Region-based Deployment Scheme for Wireless Sensor Networks

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Abstract
This paper proposes Region-based Deployment Scheme for wireless sensor networks. Before deployment, we can divide the sensor field into several regions. According to the position of each region relative to the BS and the popular level of each region, we can decide how many sensor nodes should be deployed into each region. Under this scheme, the lifetime of each region can be shown to approximately identical. Experimental results confirm such an observation.

1. Introduction

In recent years, the research and implementation of wireless sensor networks develops rapidly, ex. IEEE 802.15.4 [1] and ZigBee. There are plenty of wireless sensor network applications in various domains. For example, the security system in the community, temperature and moisture monitoring in agriculture, fire detecting in forest, and enemy monitoring in the battlefield, no matter in which application, there are many sensor nodes in a sensor network. Each sensor is comprised of the processing unit, transmission unit, sensing unit and power unit [2]. When sensor nodes are deployed into the sensor field, they configure themselves automatically and form a topology.

When deploying, sensor nodes can be either thrown in as a mass or placed one by one in the sensor field [2]. A sensor network with hundreds to several thousands of sensor nodes is usually established in the former way. For example, in the application which detects fire in forest, we would drop sensor nodes from a plane. If sensor nodes are placed by one by one, the number of sensor nodes must be few enough to be placed either by a human or a robot.

The scenario of Region-based Deployment Scheme is that we have to deploy hundreds to several thousands of sensor nodes into a wide area. And we have the ability to deploy sensors into a certain region, but not an accurate position. For example, we can throw a certain number of sensor nodes to a region from a plane. By the way, a few scenarios that sensor nodes are deployed by hand can also adopt Region-based Deployment Scheme. For instance, in the application gathering students’ motions in the campus, we can divide the campus into several regions, and deploy a certain number of sensor nodes into each region according to its popular level.

The simplest deployment method is average deployment which assumes all regions are equal, and the number of sensor nodes deployed into every region is the same. If we are going to deploy \( N \) sensor nodes into entire sensor field, then \( \frac{N}{m} \) sensor nodes have to be deployed into each region. However, such deployment method is not good, because the loading of regions is always different. It may causes that some regions remain much energy when the high-loading region is died.

In general, there is a base station (BS) in sensor network. Only the BS can communicate with the user via the Internet or satellite. So it must possess powerful processing ability and sufficient power to play the bridge between the user and sensor nodes.

The position of a region also affects its power consumption. When a sensor node reports data to the BS, the routing path may pass through other regions. Then regions that have to route the data will spend much energy on routing. So we have an intuition that regions near the BS have to consume lots of power on routing. Hence, we must take the position of the region into consideration when we are evaluating how many sensor nodes should be deployed into a region.

Generally, the fact that a region is died means we cannot monitor this region anymore and the sensor network will lose the integrity. So when a region is died, we must redeploy new sensor nodes into the sensor field to maintain the sensor network functions. We can say the lifetime of the sensor network depends on the minimum lifetime of regions. Hence, we hope the lifetime of every region is equal, and when a region is died, the energy of other regions is also exhausted. The energy of entire sensor network is not wasted. The lifetime of the sensor network will become maximum.

2. Related Works

There are some researches on the deployment of wireless sensor networks. [2] points out the deployment of wireless sensor network can be divided into three phases: predeployment and deployment phase, post-deployment phase, and redeployment phase. The
Region-based Deployment Scheme proposed in this paper belongs to the predeployment phase. With our scheme, we can analyze how many sensor nodes should be deployed into each region before deployment. Furthermore, we can adopt Rotational Wakeup Mechanism after deployment.

Sampling based deployment [5] considers the problem of placing networked sensor nodes in a way that guarantees coverage and connectivity. It proposes sampling based deployment and the algorithms that guarantee coverage and connectivity with a small number of sensor nodes. It has considered two scenarios. One is that deployment has to be accomplished in one step. Another is that the deployment can be implemented in multiple steps, and then the awareness of coverage and connectivity can be updated. For the latter, it presents incremental deployment algorithms which consider the current placement to adjust the sampling domain.

QoM and Lifetime-constrained Random Deployment [7] considers the problem of energy efficient random deployment of sensor network. It finds the energy resource density at every point inside a given deployment region, which results in allocating the minimum total number of deployed sensor nodes or the minimum total energy source subject to constraints on the Quality of Monitoring (QoM) and network lifetime. The QoM is defined as the average of spatial distortion in reconstructed signal at the base station and can be bounded for a random deployment of sensor nodes when sensor nodes are points of a Poisson process in the deployment region.

[3] mentions that a method to maintain long network lifetime is to turn off redundant sensor nodes. It analyzes minimum and maximum number of neighbors that are required to provide complete redundancy and introduces a method to estimate the degree of redundancy without the knowledge of location or directional information.

[4] investigates detection of a target traversing the region being monitored by using collaborative target detection algorithms among sensor nodes. It defines a path exposure metric as a measure of goodness of deployment and cost functions that take into account the cost of single sensor nodes and the cost of deployment. It illustrates that the cost of deployment can be minimized to achieve the desired performance by appropriately choosing the number of sensor nodes deployed in each step of the sequential deployment.

However, no paper focuses on the region-based deployment of wireless sensor networks. Hence, this paper proposes Region-based Deployment Scheme which evaluates how many sensor nodes should be deployed into each region. With this scheme, the lifetime of the sensor network is prolonged.

3. Region-based Deployment Scheme

In this section, we will divide the sensor field of wireless sensor networks into several regions and explain how Region-based Deployment Scheme decides how many sensor nodes should be deployed on these regions with the consideration of two factors. With Region-based Deployment Scheme, the lifetime of each region will be almost equal. In other words, when a region is died, the energy of other regions is also exhausted. Then the energy of entire sensor network is not wasted at all. Thus, the lifetime of the sensor network is prolonged.

3.1. The environment

As Fig. 1 shows, we assume we divide the sensor field of wireless sensor networks into several square regions, and we have the ability to deploy a certain number of sensor nodes in each region. There is a base station (BS) in the sensor network. The BS is located at the crossing place of regions, and does not lie in any region. When sensor nodes detect the events, they will report data to the BS. With a multihop routing protocol, data are relayed back to the BS hop-by-hop by sensor nodes on the routing path.

The power consumption of sensor nodes is different because the practical situation of each region is different. Hence the lifetime of each region is also different. However, in most applications, the fact that a region is died means we cannot monitor this region anymore and the sensor network loses the integrity. It also indicates that other regions cannot report data through this region. Hence, when a region is died, we have to redeploy new sensor nodes into the sensor field to maintain the sensor network functions.

We have to redeploy new sensor nodes into entire sensor field because a region is died, even if many powerful sensor nodes remain in other regions. The cost of deployment is always very high, including the cost of sensor nodes, the cost of the trip to the target place, the cost of putting the sensor nodes into the sensor field, and the cost of network configuration. On the other hand, the energy of remaining sensor nodes is wasted. Therefore, to equalize the lifetime of regions and prolong the lifetime of the sensor network, a good distribution of the sensor nodes is important.

3.2. Parameters to be considered

To decide adaptive number of sensor nodes, we have to consider the popular level of regions. In general, the
applications of sensor network can be categorized as event-driven, query-driven, or time-driven. No matter what kind of the application is, a region’s popular level is proportional to its reporting rate. For example, in an event-driven application, a region is more popular indicates events occur more frequently. In a query-driven application, a region is more popular indicates the user queries more frequently and the reporting rate is higher.

The popular level should be decided by the user according to specific applications. For example, in the application gathering students’ motion in the campus, the entrance of campus should be most popular, so we can set a high popular level to this region. On the contrary, we can set a low popular level to the corner of the campus. Besides, if we have previous sensing data, we can calculate the reporting rate of each region.

Another important parameter is the position of a region relative to the BS. When a sensor node reports data to the BS, there are many sensor nodes in the routing path, whether the routing protocol is multihop or hierarchical. Some sensor nodes in the region that lie between source node and the BS will route the reported data. Regions that lie between source node and the BS will spend much energy on routing. For example, in Fig. 1, when the source node in region C reports data to the BS, some sensor nodes in region B will route the data. Therefore, not only region C consumes energy in the data report, but also regions A and B consume much energy since they lie between region C and the BS. Now we have an intuition that regions near the BS have to consume more energy on routing. For this reason, we have to allocate more energy in these regions.

3.3. The length of routing path

It’s not easy to estimate a region’s power consumption of transmitting data. The reasons are listed below. First, we don’t know the precise position of sensor nodes. What we know is the number of sensor nodes deployed in each region. So we cannot predict which sensor node would forward the data. Second, we don’t know the exact routing protocol of the application. Tens of routing protocols are proposed for wireless sensor networks [6]. Each routing protocol has its advantages and disadvantages, and is suitable for some applications. We cannot estimate the routing path when we don’t know the exact routing protocol.

In fact, a routing protocol decides the routing path according to available power of sensor nodes and the energy required for transmission. In [2], routing protocols are classified into four categories: (a) Minimum Hop (b) Minimum Energy (c) Maximum Available Power (d) Maximum Minimum Available Power node. When sensor nodes transmit without any power control, Minimum Hop is equivalent to Minimum Energy. In this paper, we assume the routing protocol is Minimum Hop which chooses the route that makes the minimum hop to the sink. Sometimes we call it shortest path routing.

In Fig. 1, region B has to relay data when the source node in region C reports data to the BS. But as we said in the above, we cannot accurately calculate how many sensor nodes the data would pass through in region B. Hence, we are going to calculate the length of the line segment to estimate the minimum hop number that data would pass through in region B. In Fig. 2, the line segment from source node to the BS is the shortest path that connects source node with the BS. And the line segment lies on region B represents the path that data pass through region B.

As Fig. 3 shows, we assume the BS is located at the origin of the coordinate plane. For simplicity, here the square regions are assumed to have lengths 1. Region \((i,j)\) denotes the region satisfies \(i-1 \leq x \leq i\) and \(j-1 \leq y \leq j\), for which \(i\) and \(j\) are positive integers. We also assume that the routing paths in different quadrants are independent; that is, the routing paths of the sensor nodes in the first quadrant do not lie on other three quadrants. The following analysis is based on regions in the first quadrant. If the region is in other quadrants, we have to take the absolute value of all coordinates and apply the same method.

We assume that the coordinate of the source node is \((x_0,y_0)\), the linear equation of the line passes through the source node and the BS is \(y = \left(\frac{y_0}{x_0}\right) x\). If the line makes an angle \(\theta\) with the x-axis. Then the slope of the line is \(\tan \theta = \frac{y_0}{x_0}\), and the linear equation can be written as \(y = (\tan \theta) x\). In fact, the length of line...
segment that lies on a region is a function of $\theta$, and let $d(\theta)$ denote it. Since the analysis of $d(\theta)$ is just a complicated geometrical operation, we omit the computation process here and show the result only.

When $i > j$, the length of $y = (\tan \theta)x$ that lies on the region $(i, j)$ is
\[
d(\theta) = \begin{cases} 
  i \sec \theta + (1 - j) \csc \theta 
  & \text{if } \tan^{-1}\left(\frac{j-1}{i-1}\right) \leq \theta \leq \tan^{-1}\left(\frac{j}{i}\right) \\
  - (1 - i) \sec \theta + j \csc \theta 
  & \text{if } \tan^{-1}\left(\frac{j}{i}\right) \leq \theta \leq \tan^{-1}\left(\frac{j-1}{i-1}\right) \\
  0 & \text{if } \theta \geq \tan^{-1}\left(\frac{j}{i-1}\right) \text{ or } \theta \leq \tan^{-1}\left(\frac{j-1}{i}\right)
\end{cases}
\]
(1)

When $i \leq j$ and $i \neq 1$, the length of $y = (\tan \theta)x$ that lies on the region $(i, j)$ is
\[
d(\theta) = \begin{cases} 
  i \sec \theta + (1 - j) \csc \theta 
  & \text{if } \tan^{-1}\left(\frac{j-1}{i-1}\right) \leq \theta \leq \tan^{-1}\left(\frac{j}{i}\right) \\
  - (1 - i) \sec \theta + j \csc \theta 
  & \text{if } \tan^{-1}\left(\frac{j}{i}\right) \leq \theta \leq \tan^{-1}\left(\frac{j-1}{i-1}\right) \\
  0 & \text{if } \theta \geq \tan^{-1}\left(\frac{j}{i-1}\right) \text{ or } \theta \leq \tan^{-1}\left(\frac{j-1}{i}\right)
\end{cases}
\]
(2)

When $i = 1$, the length of $y = (\tan \theta)x$ that lies on the region $(i, j)$ is
\[
d(\theta) = \begin{cases} 
  i \sec \theta + (1 - j) \csc \theta 
  & \text{if } \tan^{-1}(j-1) \leq \theta \leq \tan^{-1}(j) \\
  \csc \theta 
  & \text{if } \theta \geq \tan^{-1}(j) \\
  0 & \text{if } \theta \leq \tan^{-1}(j-1)
\end{cases}
\]
(3)

Next, we will analyze the average power region $p$ consumes while a sensor node in region $q$ transmits data to the BS. As Fig. 4 shows, region $p$ satisfies $i - 1 \leq x \leq i$ and $j - 1 \leq y \leq j$; region $q$ satisfies $k - 1 \leq x \leq k$ and $l - 1 \leq y \leq l$. Let $R_p$ denote region $p$, $R_q$ denote region $q$.

![Fig. 4. Region $p$ has to route the data from region $q$.](image)

Let $L$ denote the line passes through a node in region $q$ and the origin, and $L$ makes an angle $\theta$ with the x-axis (see Fig. 4). We define a function $d_q(\theta)$ as the length of the line segment which $L$ lies on the region $p$. And then define a function $d_q(\theta)$ as the length of the line segment which $L$ lies on the region $q$. Let $\hat{L}_q$ denote the length of the line segment on $L$ from the source node to the boundary of region $q$. Let $[R_q]$ denote the area of region $q$. Let $D_{c,p,q}$ be a random variable that denotes the length of the line segment which $L$ lies on the region $p$. Let $D_{c,q}$ be a random variable that denotes the length of the line segment on $L$ from the source node to the boundary of region $q$.

What we want to know is the expected value of $D_{c,p,q}$. We assume the nodes in the region are distributed according a homogeneous spatial Poisson process, and hence the nodes have the same probability of being located at any point in the region. Then,
\[
E[D_{c,p,q}] = \iiint_{R_q} d_q(\theta) \cdot \frac{1}{[R_q]} dA = \iint_{R_q} d_q(\theta) \cdot \frac{1}{[R_q]} dA = \iint_{R_q} d_q(\theta) dA
\]
(4)

where $d_q(\theta)$ is equivalent to (1), (2), (3).

The expected value of $D_{c,p,q}$ changes with the position of region $q$.

When $k > l$,
\[ E[D_{\text{relay},p,q}] = \int_{\sec\theta}^{\sec\theta} \int_{\tan\theta}^{\tan\theta} d_P(\theta) \cdot r \cdot d\theta \]

\[ + \int_{\sec\theta}^{\sec\theta} \int_{\tan\theta}^{\tan\theta} d_P(\theta) \cdot r \cdot d\theta \]

When \( k \leq l \) and \( k \neq 1 \),

\[ E[D_{\text{relay},p,q}] = \int_{\sec\theta}^{\sec\theta} \int_{\tan\theta}^{\tan\theta} d_P(\theta) \cdot r \cdot d\theta \]

Then analyze the expected value of \( \hat{D}_{\text{cp}} \). When the slope of \( L \) is fixed, the expected value of \( \hat{d}_q \) is \( \frac{1}{2} d_q \), so

\[ E[\hat{D}_{\text{cp}}] = \int_{\theta}^{\theta} \frac{1}{2} d_q(\theta) \cdot \left( \frac{1}{R_q} \right) d\theta \]

\[ = \frac{1}{2} E[D_{\text{cp},p,q}] \]  

3.4. The analysis of power consumption

Next, we define \( H_{\text{cp},p,q} \) to be a random variable that denotes the hop number of the routing path in region \( p \) while a sensor node in region \( q \) transmits to the BS. We assume all sensor nodes have the same transmission range \( r \). The actual length of a region is \( a \). Then,

\[ E[H_{\text{cp},p,q}] = \begin{cases} E[D_{\text{cp},p,q}] \cdot a \cdot r, & \text{when region } q \\
\end{cases} \]

\[ \text{lies to the right or the top of region } p \\
\]

\[ = \begin{cases} E[D_{\text{cp},p,q}] \cdot a \cdot r, & \text{when region } q \\
\end{cases} \]

\[ \text{lies to the left or the bottom of region } p \\
\]

Let \( E_{\text{relay},p,q} \) to be a random variable that denotes the energy that region \( p \) consumes while a sensor node transmits 1 unit of data to the BS. We assume the transmission power consumption of the sensor node is \( p_i \); the receive power consumption of the sensor node is \( p_r \). And we can get the value of \( p_i \) and \( p_r \) from the factory manual of the sensor node. If a sensor node consumes energy \( e_i \) when it transmit 1 unit of data and consumes energy \( e_r \) when it receive 1 unit of data, then

\[ E[E_{\text{relay},p,q}] = E[H_{\text{cp},p,q}] \cdot \left( e_i + e_r \right) \]

\[ = E[H_{\text{cp},p,q}] \cdot \left( \frac{p_i + p_r}{r_{\text{ba}}} \right) \]  

where \( r_{\text{ba}} \) is the transmission/receive bitrate of sensor nodes.

We divide the sensor field into \( m \) regions, and we would deploy \( n_i \) sensor nodes in each region, where \( i = 1,...,m \). Let \( \lambda_i \) denote the reporting rate of each region. It means the amount of data that a region reports to the BS in 1 unit of time. Let \( P_{\text{relay},i,j} \) to be a random variable which denotes the power consumption in relaying data of region \( i \). Then,

\[ E[P_{\text{relay},i,j}] = \sum_{j=1}^{m} \left( \lambda_i \cdot E[H_{\text{cp},i,j}] \cdot \frac{p_i - p_r}{r_{\text{ba}}} \right) \]

However, the transmission unit of the sensor node not only consumes energy when it transmits data, but also when it listens. Sensor nodes are listening frequently. The listening time period of a sensor node is decided by the duty cycle of the MAC layer. We let \( \delta \) denote the duty cycle of the MAC layer. Let \( P_{\text{ba}} \) to be a random variable that denotes the power consumption of the transmission unit of region \( i \). Then

\[ E[P_{\text{ba},i,j}] = E[H_{\text{cp},i,j}] + E[P_{\text{ba},i,j}] \]

\[ = n_i \cdot \delta \cdot p_r + \sum_{j=1}^{m} \left( \lambda_i \cdot E[H_{\text{cp},i,j}] \cdot \frac{p_i - p_r}{r_{\text{ba}}} \right) \]  

where the first term is the power consumption in listening. The second term is the additional power consumption in transmission.

\[ E[P_{\text{cp},i,j}] = n_i \cdot \delta \cdot p_r \]  

But how could we know the reporting rate of regions? One possibility is we had run the same application in this place before. Then we can analyze the reporting rate of regions according to previous data. If we had not run the same application in the same place before, then we have to estimate the reporting rate of regions. Generally, the reporting rate is easy to be estimated only in time-driven applications. To consider the case we cannot estimate the reporting rate, we define \( \kappa_i \) as the popular level of the region. We can estimate the popular level of the region according to the application and the place to be deployed in. The principle is the popular level is proportional to the reporting rate (i.e. \( \kappa_i \propto \lambda_i \)). For instance, in the application that gathers statistics about students’ motion in the campus, we can set the populous entry to 10, while
the lonely corner is set to 1. Let $\lambda_0$ to be a constant such that $\lambda_i = \kappa_i \lambda_0$. Then,  
\begin{equation}
E[P_{ij}] = E[P_{\text{r}ij}] + E[P_{\text{t}ij}]
\end{equation}
\begin{align}
&= n_i \cdot \delta \cdot p_s + \sum_{j=1}^{n} \left( \kappa_j \cdot \lambda_0 \cdot E[H_{\alpha,j} \cdot (p_s - p_i)] \right) \quad (15) \\
& \text{while the additional power consumption in transmission is} \\
E[P_{\text{t}ij}] &= \sum_{j=1}^{n} \left( \kappa_j \cdot \lambda_0 \cdot E[H_{\alpha,j} \cdot (p_s - p_i)] \right) \quad (16)
\end{align}
Let $P_{\text{r}ij}$ to be a random variable that denotes the sensing power consumption of region $i$; let $P_{\text{t}ij}$ to be a random variable that denotes the processing power consumption of region $i$. We assume $p_s$ is the average sensing power consumption of the sensor node; $p_c$ is the average processing power consumption of the sensor node. And we can get the value of $p_s$ and $p_c$ from the factory manual of the sensor node. Then,  
\begin{align}
E[P_{\text{r}ij}] &= n_i \cdot p_s \\
E[P_{\text{t}ij}] &= n_i \cdot p_c
\end{align}
(17) (18)
Let $P_{\text{r}ij}$ to be a random variable that denotes total power consumption of region $i$. Then, 
\begin{align}
E[P_{ij}] &= E[P_{\text{r}ij}] + E[P_{\text{t}ij}] + E[P_{\text{r}ij}]
\end{align}
(19)

3.5. The number of sensor nodes should be deployed into each region

Now, let us go back to the original question. To average the lifetime of regions, how many sensor nodes should we deploy in each region? Let $T_i$ denote the lifetime of region $i$. Assume the initial battery power of all sensor nodes is $e$. In ideal situation, the energy of all sensor nodes is exhausted when the region is dead. Then, 
\begin{equation}
T_i = \frac{n_i \cdot e}{E[P_{ij}]}
\end{equation}
(20)
However, if we have to adopt the redeployment in all regions while only one region is dead, then the remaining energy of alive region is going to waste. Besides, the cost of deployment is very high. So we hope the length of regions’ lifetime is close. Our goal is each region has the same lifetime $T$. Then, 
\begin{align}
&T_1 = T_2 = \cdots = T_m = T \\
&\Rightarrow \sum_{i=1}^{n} \frac{n_i \cdot e}{E[P_{ij}]} = T \\
&\Rightarrow n_i = \frac{T E[P_{ij}]}{e}, i = 1, \ldots, m
\end{align}
(21)
If we would deploy $N$ sensor nodes in the entire sensor network, then 
\begin{align}
N &= \sum_{j=1}^{m} \frac{T E[P_{ij}]}{e} = T \sum_{j=1}^{m} E[P_{ij}]
\Rightarrow T = \frac{N \cdot e}{\sum_{j=1}^{m} E[P_{ij}]}
\end{align}
(22)
Substituting (19) into the above, we obtain 
\begin{align}
n_i &= \frac{E[P_{\text{r}ij}] + E[P_{\text{t}ij}]}{E[P_{\text{r}ij}] + E[P_{\text{t}ij}]} \cdot n \quad i = 1, \ldots, m
\end{align}
(23)
shows, if we deploy \( \sum_{i=1}^{m} \left( \lambda_i \cdot E[H_{\alpha,j} \cdot j] \right) \cdot N \quad i = 1, \ldots, m
(24)
sensor nodes in each region, the length of regions’ lifetime will be close, and then the lifetime of entire sensor network will be maximum.

In the case that we can only estimate the popular level of each region instead of reporting rate, we must calculate the expected value of $P_{\text{r}ij}$ with (15). Then, 
\begin{align}
&\Rightarrow n_i = \frac{\sum_{j=1}^{m} (\lambda_j \cdot E[H_{\alpha,j} \cdot j])}{\sum_{j=1}^{m} (\lambda_j \cdot E[H_{\alpha,j} \cdot j])} \cdot N \\
&\Rightarrow n_i = \frac{\sum_{j=1}^{m} (\lambda_j \cdot E[H_{\alpha,j} \cdot j])}{\sum_{j=1}^{m} (\lambda_j \cdot E[H_{\alpha,j} \cdot j])} \cdot N \quad i = 1, \ldots, m
\end{align}
(25)
Although the above analysis is correct, but in the real case, a region requires a minimum number of sensor nodes to maintain its network function. Hence, we have done some modification to (23). Assume a region requires at least $n_{\text{min}}$ sensor nodes to maintain its network function. And entire sensor network requires at least $N_{\text{min}}$ sensor nodes, where $N_{\text{min}} = m \cdot n_{\text{min}}$. Then, 
\begin{align}
n_i &= \frac{\sum_{j=1}^{m} (\lambda_j \cdot E[H_{\alpha,j} \cdot j])}{\sum_{j=1}^{m} (\lambda_j \cdot E[H_{\alpha,j} \cdot j])} \cdot (N - N_{\text{min}} + n_{\text{min}})
\end{align}
and in the case that we consider the popular level of regions,
\[ n_i = \frac{\sum_{j=1}^{n} (k_j \cdot E[H_{i,j}])}{\sum_{k=1}^{m} \sum_{l=1}^{n} (k_j \cdot E[H_{k,l}])} \cdot (N - N_{\text{min}}) + n_{\text{min}} \]  

(26)

4. Experiments

Fig. 5. The number of sensor nodes deployed into each region with Region-based Deployment Scheme.

Fig. 6. The number of sensor nodes deployed into each region with average deployment.

4.1. The program which contains our model

In previous section, we have analyzed the average length of the routing path and how much energy each region would spend in a data report. However, it’s too complicated to compute the length of the routing path by hand because there are too many cases. Hence, we have written a program which contains these formulas. And we also added our model into this program. With our model, the program will calculate how many sensor nodes should be deployed into each region.

4.2. Simulation environment

Next, we are going to evaluate Region-based Deployment Scheme in Ns-2. As Fig. 5, the sensor field is set to \(3000 \times 3000 \text{ m}^2\), and the BS is located at the left-bottom corner. The number of sensor nodes to be deployed is 350. The transmission range of the sensor is 200 m. We have divided the sensor field into \(3 \times 3\) regions. Each region requires at least 25 sensor nodes to maintain its network function.

First, let us see the average length of the routing path in regions. As Fig. 7 shows, the average length of the routing path lying on region (1,1) is 956.1 m. The one lying on region (1,2), (2,1) and (2,2) is about 270 m. And the one lying on the other regions is about 100 m. It indicates that region (1,1) spends much more energy on routings than other regions.

As Fig. 5 shows, the program had a result that we have to deploy 49 sensor nodes into region (1,1), and 39 sensor nodes into region (1,2), (2,1) and (2,2) respectively, and 36 sensor nodes into other regions. On the other hand, we have to deploy 38 sensor nodes into each region while applying the average deployment (Fig. 6).

Besides, we have set the reporting interval of each sensor to \(n_i/4k_i\). In this example, the popular level of all regions is the same. That is to say, the reporting rate of all regions is the same. Therefore, the reporting rate of the sensor in each region is set to \(n_i/4\).

4.3. Simulation result

We used Ns-2 as the simulation environment, and S-MAC as MAC layer, and DSDV as routing protocol. Our judging criterion is the lifetime of the sensor network which depends on the shortest lifetime of all regions. Hence, we have analyzed the trace file of Ns-2 after the simulation has run for 3000 seconds. We have recorded the time that each region remains 30, 25, 20 and 15 sensor nodes, and the time that each region remains 80%, 60%, 40% and 20% sensor nodes.

Fig. 8 shows the time each region remains 25 sensor nodes. Under the average deployment, region (1,1) has the shortest lifetime. And under our scheme it becomes that region (2,3) has the shortest lifetime which is longer than the average deployment. Hence, when we take remaining less than 25 sensor nodes as that a region is
Fig. 8. The time each region remains 25 sensor nodes.

Fig. 9. The time each region remains 60% sensor nodes.

dead, under our scheme the lifetime is longer by about 10%.

Fig. 9 shows the time each region remains 60% sensor nodes. Under our scheme the lifetime is longer than under the average deployment by about 10%.

Now let us observe the lifetime of the sensor network. We define the lifetime of the sensor network as the shortest lifetime of regions. Fig. 10 shows the lifetime of the sensor network under two schemes. If the criterion is 25 nodes, the lifetime under Region-based Deployment Scheme is longer than under the average deployment by about 10%. The simulation has proved our theory is correct. Deploying more sensor nodes in high-loading region can make it have longer lifetime.

5. Conclusion

In this paper, we have proposed the Region-based Deployment Scheme. We suggest that we divide the sensor field into several square regions, and input the reporting rate or the popular level of each region into our mathematical model. With our mathematical model, we can know how many sensor nodes should be deployed into each region. Under this scheme, the lifetime of each region will be almost equal. In other words, when a region is died, the energy of other regions is also exhausted. Then the energy of entire sensor network is not wasted. Hence, the lifetime of entire wireless sensor network becomes maximum.

6. References