Energy Distributed Algorithm for Ad Hoc Sensor Networks

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***Abstract*—Power consumption is a crucial problem for energy-constrained ad hoc sensor networks. This paper proposes a new scheme called energy distributed algorithm to improve the energy efficiency of ad hoc sensor networks, in which all data is usually sent to data sink for further analysis. In this algorithm, the network is divided into many circles with a data sink in the center of all circles other than the first layer circle around the data sink, creating a cycle, and each circle is divided into many sub-sections called sectors.**

Energy distributed algorithm improves energy efficiency using three methods. (1) In each sector, only one node is active at any time. Energy is then saved by putting other nodes in the sector into sleep state. (2) Only one route from the source to the destination is available. Energy is then saved by reducing floods in route discovery and avoiding duplicated data transmission by multiple routes. (3) Each circle has the same lifetime. Power consumption is then completely distributed in the entire network and all energy in the network can be efficiently used.

One-dimensional and two-dimensional scenarios show that energy distributed algorithms improve energy efficiency for ad hoc sensor networks.

***Index Terms*—Power consumption, ad hoc sensor networks, energy distributed algorithm.**

I. Introduction

Ad hoc sensor networks are self-organizing multihop systems of sensor nodes. These systems do not have pre-existing infrastructure but each node can act as a router to relay packets to its neighbors.

The nodes in sensor networks are usually battery energy supply based. The large number of nodes and the abominable work environment are incompatible to energy recharge. Therefore efficient power consumption becomes important. Nowadays, more attention is being paid to power consumption in ad hoc sensor networks.

Much researching has been conducted to improve energy efficiency of sensor networks. The previously proposed schemes can be classified into the following categories:

1) **Scheduling active and non-active nodes**
The non-active nodes can enter low power consumption state.

2) **Clustering the nodes in the network**
The topology of the network can be simplified.

3) **Optimizing route**
The distance or number of hops of the route from the source to the destination can be reduced.

This paper proposes a scheme called energy distributed algorithm to extend the lifetime of ad hoc sensor network, in which there is usually a data sink at the center of the network to collect all data of the network for further analysis.

In this algorithm, the network is divided into many circles, not squares. A data sink is set at the center of all circles. Each circle is divided into sub-sections called sectors, as described in Figure 1.

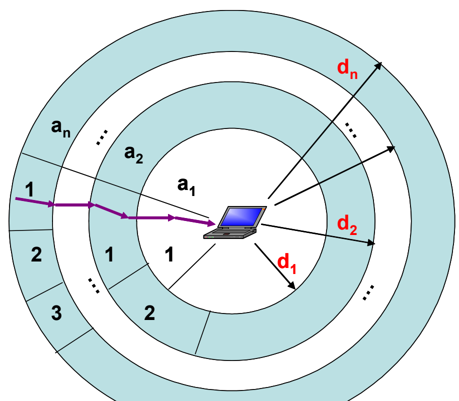

Fig. 1. Network is separated into circles.

The aim of energy distributed algorithm is to maximize the lifetime of the network. Energy efficiency in this algorithm is improved by the following ways:

(1) In each sector, there is only one node active at a time. Energy is then saved by putting other nodes into sleep state.

(2) From the source to the destination, there is only one route available. Energy can then be saved from reducing flooding in route discovery and duplicated data transmission by multiple routes.

(3) Each circle shares equal life spans. Power consumption is then completely distributed in the entire network. All energy in the network may be efficiently used.

The paper is organized as follows: Section II reviews the previously related work; an overview of energy distributed algorithm is outlined in Section III; one-dimensional and two-dimensional scenarios are analyzed in Section IV and V,

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respectively; summary and future work is concluded in Section VI.

II. Related Work

Power consumption is important in ad hoc sensor networks. Many schemes have been proposed to improve the energy efficiency. We reviewed some of these schemes and classified them into three categories: (1) scheduling active and non-active nodes, (2) clustering the network nodes, and (3) optimizing the route from source to the destination.

Scheduling active and non-active nodes

Scheduling methods save energy by assigning only part of the nodes to be active while other non-active nodes are put into sleep state [1-8]. There are four methods to improve the energy efficiency in this category.

The first one is to separate the network into different sections and make only one node active in each grid at any time [1].

The second method is to put the node into sleep or low power consumption state by some criteria depending on self-configuration algorithm [2], its number of neighboring nodes [3], when it is in idle time [7], and when the network capacity is traded off [5].

The third one is to form a backbone of the network while the other nodes are put into sleep state more frequently [4, 6]. The backbone nodes are then rotated to distribute the power consumption.

The fourth method allows the nodes to only receive the special message they are interested in. Other portions of the schedule that do not match their particular event subscription are allowed to sleep [8].

Clustering the network nodes

In clustering networks, the nodes are grouped into different clusters. In each cluster, there is a clusterhead (CH) to act as a local controller. Only the CHs form the backbone networks and energy is then saved by reducing flooding in route discovery and duplicate data transmission by multiple routes [9-15]. In clustering networks, energy efficiency is improved by two methods: optimizing the sizes of the clusters or distributing the power consumption among CHs and normal nodes.

The size of the cluster is an important parameter. If the size decreases, the power consumption within each cluster shrinks. Yet the number of CHs increases so backbone network formed by these CHs becomes more complicated. A smaller number of CHs would form a simpler backbone network. Yet that would require a larger cluster size so the transmission power of the nodes in each cluster rises or the mutihop routes within the cluster complicates. There is then a tradeoff between the cluster size and the number of CHs. Therefore, optimizing the size of the cluster [9-12] can improve the energy efficiency.

The normal nodes in a cluster only transmit their data to their CH and will relay the data in case of a multihop cluster. In addition to transmitting their data, the CHs will receive all data from the normal nodes and relaying the data. The CHs therefore consume more energy than the normal nodes and when the CHs run out of energy the clusters will break down. Therefore energy can be saved by averaging the power consumption among these nodes through rotating the roles of CHs among the nodes [13-15].

Optimizing the route from source to destination

Optimizing the route from source to destination means to find out the best route to reduce the power consumption for transmitting and relaying the packets [16-19]. There are three methods in this category.

The first one is to find the shortest route to the next hop or the destination to improve energy efficiency [16, 18].

The second method is to minimize the power consumption of each route [17].

The third method is to organize the nodes into different power level clusters. Each node can belong to several power level clusters making multiple power lever routes available. Energy can be saved by optimizing these routes [19].

III. Overview of Energy Distributed Algorithm

The objective of energy distributed algorithm is to improve the energy efficiency of ad hoc sensor networks. This algorithm has two important contents: (1) designing a unique route from source to the destination and (2) distributing the power consumption in different circles in the entire network.

Unique routing

The ID of the node in this algorithm is set according to its distance to the date sink. If the node is closer to the data sink, it will have a lower ID number (Figure 2). The rest of the nodes in the same circle will own the same ID number.

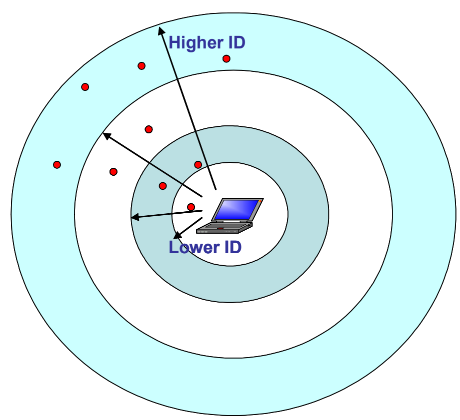

Fig. 2. ID number setting.

There are two rules in unique route design:

(1) Only the nodes with a lower ID number than the transmitter node within the transmission range of the transmitter can receive the data.

(2) Among the available nodes in the first rule, only the nodes with the highest residual energy can receive the packets.

The first rule reduces flooding in route discovery, yet, multiple routes still exist. From Figure 3, there are still two routes available. Applying the second rule, unique routing can be determined so that energy may be conserved.

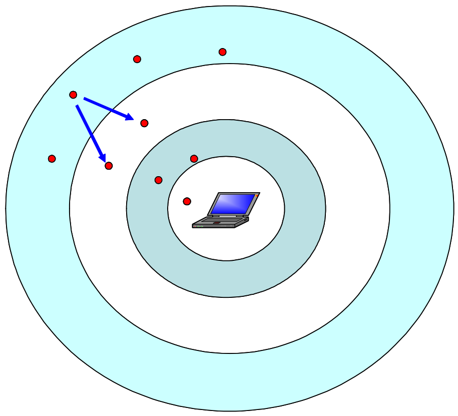

Fig. 3. Multiple routes available.

Distribute power consumption among all circles

Distributing power consumption aims to make all circles maintain an identical lifespan.

In an energy distributed algorithm, the network is divided into different circles with the same center and each circle is separated into many sectors, as shown in Figure 4. Only one node is active in each sector at any time.

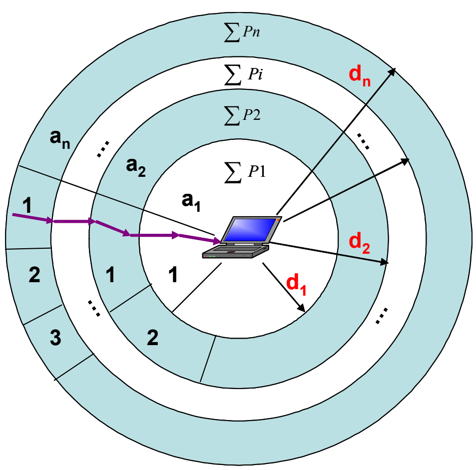

Fig. 4. Network divided into circles and sectors.

In sensor networks, all data is sent to the data sink for further analysis. The nodes near the data sink encounter higher traffic and will run out of energy at an early stage. With the result, the data sink is isolated due to the transmission power limitation of the nodes. Energy stored in other areas becomes wasted.

If the total energy stored in each circle is proportional to its total power consumption, all circles would have the same lifespan. The energy in some areas exhausted earlier is then avoided. Energy can be efficiently used.

The following two sections introduce the one-dimensional scenario and the two-dimensional scenario designs of an energy distributed algorithm. In this algorithm, we assume the nodes are distributed in the networks equably and each node has the same initially energy store.

IV. One-Dimensional Energy Distributed Algorithm

In one-dimensional scenario, the nodes are set in a queue with the data sink at the end, as shown in Figure 5.

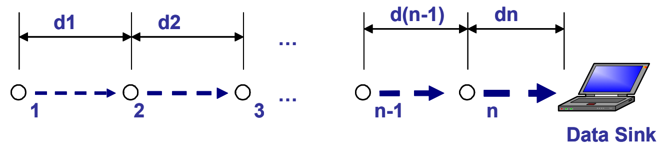

Fig. 5. One-dimensional algorithm.

Suppose that the data generation rate is *1* unit. The bit rate of the network is a constant *b*.

In Figure 5, if node 1 would like to send packets to the data sink, it will send them to node 2 first. Then node 2 relays the packets to node 3 etc and at last to the data sink. In this situation, node 2 should transmit *2* unit data, one unit of which is generated alone and another of which is from n1. At last node n should transmit *n* unit data: One is generated by itself and the others are from the former nodes.

For a simplified power model of radio communication, the power consumption of a node can be separated into 3 parts: transmitting packets, receiving packets and idle state, as expressed in Equation (1).

$$\begin{aligned} P &= PT + PR + PI \\ &= (e_t + e_d d^n)\times b\times\alpha + e_r\times b\times\beta + e_r\times b\times(1-\alpha-\beta) \qquad (1) \\ &= (e_t + e_d d^n)\times b\times\alpha + e_r\times b\times(1-\alpha) \end{aligned}$$

The denotation of each parameter is shown in table 1. From [20], the PR and PI are similar.

Table 1. Parameters and their denotations.

Parameters	Denotations
PT	Power consumption on transmitting data
PR	Power consumption on receiving data
PI	Power consumption of the idle state
$(e_t + e_d d^n)$	Power consumption on transmitting data
e_t	Power consumed by the transmitter electronics
e_d	Power dissipated in the transmit amplifier
d	Range of hop
n	Power index for the channel path loss of the antenna from 2 to 4.
α	Time on transmitting 1 unit data
β	Time on receiving 1 unit data
b	Amount of data
e_r	Power consumed by receiver electronics

From [21], the typical number for currently available radio transceivers are: $e_t = e_r = 50\times10^{-9}$ *J/bit*, $e_d = 100\times10^{-12}$ *J/bit/m*^{2} ; here $n = 2$.

Suppose that each node has a data rate of 1 unit and 1 unit data transmission occupies time α = 0.04. The value means, if the amount of the data that needs to relay becomes 10 units, the occupied time for transmitting data becomes 0.4.

Then the power consumption of the node *i* in Figure 5 is

$$Pi = PT + PR + PI$$
$$= (e_t + e_d d_i^{\ n}) \times b \times \alpha \times (n-i) + e_r \times b \times (1-(n-i)\alpha) \quad (2)$$

where n is the total number of the nodes.

A special scenario

In this section, we first give our energy distributed algorithm^ and compare our design with a non energy distribute algorithm.

(1) Energy distributed algorithm

In this special scenario, we assume that there are 6 nodes in the system. We call them n1, n2,…, n6, as shown in Figure 6.

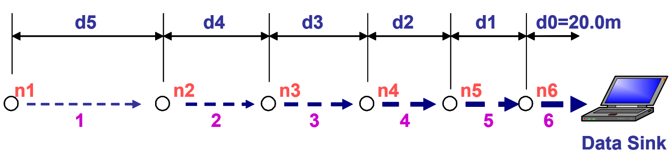

Fig. 6. Special Scenario for One-dimensional system.

Energy distributed algorithm would like to average power consumption among all nodes having the same energy store. If their power consumption is the same, they will then have the same lifetime. Therefore we can get Equation (3).

$$Pn = (e_t + e_d d^n) \times b \times \alpha \times (m-n) + e_r \times b \times (1-(m-n)\alpha) \Rightarrow$$
$$(5\times10^{-8} + 10^{-10} d0^2) \times 6 \times 0.04 + 5\times10^{-8} \times 0.76 =$$
$$(5\times10^{-8} + 10^{-10} d1^2) \times 5 \times 0.04 + 5\times10^{-8} \times 0.8 = \quad (3)$$
$$\cdots =$$
$$(5\times10^{-8} + 10^{-10} d5^2) \times 1 \times 0.04 + 5\times10^{-8} \times 0.96$$

Where P_n means the power consumption of node n, *(m-n)* means the amount of data the node n should transmit. In this special scenario m=6. We assume d0=20m, then:

$$d_n^{\ 2} = \left(\frac{5.96 - 5\times(1-(6-n)0.04)}{(6-n)\times 0.04} - 5\right)\times 100 \ (n=0,1\ldots.5) \quad (4)$$

We can get the distance among two neighboring nodes in Table 2.

Table 2. Distance among two neighboring nodes.

dn	d0	d1	d2	d3	d4	d5
distance (m)	20.0	21.9	24.5	28.3	34.6	49.0

In one-dimensional scenario with 6 nodes, we set the nodes as the distances shown in Figure 7; they will then run out of energy at the same time. No energy will be wasted before the whole network exhausts energy.

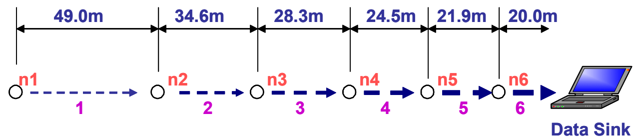

Fig. 7. Distance of each node.

If the sensor has 1 unit initially stored energy then the lifespan of all nodes would be:

$$T = 1/(5.96\times10^{-8}) = 1.7\times10^{7} \quad (5)$$

From calculations, we are given the total distance of the nodes which is 178m.

(2) Non-energy distributed algorithm

Another method is to separate the nodes at an equal distance, as shown in Figure 8.

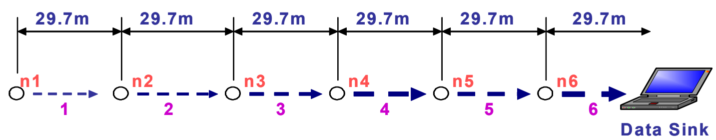

Fig. 8. Averaging distance design.

Then we can get the lifespan of each node, as shown in Table 3, where P represents the power consumption and T represents the lifetime of each node.

Table 3. Power consumption and lifetime of the nodes.

n	1	2	3	4	5	6
P ($\times10^{-8}$)	5.4	5.7	6.1	6.6	6.8	7.1
T ($\times10^{7}$)	1.9	1.8	1.6	1.5	1.5	1.4

From Table 3, we can find that the lifetime of each node is different. Some nodes run out of energy earlier. Energy will then be wasted.

V. TWO-DIMENSIONAL ENERGY DISTRIBUTED ALGORITHM

The energy distributed algorithm in two-dimensional scenario is shown in Figure 9.

Suppose in Layer m, the circle is divided into m sectors. In each sector, only one node is active. One active generates 1 unit data. Then in Layer m, the total number of active nodes is m, these m active nodes will generate m unit data.

The total power consumption of each circle is then expressed in following Equations serials (6).

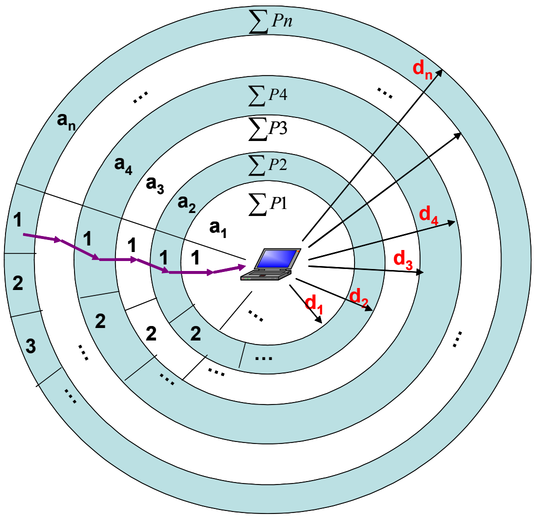

Fig. 9. Two-dimensional scenario of energy distributed algorithm.

$$\sum P1 = (e_t + e_d {d_1}^n)\times\sum_{i=1}^{n} a_i \times b\times\alpha + e_r\times b\times(1-\frac{\sum_{i=1}^{n} a_i}{a_1}\alpha)\times a_1$$

$$\sum P2 = (e_t + e_d (d_2 - d_1)^n)\times b\times\sum_{i=2}^{n} a_i\times\alpha$$

$$+ e_r\times b\times(1-\frac{\sum_{i=2}^{n} a_i}{a_2}\alpha)\times a_2$$

...

$$\sum Pm = (e_t + e_d (d_m - d_{m-1})^n)\times b\times\sum_{i=m}^{n} a_i\times\alpha$$

$$+ e_r\times b\times(1-\frac{\sum_{i=m}^{n} a_i}{a_m}\alpha)\times a_m \quad (6)$$

...

$$\sum Pn = (e_t + e_d (d_n - d_{n-1}3)^n)\times b\times a_n\times\alpha$$

$$+ e_r\times b\times(1-\alpha)\times a_n$$

Where $\sum Pm$ is the total power consumption of circle m, a_m is the number of sectors in that circle. The relationship between a_m and d_m is described in Equation (7).

$$a_m = \frac{2\pi d_{m-1}}{d_m - d_{m-1}} \quad (2 < m < n) \quad (7)$$

Because each circle has the same lifespan, the Equation (8) can then be achieved:

$$\frac{\pi({d_m}^2 - {d_{m-1}}^2)}{\sum P_m} = cons \quad (8)$$

A special scenario

In this section, we first give our energy distributed design, and then we will compare our design with non-energy distributed algorithm.

(1) Energy distributed algorithm

In this special scenario we assume that there are 2 layer circles, where d_1=20m and a_1=6, as shown in Figure 10.

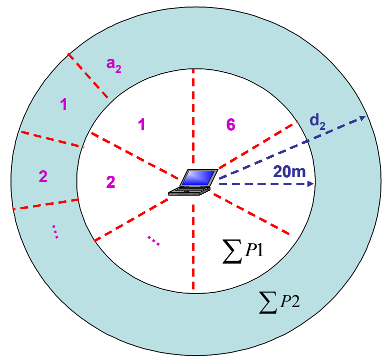

Fig. 10. Special Scenario for two-dimensional system.

From Equation (6) and (7), we can get Equations (9) (in this algorithm, we set π=3):

$$\sum P1 = (0.24 d_2 (d_2 - 20)\times 10^{-10} + 30\times 10^{-8}$$

$$\sum P_2 = 10^{-10} {d_2}^2 \times\frac{4.8}{d_2 - 20} + 5\times\frac{120}{d_2 - 20}\times 10^{-8} \quad (9)$$

Because:

$$\frac{E1}{\sum P1} = \frac{E2}{\sum P2} \quad (10)$$

Where E is the total energy and is proportional to the area of the circle, we suppose each node has 1 unit energy and the nodes are distributed in the network equably.

Then, we can hold the result of Table 4. From this Table, these two layers have the same lifespan; the energy in the networks can then be completely used.

Table 4. Parameters of the network.

Layers	d (m)	a	$\sum Pm(\times 10^{-8})$	Lifetime ($\times 10^{9}$)
1	20	6	33	3.6
2	32.6	10	54.7	3.6

(2) Non-energy distributed algorithm

Another method is also to separate the network into two layers, as shown in Figure 11. But different from our energy distributed algorithm, the number of sectors is distributed among the circles and each layer has 8 sectors.

We can then get the result of Table 5.

Table 5. Parameters of the network.

Layers	d (m)	a	$\sum Pm(\times 10^{-8})$	Lifetime ($\times 10^{9}$)
1	20	8	43.6	2.8
2	32.6	8	40.2	4.8

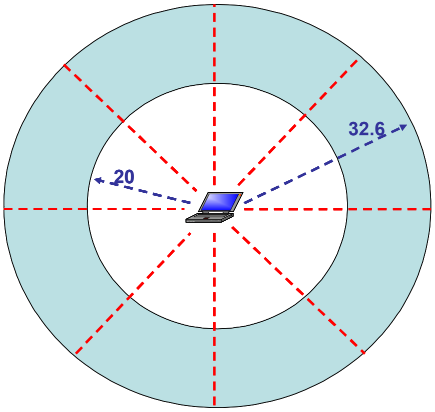

Fig. 11. Distribute sectors into two layers.

From Table 4, we find that all the energy is distributed. Yet from Table 5, the two layers have different lifespans. The first layer runs out of energy earlier and the data sink becomes isolated and energy is wasted.

VI. Conclusion

Power consumption is a crucial issue of ad hoc sensor networks. This paper proposes a new energy distributed algorithm to improve the energy efficiency of the ad hoc network.

In this algorithm, we (1) design a unique route from the source to the destination and (2) solve the issue that some areas run out of energy earlier in sensor networks by distributing the power consumption in the entire network.

Energy efficiency is then improved by (1) putting the redundant nodes into sleep state, (2) reducing floods in route discovery, (3) avoiding duplicate data transmission, and (4) using the total energy of the network completely. Comparisons between energy distributed algorithm and non energy distributed algorithm show that the proposed algorithm does improve the energy efficiency for ad hoc sensor networks.

Further work will complete the simulation of energy distributed algorithm.

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