Energy Efficient Position-Based Three Dimensional Routing for Wireless Sensor Networks

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ABSTRACT

In this paper, we focus on an energy efficient position-based three dimensional (3D) routing algorithm using distance information, which affects transmission power consumption between nodes as a metric. In wireless sensor networks, energy efficiency is one of the primary objectives of research. In addition, recent interest in sensor networks is extended to the need to understand how to design networks in a 3D space. Generally, most wireless sensor networks are based on two dimensional (2D) designs. However, in reality, such networks operate in a 3D space. Since 2D designs are simpler and easier to implement than 3D designs for routing algorithms in wireless sensor networks, the 2D assumption is somewhat justified and usually does not lead to major inaccuracies. However, in some applications such as an airborne to terrestrial sensor networks or sensor networks, which are deployed in mountains, taking 3D designs into consideration is reasonable. In this paper, we propose the Minimum Sum of Square distance (MSoS) algorithm as an energy efficient position-based three dimensional routing algorithm. In addition, we evaluate and compare the performance of the proposed routing algorithm with other algorithms through simulation. Finally, the results of the simulation show that the proposed routing algorithm is more energy efficient than other algorithms in a 3D space.

Keywords: Wireless Sensor Networks, Three Dimensional Routing, Energy Efficient Routing.

1. INTRODUCTION

Advancements in microelectronics technology have brought Wireless Sensor Networks (WSN) from concepts to applications. WSN are composed of a large number of tiny sensor nodes deployed in a region of interest, where each node is capable of processing and communicating wirelessly and power-constrained. Also WSN have wide and various applications such as military surveillance system in battle fields or disaster detection system in buildings or bridges. In these applications, most routing algorithms were studied in a 2D environment. However, in reality, such networks operate in a 3D space. Even though 2D designs are simpler and easier to implement than 3D designs for routing algorithms in WSN. In some applications such as an airborne to terrestrial sensor networks or sensor networks, which are deployed in mountains, considering about 3D designs is more reasonable and can reflect more accurately real world than 2D designs.

In order to implement 3D routing, position-based routing algorithms with using low-power GPS can be available. In this area, various routing algorithms exist which can be extended from 2D to 3D such as for example Greedy [1], Compass [2] or Ellipsoid [3]. However, these routing algorithms don't consider energy efficiency, which is important factor in wireless sensor networks. Also, in energy aware position-based routing algorithms, Minimum Energy communication Network (MECN) [5] and Small Minimum Energy Communication (SMECN) [6] construct power optimized paths between a set of source nodes to one destination node using distance information between nodes. However, these routing algorithms take a geometric problem described only by the positions of the nodes on a two dimensional plane. In this paper, we focus on network initialization for energy efficient routing paths in WSN, and propose the Minimum Sum of Square distance (MSoS) algorithm as a routing algorithm which considers not only a viability in a 3D space, but also an energy efficiency by using distance information.

The rest of the paper is organized as follows. We introduce the power consumption model in Section 2. Our proposed algorithms are presented in Section 3. Simulation and evaluation results are in Section 4. Section 5 concludes the paper.

2. PRELIMINARIES

Power consumption model

In general, path loss model [4] is used for wireless signal propagation modeling. In this model, the received signal power for the radio frequency communication decreases by a factor of $1/d^{\alpha}$, where d is the distance between transmitting node and receiving node, and α is a constant between 2 and 5 dependent on the wireless transmission environment. A value of α=2 is often used for the free-space propagation model, while α=4 is used for the two-ray ground reflection model. In this paper, we define the $d(u, v)$ as the Euclidean distance between the node u and v in a 3D space.

$$d(u,v)=\sqrt{(u_x-v_x)^2+(u_y-v_y)^2+(u_z-v_z)^2} \quad (1)$$

Furthermore, node u is a node that wishes to transmit information to node v. Accordingly, node u is called the 'transmitting node' and node v the 'receiving node. Additionally, the sum of all the power consumption for one signal transmission amounts to $td^{\alpha}+c$, where t denotes the pre-detection threshold at the receiver. Altogether this leads to an expression td^{α}, which denotes the minimum power the sender has to radiate in order to enable a signal detection at distance d. Besides, constant c may also incorporate additional power expenditure due to computer processing and encoding and decoding on the sending and receiving devices. In this paper, we assume that each node can control its transmission power, and that all receivers have the same power threshold for signal detection, which are then typically normalized to one, also we assume that the constant c is a very small value. Finally, we will use the free-space model for routing in a 3D space.

As a simple illustration, consider the three nodes S, r and D in a 3D space of Figure 1. We assume that all three nodes use identical transmitters and receivers and α=2. The power consumption to transmit a signal from S to D is therefore $d(\mathrm{S},\mathrm{D})^2$ (i.e., the square of distance between node S and D). If the relay node r can be used for the transmission between S and D, the total power consumption is $d(\mathrm{S}, r)^2 + d(r, \mathrm{D})^2$, which is less than $d(\mathrm{S},\mathrm{D})^2$. In other words, if S wants to send a packet to any node D lying in the right side of the plane P, relaying through node r always consumes less power than directly transmitting to D.

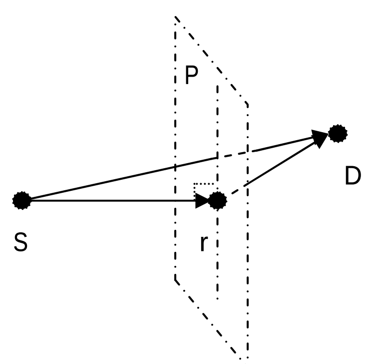


Figure 1: Relaying through node r consumes less power than directly transmitting from S to D in 3D.

For the power consumption model in a 3D space, if we assume that $pt= (u, u_1,\ldots, u_{k-1}, v)$ is a set of nodes in the path between u and v, where $u=u_0$, $v= u_k$. Then we can write power consumption between u and v as:

$$P(u,v)=d(u,v)^{\alpha} \qquad (2)$$

The total transmission power consumption of a path like pt is given by:

$$C(pt)=\sum_{i=1}^{k}(p(u_{i-1},u_i)) \qquad (3)$$

In MECN [5], Rodoplu and Meng also use the path loss model. The main idea is to find a sub-network, which will have less number of nodes and require less power for transmitting between any two particular nodes. In this way, global minimum power paths are found without considering all the nodes in the network. Moreover, SMECN [6] is an extension to MECN by reducing the number of edges in sub-network for improvement of performance. These routing algorithms are performed using a localized search for each node considering its relay region (i.e., the area where indirect transmissions consume less energy than direct transmissions). However, they took a geometric problem described only by the positions of the nodes on a two-dimensional plane.

Related Routing Algorithms

In mobile ad-hoc networks, various position-based routing algorithms exist which can be applicable to a 3D space.

Greedy routing [1]: the current node forwards the packet to the neighbor that minimizes the remaining distance to the destination. The same procedure is repeated until the destination node is reached.

Compass routing [2]: the current node forwards the packet to the neighbor node that minimize the angle between the current node, next node and the destination node locations. The same procedure is repeated until the destination node is reached.

Ellipsoid routing [3]: the current node selects the neighboring node that has the smallest sum of distances from itself to the neighboring node and then to the destination node.

These routing algorithms have advantage in the aspect of reducing hop count or increasing the route construction success probability. However, they don't consider energy efficiency, which is important in wireless sensor networks in a 3D space.

3. ROUTING ALGORITHM

We propose an energy efficient routing algorithm which considers the capability to implement in a 3D space by using distance information, which affects transmission power consumption between nodes without relay region. As explained in section 2, we assume that each node is aware of its own location, and that each node can know the location of its neighbors and destination node. In addition, each node is randomly deployed, is static and has the same communication range in a 3D space.

First of all, from the simplified equation (2) in section 2, we can get the basic concept about selecting the energy efficient neighbor node in one hop range as follows.

$$d(u, n)^2 + d(n, v)^2 \qquad (4)$$

When we define a set of all neighbor nodes of *u* as N_u, where $n \in N_u$, and *d(u, n)* is the distance between the transmitting node *u* and its neighbor node *n* and *d(n, v)* is distance between the neighbor node *n* and receiving node *v*. In this section, we use the sum of the square of the distance between two nodes in order to select the energy efficient neighbor node (which has the lowest transmission power consumption among neighbors) using the formula (4), and our routing algorithm is composed of two phases.

Phase 1 algorithm

In Phase1 algorithm, the source node can calculates the sum of the square of the distance (SoS) for each neighbor node and selects the node that has the smallest SoS value. In Figure 2, S is the source node (which has sphere-shaped communication range in a 3D space), nodes A and B are neighbor nodes of S, and D is the destination node. And then, S calculates and compares the value of SoS, and based on these values, S selects the node A according to the following inequality (5).

$$d(S, A)^2 + d(A, D)^2 < d(S, B)^2 + d(B, D)^2 \quad (5)$$

Phase 1 has two purposes. First one is reducing the power consumption by the distance in case that the source node is adjacent to the destination node. Second one is to overcome Greedy's void node problem (which is the case of that the closest distance from D to neighbor of S is bigger than distance between S and D) in a 3D because phase 1 can select any node by using inequality (5) even in that case.

Furthermore, we can consider inequality (5) as another method. If we define point *m* as the middle point between S and D. In this case, we can observe that a set of each point, which has the same value of SoS for every node A or B is a circle with *m* as origin. From this observation, we can represent the inequality (5) to another inequality where S selects its neighbor node that has the smallest distance from the middle point *m*. In other words, inequality (5) has same meaning with following inequality (6).

$$d(A, m) < d(B, m) \quad (6)$$

Therefore, we can use this inequality (6) which is simpler than inequality (5) to simplify of our proposed phase 1 algorithm.

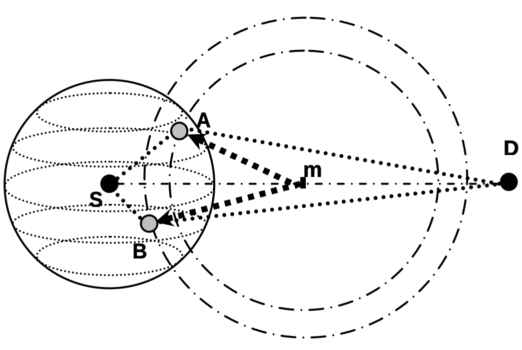


Figure 2: Phase 1 algorithm using middle point *m*

This simplified algorithm can reduce the complexity of the calculation compared to the inequality (5) for finding a routing path in the whole network. In addition, from the phase 1 of the algorithm, we can expect a reduction of power consumption in case that the source node is adjacent to the destination node. However, in the cases of multi hop, it is not optimal. Therefore, we propose the phase 2 algorithm for energy efficient 3D routing algorithm.

Phase 2 algorithm

First of all, let *t* be the transmitting node, *r* is the receiving node and *i* is the intermediate node (Figure 3). We define the Energy Efficient Area between transmitting node and receiving node as follows:

Definition 1: The Energy Efficient Area (EEA) is the sphere-shaped area satisfied by following inequality between transmitting node *t* and receiving node *r*

$$d(t, i)^2 + d(i, r)^2 < d(t, r)^2 \quad (7)$$

Definition 2: An energy efficient node is a node, which has the smallest value of SoS within the EEA.

Figure 3 shows well the EEA sphere in a 3D space. In this figure, boundary face (i.e., dotted circle) is satisfied by the equation $d(t, i)^2 + d(i, r)^2 = d(t, r)^2$. Therefore, if the intermediate node *i* is contained in this sphere, the indirect routing through *i* is more energy efficient than both the direct routing and the case where *i* is outside of this sphere.

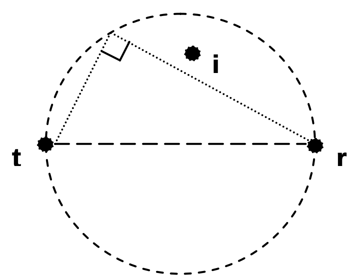


Figure 3: Energy Efficient Area (EEA)

The purpose of phase 2 is only reducing the power consumption by both finding energy efficient nodes and renewing routing paths. So, the Phase 2 algorithm is performed consecutively on the one hop distance interval which was determined by phase 1 algorithm. In this algorithm, the transmitting node first finds the energy efficient nodes in the EEA. If there are nodes in that area, the transmitting node calculates and compares the value of the SoS and select the node which has the smallest value of the SoS. In the next step, the transmitting node recalculates the EEA between the newly created hops, in order to find further energy efficient nodes in those areas. If no node exists in EEA, the execution of phase 2 algorithm is transferred to the next hop. Finally, all this process is repeated until no more nodes exist in any EEA. Then nodes found by phase 2 are placed into a routing path list that assures minimum power consumption. Figure 4 shows well phase 2 algorithm. In figure 4, the arc *f* is the communication range of transmitting node *t*, and receiving node *r* is selected by the phase 1 algorithm among the neighbor nodes of *t*. In addition, various sizes dotted circles represent the boundary face of EEA. As we can see, consequently, the indirect transmission (t-b-a-r) consumes less power than the one hop direct transmission (t-r) defined by phase 1.

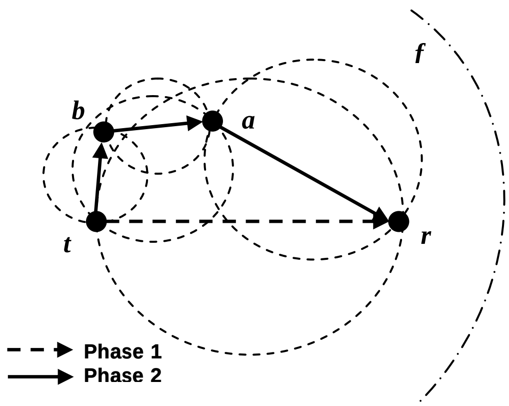


Figure 4: Selecting energy efficient path in phase 2

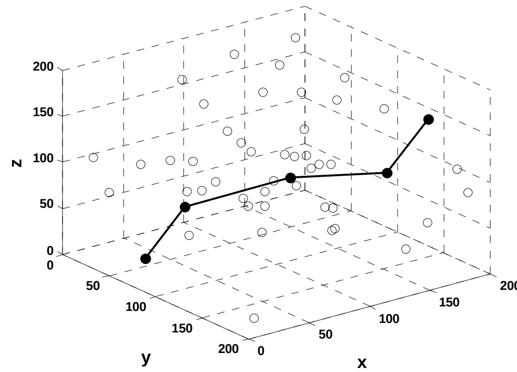
Phase 2 algorithm is a supplementary algorithm that aims to overcome the limitation of phase 1 for long distance multi-hop cases. Additionally, in phase 2 algorithm, as the number of energy efficient nodes increases, we can expect the reduction of the total power consumption in the whole 3D sensor network using the phase 2 algorithm. As stated above, phase 1 and phase 2 algorithms can be performed simultaneously and sequentially. Hereafter, we call the hybrid routing algorithm composed of both the phase 1 and phase 2 algorithms as the Minimum Sum of Square distance (MSoS) algorithm.

4. SIMULATION AND EVALUATION

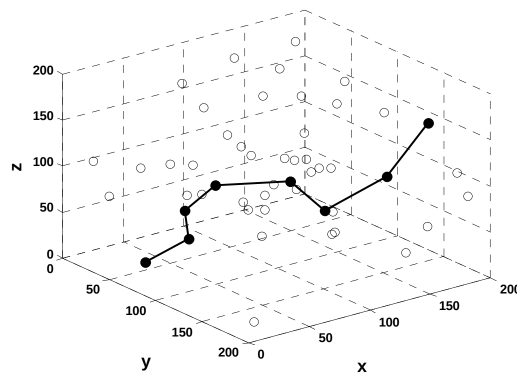
In this paper, the performance of the MSoS routing algorithm was evaluated by a computer simulation. To verify the effectiveness of our scheme, the simulation was performed with MATLAB. In our simulation, we investigate the total average transmission power consumption in a 3D space.

The simulation condition is to randomly arrange the nodes which are uniformly distributed in a 200m × 200m × 200m virtual 3D space. The communication range (*R*) of each node is a fixed value in execution of simulation, and we changed the value of *R* at each simulation case from 60m to 110m. In addition, source nodes and destination nodes are randomly selected, and the number of nodes (*n*) at each simulation was also varied from 10 to 100. Figure 5 demonstrates an example simulation case of the routing path obtained with the proposed algorithms with regard to randomly deployed sensor nodes in a 3D space.

Figure 5(a) depicts the routing path obtained with the phase 1 algorithm in the condition of fixed 100m communication range and 50 nodes, whereas Figure 5(b) depicts the routing path with the MSoS algorithm with the same configuration. As we can see in these figures, even if the Figure 5(b) bears a bigger number of hops, it contains more energy efficient nodes than Figure 5(a) in the final routing path.



(a) Routing path with phase 1



(b) Routing path with MSoS (phase 1 + phase 2)

Figure 5: Example of routing path for randomly deployed sensor nodes in a 3D space (R =100, n =50)

Figure 6 shows the comparison of the total average power consumption between various routing algorithms such as Ellipsoid, Greedy and Compass as the number of nodes increase. Each point of value on the each line represents total average power consumption which is calculated by equation (3) and running the simulation a hundred times. We can see that the total average power consumption of Greedy, Compass and Ellipsoid is continuous or increasing as the number of nodes increases, whereas the consumption of MSoS is decreasing as the number of nodes increases.

This figure shows that our proposed scheme (MSoS) has definitely better performance than other algorithms in terms of energy efficiency in a 3D space. In addition, when the number of nodes is 100, the MSoS achieves 40.4% of power savings in total average power consumption in comparison with the Greedy algorithm. Furthermore the MSoS has also 25.7% and 31.6% power savings comparing to Ellipsoid and Compass algorithm respectively. These results confirm that the energy efficiency increases along with the increasing probability of containing energy efficient nodes in the routing path.

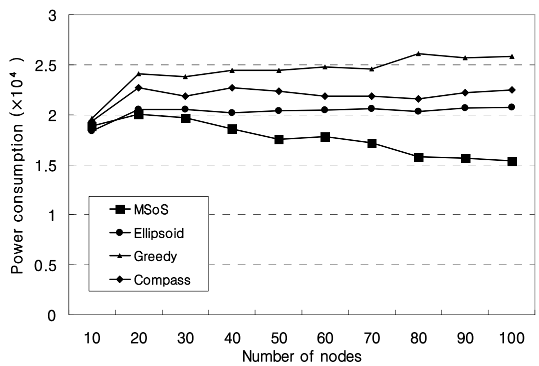


Figure 6: Comparison of total average power consumption with various routing algorithms as the number of nodes increase (R =100).

In Figure 7, we can observe that total average power consumption approximately decreases along with the increase of the number of nodes and decrease of the communication range. However, when the number of nodes is below about 30 and the communication range exist between 60m and 80m, we can observe that total average power consumption decrease rapidly. This is because the routing success rates decrease rapidly in this area. Nevertheless, in general the total average power consumption decreases as the number of nodes increases and communication range decreases, the point, which has minimum total average power consumption on the face graph is one denoted by the following values (R =60, n =100) .

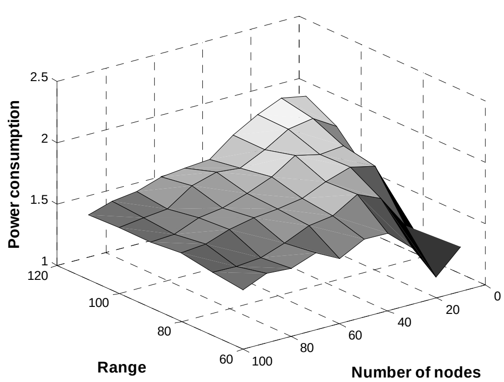


Figure 7: Total average power consumption related with the communication range and the number of nodes in MSoS.

5. CONCLUSION

In this paper, we considered not only viability in a 3D space, but also energy efficiency for network initialization. Also we proposed an energy efficient position-based three dimensional routing algorithm using distance information, which affects transmission power consumption between nodes in wireless sensor networks. The proposed scheme (MSoS) shows that the energy efficiency can be improved simply by using the location information about the sensor nodes which is randomly deployed in a 3D space without using an enclosure graph. In addition, the proposed scheme shows that the total average power consumption in a 3D depends on the communication range and the number of nodes. As a result, the proposed scheme provides a better way to reduce the transmission power than other position based routing algorithms in a 3D space.

6. ACKNOWLEDGMENTS

This work was supported by "Development of Korean u-SCM platform and wireless identifying application technology" project of MOCIE, Korea and "Brain Korea 21."

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