing of information is used in [6] and [7]. The data is always routed towards the geographic direction of the destination. They are also localized algorithms which use multiple paths to send data from the source to the destination.

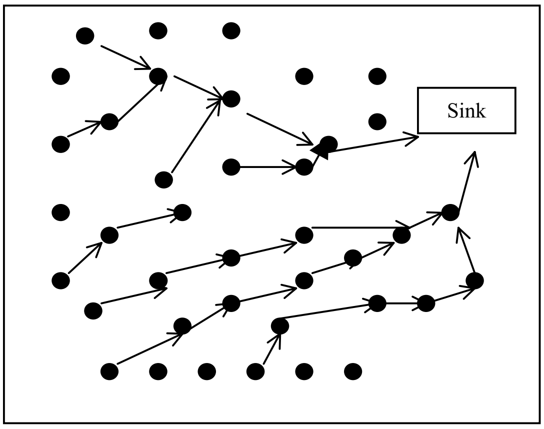

Fig. 1: A normal Sensor Network with flat routing scheme

Fig.1 shows a typical sensor network, where each node forwards data to the nodes closest to the sink using multi hop communication. The actual routing between the nodes depends on local as well as global information. The local information includes the neighbor list where as the global information includes the knowledge of position of sink in the network and the direction of destination. Kannan et. al in [8] have used game theoretic approach to solve the problems involved in routing data in the most energy efficient manner. Most routing protocols use the energy as a parameter to decide the path taken by data like Max-Min Length Energy constrained protocol [9].

Our protocol uses a localized algorithm which runs at the node and each node uses the destination location information. The destination location is the only global parameter each node is expected to maintain. The nodes forward data to those neighbors which are both closer to the destination and are in a higher energy band. The fig. 1 shows a typical sensor network with a sink and different sources of information. The data is routed using multi hop communication along multiple paths to the destination.

3. OUR MODEL

The main design goal is to come up with a routing protocol that can utilize the energies of all the nodes in the network in an intelligent manner so that the network lifetime increases. Network lifetime can be defined as the time it takes for the first node, or a fraction of all the nodes in the network to be depleted of their energies. A good routing protocol always takes maximization of network lifetime as an important metric in the design of the network. As the network lifetime depends on the lower energy nodes it becomes necessary to offer the low energy nodes more protection.

The rates of depletion of energies of all the nodes in the network are not the same because some nodes have to expend more energy due to their location in the network. For example, nodes closer to the base station are in a critical region because they have to forward data continuously, which results in draining their energies much faster than the other nodes. This disparity in energy consumption results in a network, which has a non-uniform energy distribution, where different nodes would have different energies.

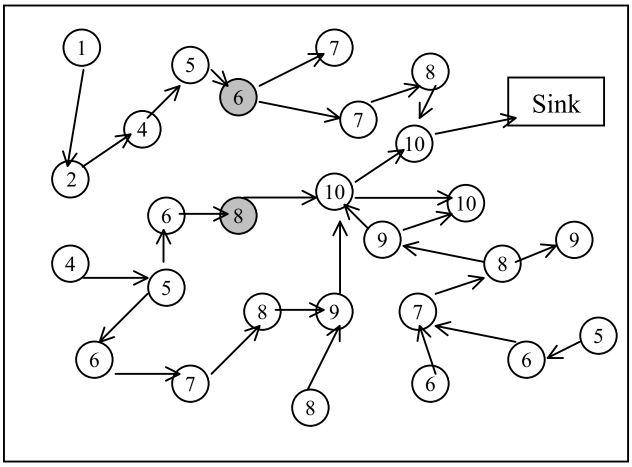

Fig. 2: This is the schematic representation of our model. The numbers represent the energy bands to which the nodes belong

There can be many such energy bands in the network. The nodes, which have the lowest energies, form the leaves of the virtual tree. Once the network is stratified into energy bands we can impose a few constraints and construct a virtual tree structure. The main constraint this tree imposes is that the nodes belonging to a particular energy band and also happen to be in each others vicinity become the nodes at the same level in a tree. These nodes can communicate only with the nodes that are in higher levels in the tree. There could be a periodic reverse communication capability for specific reasons like sending "Distress" signals. But the most interesting aspect is that the nodes on a particular level always communicate with the ones directly above them. The main advantage of this scheme is that the nodes that have less energy are protected from draining their energies while trying to participate in the communication process with the nodes having higher energies.

The first step in forming the tree is that we divide the entire network into energy bands. These bands are ordered based on increasing energies. There can be a unidirectional link between nodes of two different energy bands. The direction of the link is always from the nodes belonging to the lower energy bands to the nodes belonging to the higher energy bands.

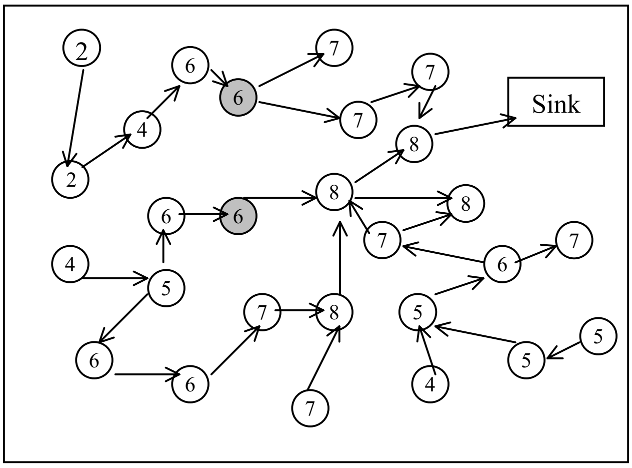

Fig. 3: After some time all the nodes come closer to lower energy bands

A. Energy Band Formation Protocol

Our protocol stratifies network nodes into distinct energy bands using the maximum value of residual energy in the entire network as the initial basis. We assume that nodes have location information of their neighbors and the sink and the energy distribution among nodes is non-uniform. Our protocol has the following steps:

1. All the nodes query each other for their residual energies and each node has the information about the location, node ID and residual energy of its neighbors.
2. All the nodes in the network exchange this information to get the global maximum value of the residual energy.
3. The network is initially divided into $1/\delta$ bands where δ ($0 < \delta < 1$) is an experimental parameter. Let Ei be residual energy of node i. Each node computes its band using $\lceil E_i/(E_{max} * \delta)\rceil$.

The concept of energy bands is illustrated in Fig. 2 and we use the integral values for clarity of expression

B. Energy Band Routing algorithm

We now describe the steps in the routing algorithm used by each node to decide the next hop neighbor for data forwarding. Note that each node already possesses the location and energy band information of its neighboring nodes.

1. If S_i is the set of all the neighbors of a given node i, the next hop neighbor is chosen on the following basis: Let k be the energy band of the given node. Let S_j be the set of neighboring nodes ($S_j \subseteq S_i$), in band k+1which are also closer to the sink than the node i. If there are no nodes in the immediate higher band, similarly find the nodes that are in the next higher band k+2 and so on.
2. If S_j is empty then node i chooses as next-hop, the node(s) in the highest energy bands among its neighbors that are also closer to the sink than itself. If no such node exists (there is a geographic hole at i) then i simply forwards to the highest energy band neighbor.
3. Once the list of nodes to which the data can be forwarded is found then use round robin schedule to forward data. In every round the data is sent to one of the neighbors.
4. If a node goes down in energy it can shift to a lower energy level after updating all its neighbors with its residual energy value by sending a special Distress control signal.
5. When a majority of nodes have gone down below 50% of their initial residual energies we refresh the paths so that the same paths are not used. This has the advantage of saving the higher energy nodes as the step size decreases as the global maximum decreases.

4. SIMULATION RESULTS

We simulated the protocol on SenSim platform [10]. This is a discrete event simulator developed at Louisiana State University for wireless sensor networks, modeled on top of OMNeT++ [11] simulation framework. We tried to compare our protocol with GPSR.

We assume that when the execution of the protocol starts i.e. at the beginning of the simulation there is a non-uniform energy distribution in the network. The nodes are all assigned energies in a random manner so that the simulation can model the actual protocol, as this is the case in our protocol.

We consider a network of 100 nodes distributed randomly on a 40 X 40 grid with each node getting a random initial energy value. The nodes have a fixed transmission range and it cannot be changed during the simulation. Each node keeps the location and initial residual energy information of all its neighbors. The neighbor list is updated by keeping information about the neighboring nodes that are in the higher energy bands and removing the information about the nodes in the lower energy bands. Each node has a neighbor list and hence it can forward data to the destination based on the neighbor list. The neighbor list is updated after the entire network achieves uniform energy distribution and the bands are recomputed.

In the simulation, we measure the energy fairness of the entire scheme using a formula. As the current residual energy of all the nodes is known at any given time we can calculate the fairness of load distribution. As the nodes attain uniform energy distribution, the fairness comes closer to the optimal value.

Fairness is given by f, where

$$f = \left(\sum_{i=1}^{n} (E_n) \right)^2 \div \left(n * \sum_{i=1}^{n} (E_n)^2 \right)$$

and $0 < f < 1$

Fig. 3 shows the results of simulation where we calculate the fairness of load across the network using the above formula. At any given instant of time we take the residual energies of all the nodes in the network and calculate the fairness. Optimal value of fairness is 1. Our protocol comes close to being fair in distributing the energy across the network. From the figure we can infer that in the initial stages of simulation when we have a non uniform energy distribution the fairness is low and then as the protocol executes and the simulation time elapses slowly the network attains uniform distribution of energy.

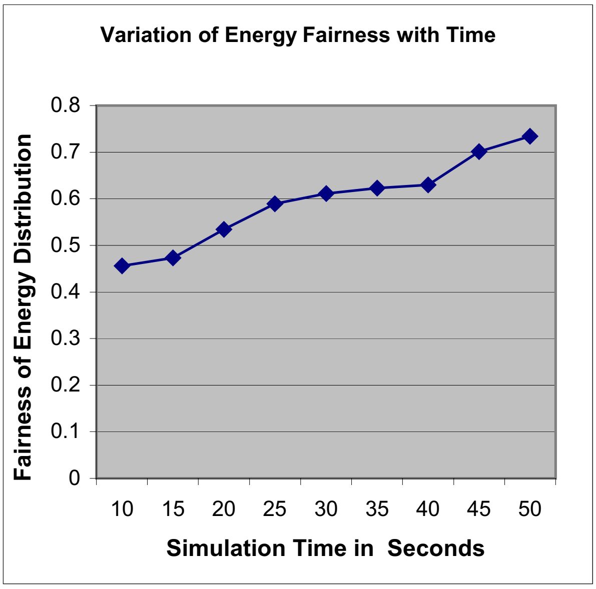

Fig. 3 Change of Energy Fairness with time

If most of the nodes have similar energies we can say that the network has reached a steady state in terms of energy distribution. The advantage of such a scheme is that there are no sudden changes in the network topology due to the changes in energies of the nodes. The network behavior becomes more predictable and its working becomes more controlled.

We compare our routing scheme with GPSR [7]. The simulation results show a definite improvement in terms of energy distribution and the average time it takes for the low nodes in the network to die. We compare the network life time of both the protocols which is the time taken for $1/3^{rd}$ of all the nodes to die and both protocols have shown similar values in the initial stages of the network. As the simulation time increases we see that our protocol offers more protection to the nodes in the lower energy bands and the network lifetime increases gradually. But as all the nodes reach a uniform energy level we need to flood the network again so that the global maximum can be found and the network can be divided into new bands.

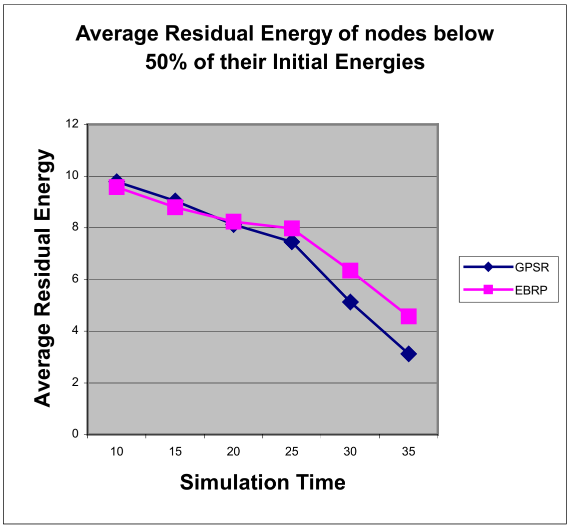

Fig. 4 Comparison of EBRP and GPSR in terms of protection offered to the nodes belonging to the lower energy bands

We have measured the fairness of the protocol in terms of energy distribution at different data rates. Fig. 5 illustrates the change in fairness with changing data rates. As the data rate i.e. the number of packets transmitted per second increases the traffic in the network increases. Due to the increase in the traffic the load on the nodes in the higher energy bands increases as they end up handling more data. The lower energy bands are always protected from the traffic in the network.

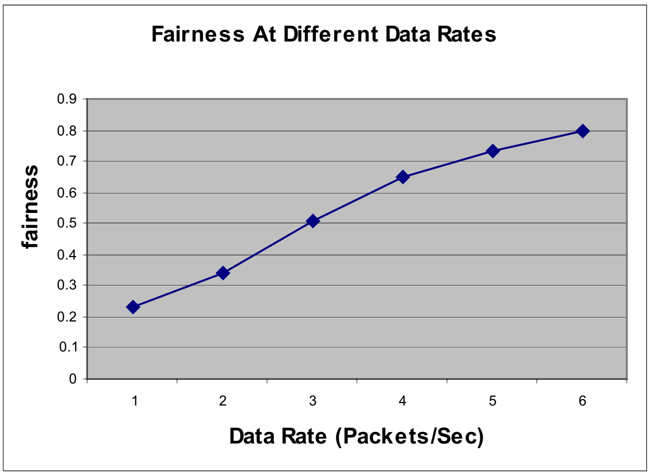

Fig. 5 Change in Fairness of the protocol with changing data rates

Due to this reason as the traffic increases our protocol still protects the lower energy bands but it then brings the high-energy nodes to the same level as the medium energy nodes and hence requires computation of the energy band based on the new global value after flooding the network. The advantage of this scheme is it ends up protecting the low energy nodes at the same time making the energy distribution uniform.

5. CONCLUSION

In this paper we proposed a novel scheme for sensor networks which results in fair distribution of load across the network. The concept of this model is based on the fact that higher energy nodes are in a better position to handle more traffic than the lower energy nodes. By dividing the entire network into energy bands we make sure that the lower energy nodes can be identified thereby making it easy to offer them more protection. The nodes belong to the lower energy bands always-forward data to the nodes in the next higher energy band among all its neighbors. Moreover this procedure is done after eliminating the nodes, which take the route away from the destination.

Our results prove that after a considerable time has elapsed, energy distribution across the network becomes uniform. This means that the nodes ended up routing traffic based on their residual energies i.e. lower energy nodes have gone down on energy at a much lower rate when compared to the higher energy nodes. The direct consequence of this behavior is that the network lifetime has been increased considerably.

Finally we conclude that our model offers protection to he low energy nodes and thereby increases the system lifetime considerably as shown in the simulation. The model is robust enough to handle traffic at different data rates. As there are no fixed paths in the network, the load distribution is uniform hence maximizing the network lifetime.

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