Evaluation of Cartesian-based Routing Metrics for Wireless Sensor Networks*

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Abstract

Routing packets within a large-scale wireless sensor network (WSN) without storage overhead and routing table updates is a challenging problem. With a large number of sensors the overhead plays a significant role in the scalability of the routing protocol. To avoid this communication overhead, WSN routing demands new and efficient methods for routing packets. Remove or reduce this overhead, the routing protocol needs some way of implicitly, rather than explicitly, defining paths. In this paper, we use the idea of directional routing, which requires only that each sensor know its location within the network relative to the sending node and the destination. Through simulation, we evaluate and compare a number of different metrics for selecting the routing path on a hop-by-hop basis. We also compare the energy usage and path length of these local methods with respect to some routing techniques based on global information. This evaluation shows that changing the routing metric can dramatically effect the performance of the sensor network. These results also show tradeoff between extending the lifetime of the WSN and reducing the average number of hops a message travels to the base station.

KEY WORDS
Sensor networks, directional routing, local, power aware.

1 Introduction

Routing packets within a large scale wireless sensor network without storage overhead and routing table updates is a challenging problem. With a large number of sensors, however, the overhead plays a significant role in the scalability of the routing protocol. To limit this communication overhead, WSN routing demands new and efficient methods for routing packets. Remove or reduce this overhead, the routing protocol needs some way of implicitly, rather than explicitly, defining paths.

In this paper, we use the idea of directional routing, which requires only that each sensor know its location within the network relative to the sending node and the destination. This allows the use of directional routing based on local information only. However, sensors are energy-constrained devices, so selecting paths within this network could benefit from an energy-aware routing process.

When considering a routing metric for WSN, we need to see what kind of information is available for routing. If we consider only the local point of view, then there is limited information that each node can get from its neighbors. First, cost of communication and distance between a source and its neighbors. Second, cost of communication and distance between a node and the base station. Finally, number of neighbors, and the power remaining at the neighbors.

Basing a routing protocol on these items only is not enough. Producing a routing table involves many control messages and also involves route discovery. But with the kind of information that is available and the limited resources that we have, we cannot have control messages to do route discovery and continually update the routing table. Instead we base the routing protocol on the local information only without using a routing table. In order to achieve this goal we used Directional Value (DV) [10]. Each node knows from the request which direction to send the packet. So the node just computes which neighbor is the most suitable to forward the message to and the neighbors will determine the rest of the route. This idea requires the node to contact its neighbors only and save many control messages throughout the whole network. This provides a routing protocol that will scale with a large number of nodes.

This protocol needs to be power aware, so we base the metrics on the power available at the source and its neighbors. In [10] the authors have shown that using a power aware protocol distributes the power usage evenly among the nodes of the network. And in [9] the authors compare the different local power aware metrics.

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The use of local information for making routing decisions may not lead to an ideal path. The lack of global knowledge could result in the choice of less efficient paths. Global knowledge of the nodes and their properties, such as available power, along with knowledge of the current traffic in the network could allow for optimal path selection for whatever goals we are attempting to achieve. However, the overhead and delay of accumulating and using global information is prohibitively expensive especially for sensor networks. Because network conditions, including each sensor node's power and availability, are dynamic properties, this global information is likely to be obsolete before it is accumulated, so the advantages of using global information are reduced or lost. Despite the fact that routing based on global information is not practical, it provides a good basis for determining how efficient routing based on only local information performs. In this paper, we evaluate several global metrics and compare these with the corresponding local metrics, showing that the local routing metrics perform reasonably well given the limited overhead.

Several criteria will be considered to compare the global methods and the local methods. The average number of hops, the number of nodes that die after a fixed number of rounds and the number of rounds when the first node dies and 5, 10, 15, and 20 percent of the nodes die, these are some of the criteria that will be used throughout this paper.

2 Related Work

Routing has been an active research area in the context of sensor networks. SPIN [3, 6], Directed Diffusion [1, 5], PEGASIS [7], and LEACH [2, 4] are four recent routing protocols for wireless sensor networks. SPIN [3, 6] is designed to address the deficiencies of classic flooding by negotiation and resource adaptation. SPIN disseminates all the information at each node to every node in the network. This protocol makes use of the property that nearby nodes have similar data and thus distribute only the data that the other nodes don't have.

Directed Diffusion [1, 5] is a data-centric paradigm and is applied for query dissemination and processing. Each query is disseminated throughout the network and gradients are setup to draw data satisfying the query toward the requesting node. More generally, a gradient specifies an attribute value and a direction. Events start flowing toward the requesting node from multiple paths. This type of protocol is suited only for persistent queries where requesting nodes are not expecting data that satisfy a query for some duration of time. This makes it unsuitable for historical or one-time queries, as it is not worth setting up gradients, etc. for queries that employ the path only once.

LEACH [2, 4] is a clustering based energy-efficient communication protocol where the cluster-head is changed randomly. In LEACH, they suggest two schemes, distributed and centralized. Data collection is centralized and done periodically. This can be appropriate for constant monitoring of a network. The user may not always need the data. So, periodic data transmissions may be unnecessary, which drains the limited energy from the sensors.

PEGASIS [7] uses a greedy algorithm to form clusters by assuming each node have a global view of the network. Each node communicates only to a close neighbor. Nodes take turns to transmit so that the average energy spent by each gets reduced. Most of the above protocols are based on the idea of flooding or improved flooding, or using a centralized approach. The idea of this paper is to eliminate any kind of flooding or overhead used in the routing. Instead base it on directional routing. Similar ideas were introduced in [8]. In [8], the basic idea is to embed the trajectory in the packet and let the intermediate nodes forward the packet to those that lie more or less on this trajectory.

In this paper, we present an idea similar to the trajectory, but based on the directional value of the destination.

3 Assumptions

In this paper, we assume a simple model where the radio dissipates E_{elec} = 50 nJ/bit to run the transmitter or receiver circuitry and E_{amp} = 100 $pJ/bit/m^2$ for the transmit amplifier to achieve an acceptable E_b/N_0 [2].

We assume that the transmission range of the nodes is variable according to the distance between nodes and each node has the capability to reach the base station if the base station directly contacted that node. Also assuming the distance between any two horizontal nodes or vertical nodes is equal to 10m and the diagonal distance is 14.14m. The number of bits transmitted in one packet is $k = 512$ bits. The topology that we are going to evaluate is a 10×10 2D mesh with a maximum of 8 neighbors (Figure 1).

Also assuming that the whole topology falls in a grid of $200m \times 200m$, the first node is located at position (x=55, y=55), and the base station is located at position (x=0, y=100) with a transmission range of 90m. When the base station transmit at that range it will reach the nodes labeled as Base Enabled nodes as shown in figure 1. The location of the base station can be at any position, but it have to determine which nodes are Base Enabled and which are not.

In this paper, we consider a system of wireless nodes that are homogeneous and highly energy-constrained. Each node produces some information as it monitors (senses) its vicinity. The basic operation in such a system is the systematic gathering of sensed data from one or more points of interest to be eventually transmitted to a base station for further processing. The key challenge in such information gathering is conserving the sensor energy, thereby maximizing the lifetime and hence the utility of the system.

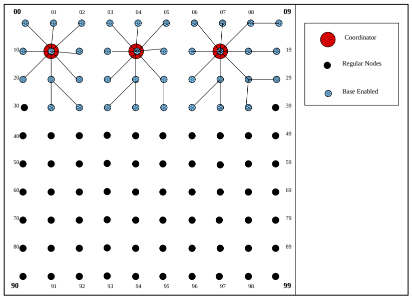

Figure 1. 10X10 2D Topology with 8 Neighbors

Each sensor in the network knows its position with respect to the network. The location of each node will be determined by using the directional value system. The Base Station (BS) will broadcast to the network and the nodes that can hear the BS will be called base enabled nodes.

4 Simulation Setup

In this paper we define a controlled environment so we can study the performance of local routing versus global routing. We have the following. First, the only nodes that can collect data and forward data toward a base enabled node are the nonbase enabled nodes, which in our experiment are nodes from node (90) to node (49) as shown in figure 1. Second, the base enabled nodes will be determined from the transmission range of the Base Station as shown in figure 1. Third, the same base enabled nodes will be used for the local and global cases. Those enabled nodes among themselves will choose a coordinators that will be used as a point of reference for the other node to transmit the packet toward that coordinator as shown in figure 1. When the packet reach one of the enabled nodes, the enable node will consult with the coordinator to see which enable node will the best one to transmit the packet to the base station. The coordinator will base the decision on the power available at the base enable node and the transmitting range. Fourth, we will compare the number of rounds until $1, 5, 10, 15,$ and 20 nodes die. Fifth, study the average number of hops each method will take to transmit to the Base Station. Finally, study the different route each method will follow at round 4000, and study how fast the nodes die.

5 Global vs. Localized Approaches

Due to the large number of sensors, network-scale interaction is indeed too expensive. Moreover, a centralized algorithm would result in a single point of failure, which is unacceptable in most applications and severely limits the advantages of using a wireless sensor network. In our system if the base station failed it is not responsible for the decision making in the network, neither can decide the routing for the network. Each node can decide locally where to send the packets. So the base station here can come and go or replaced by other base station that can gather information from the wireless sensor network.

Comparing local routing with respect to global routing gives a sense of the performance of local routing. Routing using global routing has a huge amount of overhead and will not be practical to apply to WSN. Assuming that the base station knows everything about the topology, and the network involves periodic updates to the base station. So we are using global metrics as a benchmark to measure the performance of the local methods that we used in this paper.

5.1 Global Routing

In this section, we describe the methods that were used for the cost of routing using global information.

1. Power: the power available at each node is used as the weight of the route. Dijkstra's algorithm is used to pick the route with the maximum power available from source to destination.

2. Directional Value (DV): we use the directional value and power as the weight between the nodes. We divide the DV between each node and the destination, and divide that value by the power available at each node.

3. Sum of Power: we use the sum of power at the neighbors of the source, and use that as the weight between the nodes. This will give a narrow perspective of the power available at the neighbors.

4. Hop: we use the number of hops between the source and destination, divide that by the power available, and use that as the weight between the nodes.

5.2 Local Routing

In this section we describe methods for routing packets that depend on local information only. We find the following item will be available. First, remaining power at the node and at the neighbors. Second, the number of hops between the source and the destination. Third, the sum of the remaining power at the neighbors. Fourth, the sum of the remaining power at the neighbors' neighbors of the current node. Finally, the cost of transmitting to the next hop.

All of these items can be used as local metrics for routing between a source and a destination. We have developed

Table 1. Result for Global Power and # Rounds

dead/method	Power	DV/P	Sum	Hop
Dead-1	4068	3903	4134	3938
Dead-5	4474	4326	4295	4243
Dead-10	4814	4651	4731	4700
Dead-15	4998	4876	4958	4972
Dead-20	5186	5057	5005	5166

Table 2. Result for Global Power and Ave Hops

dead/method	Power	DV/P	Sum	Hop
Dead-1	8.63	8.62	8.64	9.17
Dead-5	8.62	8.63	8.63	9.15
Dead-10	8.65	8.69	8.66	9.24
Dead-15	8.71	8.79	8.80	9.40
Dead-20	8.86	8.92	8.84	9.28

Table 3. Increase in # Rounds for Global

dead/method	Power	DV/P	Sum	Hop
Dead$(1-5)$	406	423	161	305
Dead$(5-10)$	340	325	436	457
Dead$(10-15)$	184	225	227	272
Dead$(15-20)$	188	181	47	194

several methods that can take advantage of this information to create a metric that can be used for routing. We introduce some of these metrics

1. Directional Value only: In this the algorithm considers only the DV of its neighbors with respect to the final destination. The only information that is available to the source is the IDs of its neighbors. From this the source can calculate the DV of its neighbors with respect to the final destination. The message will be forwarded to the node with the minimum value.

2. Directional Value and Power: in this the algorithm incorporates energy efficiency by considering the maximum available power and minimum directional value when picking which neighbor to use. The directional value is divided by the power available at that node. The smallest value of this power-constrained directional value is the path that is chosen. This allows for a least-transmission path that is also cognizant of power resources, although in some cases a longer path may be chosen if the available power dictates that choice.

3. Sum of Power at the next Neighbor: in this the algorithm we use the directional value and the power available at the surrounding neighbors in the forwarding direction only. Instead of looking at the power at the neighbors of the source, it looks one hop beyond these neighbors. By doing so, the protocol may have a better choice in picking the next hop on the route.

4. Sum of Power: in this the algorithm incorporates energy efficiency by considering the sum of power at neighbors of the node that is transmitting the packet. Consider only the nodes that are in the forwarding directions. This will provide a limited perspective of the power unlike the sum of power at the next neighbors.

6 Simulation Results

This section is divided in three parts. First, we will discuss the performance of the global methods and discuss the significant difference among those methods, we explain why one method is better than another method. Second, we will do the same for the local methods as we did for the global. Finally, we discuss the difference between the global and local methods from the number of round, average number of hops, and percentage of increase in the number of dead nodes at a fixed round.

6.1 Global

In table 1 we notice that the global method with power as its metric has the highest number of rounds when 20 nodes are dead. But as a tradeoff, we notice that it has a higher average number of hops as shown in table 2. This is because the algorithm picks the path with the minimum cost. We notice the same for the metric that depends on the number of hops as its cost between the nodes.

Table 3 compares the increase in number of rounds when the number of dead nodes increases from one stage to the other. We notice that the increase in the number of rounds decreases as the number of dead nodes increases. In using the Power, and DV/P, we see a decrease in the number of increased rounds, but in the sum and hop methods we see that the second stage has more increase than the first stage. This is because those two methods in the second stage are taking longer paths than the other methods as shown in table 2.

Table 4 shows the performance of different methods at a fixed round. At round 1500, we notice that the metric that depends on the number of hops has the highest average with respect to the rest. This is because this method depends on the number of hops and the power level at the next node. So the protocol tries to find the path that can minimize that relationship between the hops and the power. From table 4 we see that basing the cost function on a combination of ratios will effect the number of hops for each path.

Table 4. Results for Global, # Hops and Dead

Round	method	Power	DV/P	Sum	Hop
1500	Ave Hop	8.67	8.65	8.7	9.55
	Dead nodes	0	0	0	0
3900	Ave Hop	8.64	8.62	8.65	9.17
	Dead nodes	0	0	0	0
5000	Ave Hop	8.71	8.87	8.83	9.42
	Dead nodes	15	18	19	15

Figure 2 shows that each method takes a different path according to its cost function. Some will take longer paths and some take shorter paths.

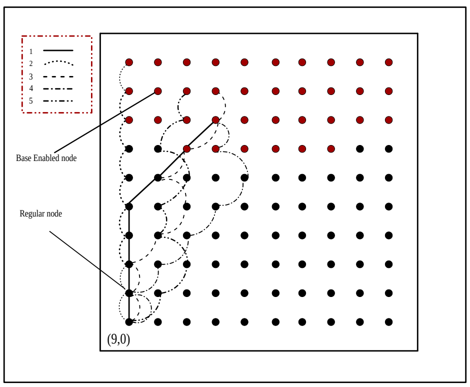

Figure 2. Global Diff Metrics Round 4000

6.2 Local

In studying the efficiency of local routing, we use two different metrics, one for for routing within the network and the other for choosing the base enabled node that will transmit to the base station. By doing this we choose the method that will give fairness among the base enabled nodes to take turns in transmitting to the base station. In an earlier paper [9], we have shown that using the sum of power at the next neighbors gives a broader perspective of the network from a local point of view.

In local routing the algorithm routes in two stages. First, route toward one of the coordinators first. Then when the packet reaches the border of the base enabled nodes, route toward the most suitable node to send directly to the BS.

Table 5 shows that local methods with directional value and power extend the network lifetime better than the rest of the methods. Also notice that with this method (the directional value and the power) when the first node died that it did not have the highest number of rounds, because the directional value influenced the decision of picking the next hop. But after the network was in use, the power has more influence in deciding the next hop. Similarly for the sum of power at the next neighbor, the directional value has the influence at the beginning then the power later.

Table 5. Results of Local Power and # Rounds

dead/method	Sum-N	DV/P	DV	Sum
Dead-1	3204	2555	2489	2549
Dead-5	4236	3956	3851	4163
Dead-10	4661	4652	4563	4520
Dead-15	4772	4852	4777	4672
Dead-20	4882	5017	4934	4795

Table 6. Results of Local and Ave # Hops

dead/method	Sum-N	DV/P	DV	Sum
Dead-1	6.70	6.83	6.63	6.65
Dead-5	7.49	7.63	7.13	7.53
Dead-10	7.90	7.93	7.38	7.85
Dead-15	8.08	8.08	7.44	8.02
Dead-20	8.17	8.16	7.47	8.10

Table 7 compares the increase in number of rounds when the number of dead nodes increases from one stage to the other. We notice that the increase in the number of rounds decreases as the number of dead nodes increase which is typical, but we also notice that from table 6, there is an increase in the average number of hops. Even if we compare the increase in the first stage with the increase in the average number of hops, we see that there is on average an increase of about one hop for all the methods.

Figure 3 shows that each method takes a different path according to its cost function. Some take longer paths and some take shorter paths.

6.3 Global vs. Local

In this section we compare global routing with local routing by using three methods for comparison. First, from the perspective of a shortest hop by using the number of hops for global and using the DV from the local, which is equiv-

Table 7. Increase # Rounds for Local Routing

dead/method	Sum-N	DV/P	DV	Sum
Dead$(1-5)$	1032	1401	1362	1614
Dead$(5-10)$	425	696	712	357
Dead$(10-15)$	111	200	214	152
Dead$(15-20)$	110	165	157	123

Table 8. Results for Local, #Hops and Dead

Round	method	Sum-N	DV/P	DV	Sum
1500	Ave Hop	6.39	6.42	6.39	6.39
	Dead Nodes	0	0	0	0
3900	Ave Hop	7.45	7.57	7.14	7.4
	Dead Nodes	4	4	5	4
5000	Ave Hop	8.16	8.21	7.48	8.22
	Dead Nodes	19	23	22	25

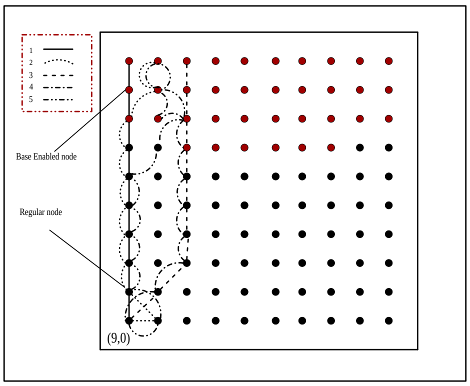

Figure 3. Local Using Diff Metrics Round 4000

alent to the shortest hop but from a local point of view. Second, using a ratio by using the DV/P for both the global and the local. Finally, using the sum of power for both the global and local.

Comparing tables 1 – 4 with tables 5 – 8 notice that global routing performs better than local routing in all the cases. There is one case where local is better than global. The reason is the global routing is a greedy approach, so it doesn't necessarily pick the total optimal value. Whether from the number of round, the average number of hops, the increase of number of rounds, increase in number of dead nodes.

In this paper we showed that local routing perform close to global routing without the overhead.

7 Conclusion and Future Work

The question that we sought to answer is whether we have to know the global state in order to make the protocol perform well. The answer in no, since the results are close, and the difference is not that great between global and local routing. In this paper we used directional routing, where the node needs to know the direction of the final destination to forward the packet to the next hop in that direction. Using the ratio of DV/P and the sum of power at the next neighbor performs better than other methods in local routing. These result are close to the performance of global routing.

Many other areas needed to be studied in the evaluation of cartesian-based routing. First, study the efficiency of using the directional value method on a randomly distributed network. By first try to have a local coordinate and then base the directional value according to this local coordinate. Next, the optimal number of coordinators in a randomly distributed network and how to ensure the fairness of choosing these coordinators. Finally, proof that basing the routing decision on local information extend the lifetime of the network in randomly distributed network.

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