Corona Sensor Cell based Deployment for Multiple-Sink Wireless Sensor Networks

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Abstract: - Wireless sensor network (WSN) scalability and energy-efficiency issues remain an interesting research problem. This paper presents a multiple-sink deployment scheme for large-scale WSNs. An 8-rings Corona style sensor network is regarded as a Corona Sensor Cell (CSC) based on coarse-grain location awareness for energy-efficiency consideration. The overall task includes nodes training and data delivery. Let a specific WSN consists of N CSCs. In training protocol periodic, the costing ratio for the traditional single-sink scheme compares with our proposed multi-sink scheme is approximately $0.7\sqrt{N}$. In data delivery period, the sensor node power consumption ratio for the traditional single-sink scheme compares with our proposed multi-sink scheme is approximately $0.9\sqrt{N}$. Thus, the proposed scheme is more energy efficiency than the traditional scheme.

Key-Words: - Wireless sensor network, Coarse-grain location aware, Corona sensor cell, Training protocol, Multiple-sink.

1 Introduction

Wireless sensor networks play an important role in monitoring and collecting data from various geographical terrains [1][2][3]. Dense sensors distributing, multi-hop ad hoc networking without pre-deployed infrastructure and self-organization are some import properties for WSN [4][5][6]. Low energy consumption and efficient routing are very important requirements [7][8][9] for WSNs. To satisfy the low energy consumption and efficient routing requirements, location awareness information supplied in a wireless node is playing a decisive role in WSN deployment. Because of the characteristic limits of WSNs, the exact geographic location is difficult to define in a real sensor if the sensor is not equipped with a Global Position System (GPS) receiver. Hence, coarse-grain location awareness is more feasible for a rough approximation of the exact geographic location. To provide coarse-grain location information, a training protocol is applied for faster deployment within a specified environment with a large quantity of wireless sensors without any costing equipment [10].

In recent years, several researchers began to take notice of the important issue of how to provide a set of efficient training protocols. A training protocol can use a single anchor node, called sink to complete the task - a rough approximation of the exact geographic location, sent by every nodes. The training protocol is used mainly to establish two classes of location awareness information: coronas and wedges [10]. A corona system means that the deployment area is covered by *k* coronas [11].

Bertossi et al. proposed a scalable energy-efficient protocol, called the Corona Training Protocol to train the coarse-grain location awareness information necessary to deploy a lot of sensors in a WSN. This protocol is helpful for sensor data aggregation, but it is only applicative to a single sink system. Instinctively, a great advantage in this system is energy-saving, when the increasing number of coronas will result in a smaller hop distance for each sensor node delivery to the single sink. Inversely, more energy consumption occurs for the sink that sends beacons to each corona when the number of coronas becomes too large. Exceeding the corona number limitation does not save energy because the hop count from a source node to the destination is increased and node lifetime is indirectly decreased.

As discussed above, a novel corona training protocol is proposed for the massive number of sensors deployed in a multi-sink WSN with no infrastructure facilities. The advantages of our proposed protocol are multi-sink enabled, energy-saving, efficient and easy to implement. We present a Corona Sensor Cell (CSC) to limit the number of coronas for better performance. We designed an energy-efficient deployment scheme. The cellular characteristic is utilized to develop a resource reuse scheme to archive the reuse goal that only four sets of signal sequences are used in a multi-sink WSN.

The rest of this paper is organized as follows. Section 2 defines the wireless sensor cell and proposed multi-sink system model architecture for an energy-efficient training protocol. Section 3 presents two training protocols for a simple WSN and a multi-sink WSN, respectively. Section 4 discusses the training cost. Section 5 discusses the data delivery power consumption. Concluding remarks are presented in Section 6.

2 System model

In this section, we first regard a simple WSN, composed of one sink node and n sensor nodes. We assume that the sink node broadcast range is denoted by R. The effective range of the sink node is assumed to be r. The area of a simple WSN is divided to k area. Each area is the concentric ring as show in Figure 1. We define a ring as the range between two neighboring corona circles. The ring width is r to be the same as the first ring radius. Notice that the first ring is the same as the first corona. Figure 1 illustrates a trained WSN using the corona training protocol [13].

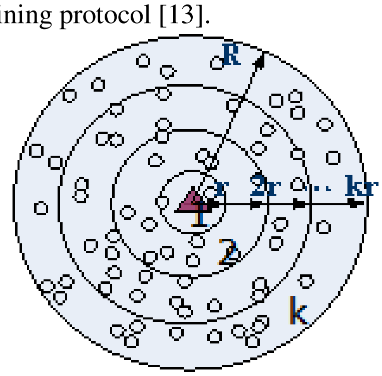

Fig. 1. A trained simple WSN

Table 1 lists the relative network parameters. For such network, the advantages are less cost and easier to realize, but the network is not appropriate for a large scale geographic area. However, for a WSN deployed in a large geographic area, a sensor node deployed farther from center needs to deliver its data to the sink node through numerous rings, resulting in a transfer delay and data aggregation problems.

Table 1. A ring scheme WSN's parameters.

Para-meter	***Description***
△	Sink node
○	Sensor node
R	Radius of broadcast range for a sink
r	Radius of each ring width
k	The number of concentric circles

We define a simple WSN consisting of k rings or concentric circles as a CSC, where k is equal to 8. The value of k will be discussed in the next section. We next deploy seven CSCs to establish a communication layout with mutually adjacent CSCs. Each sink is located at the center of a CSC as shown in Fig. 2a. The distance between both centers located between two adjacent CSCs is D equal to 2R. The shape of an equilateral hexagonal hive is similar to a cellular communication system. Some space or room called the uncover region in the near boundary of triple CSCs is not covered by this architecture, as shown in Fig. 2a. Notice that a sensor will fail to be trained if it is located in the uncover region. To improve this disadvantage, we make the neighboring CSCs overlap and cross at one point P. The uncovered room will be removed and the overlapping area is minimized as shown in Fig. 2b.

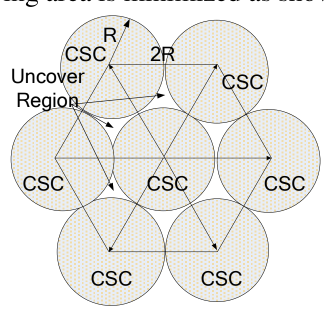

Fig. 2a

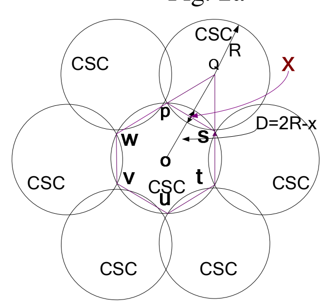

Fig. 2b Two deployments type of CSC

We define the widest overlapping area to be x as shown in Fig. 2b. According to this geometric relationship, the distance of D can be calculated using

$$D = 2R - x = 2R \times \sin 60^o$$
$$= 1.73R \quad , \tag{1}$$

where R is radius of CSC. We know that R equals to $k*r$. Hence, the overlapping length x can be obtained by

$$x = 2R - D = 0.27R \tag{2}$$

A CSC area equals to the hexagonal hive PSTUVW area as shown in Fig. 2b to be calculated using

$$A_{CSC} = 6 \times R \times \sin 60^o \times R / 2$$
$$= 2.6R^2 = 2.6(kr)^2 \tag{3}$$

3 Training Protocol

In the previous section, we introduced two trained models for a simple WSN and a multiple sink WSN, respectively. In this section, two trained protocols are proposed that apply to both models, respectively. The sending and receiving model between a sensor and its sink will be defined first and then we will use the specification to train the sensors and determine which ring of a specified CSC the sensor belongs to after the training is complete. We next introduce the sensing model and present two training protocols for multiple CSCs. In this section, we will discuss two types of training protocol architectures, single sink and multiple sinks.

3.1 Sensing Model

In a WSN, the sensitivity S (signal intensity) between a sensor node and its signal source apart from d, can be expressed by [12]

$$S(d) = \frac{\lambda}{d^\alpha} , \tag{4}$$

where λ is a positive sensor-dependent parameter. The value of α is generally between 2 and 5 and depends on the environmental parameters. In a general environment, the value of α is 2 in this paper because a larger sensitivity range is required. Notice that the sensitivity rapidly decreases as the distance increases.

We assume that the sensitivity for all sensors located in the same ring is the same. In Fig. 3, the symbol Sr_i means the receiving sensitivity for a sensor located in the i-th ring, St indicates sending sensitivity at the sink node, and r is the radius of the first ring or ring width of each ring. We are concern with signal intensity ratio between receiving and sensing sensitivities. It can be calculated using by

$$L_i = Sr_i / St = 1/(ir)^2 \tag{5}$$

where i is the ring layer's number i=$1, 2, 3,$---and r is a distance between the adjacent rings. L_i is the link gain for the sink and the nodes in the i-th ring that is a key factor for obtaining an energy-efficient CSC. Bertossi *et al*. [13] proposed an efficient corona training protocol for training a WSN but the protocol disadvantage is it consumes too much power when the number of rings is very large. To obtain better receiving/sending signal intensity, the lower boundary of the intensity is limited to 0.01. The upper ring number boundary is up to 10 as calculated by Equation (5) when the condition, k=1 holds. However, the CSC area will be reduced along with a decrease in the k value, resulting in more CSCs required in a WSN deployed over a wide area. In other words, more sinks are required for covering a wider area, therefore the WSN setup cost will increase. There is a trade-off between the setup cost and reducing energy consumption.

From Equation (2), the CSCs' overlapping length x is given as $0.27kr$. We adjust a smaller ring number k value from 10 to 8 to decrease the CSC overlapping length x from $2.7r$ to $2.1r$. The length is near the width of two rings. It is convenient for four different beacon signals as designed in Section 3.3. Table 2 presents more detail.

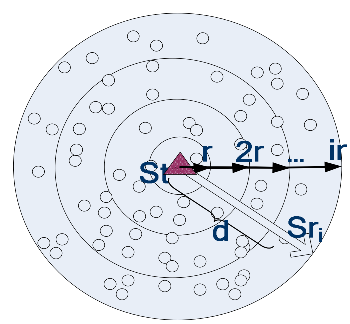

Fig. 3 The sensing model for a simple WSN

3.2 Single Sink Training Protocol

In the previous section, we introduced the sensing model. Using this model, the upper ring boundary is easily calculated. The boundary is suitable for designing an energy efficient CSC. In this section, we will use the result to design a single sink training protocol for a CSC. The process procedure for the single sink training protocol is listed as follows. First a series of ladder signals is sequentially sent by the sink from the strongest signal to the weakest to every sensor in all rings at a discrete time sequence t_i, where i is an integer and $1 \leq i \leq 9$. When the signal intensity descends below one specific value, such as 0.9, the sensor node fails to detect the signal from the sink and the ring information for this sink can be determined by summarizing the time sequence and total ring number. For instance, all sensor nodes in ring 7 detect the beacon signal at t_1 and t_2, but these sensor nodes cannot detect the beacon signal at t_3. The training job can be done for all sensor nodes in ring 7 and its ring number is calculated using the equation z=9-3+1=7. Figure 4 demonstrates that the signal *St* is sent by the sink node and the beacon signal is received by all sensor nodes in ring 7.

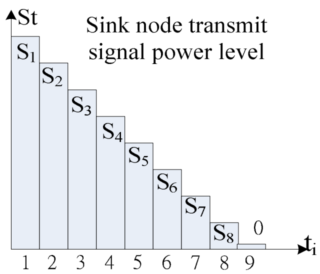

Fig.4a Transmit signal sent by the sink node

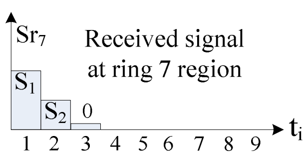

Fig.4b The received signal at ring 7

From Equation (5), the signal sent out from the sink node is $(ir)^2$ if the signal Sr_i received by a sensor in the i^{th} ring is equal to 1. The signal *St* is sent by the sink node for the entire time sequence t_i equals 1 to 9 can be given using

$$\begin{aligned} St &= (8r)^2\delta[t_1-1]+(7r)^2\delta[t_2-2]+\ldots \\ &\quad +(r)^2\delta[t_8-8]+0 \\ &= \sum_{i=1}^{9}((9-i)r)^2\delta[t_i-i] \end{aligned} , \tag{6}$$

where i is an index number, t_i is a discrete time sequence, t_i= {1, 2, 3, 4, 5, 6, 7, 8, 9}, and a unit stepping function δ is defined by

$$\delta[n]=\begin{cases}1 & n=0\\ 0 & n\neq 0\end{cases} \tag{7}$$

Assume Sr_z as the signal intensity received by a sensor in the z ring, where 1≤z≤8. A sensor in the z ring detects the sink node signal during discrete time periods t_i, where $1\le i\le z$. The sensor will fail to detect the signal during the time periods, where $z+1\le i\le 9$. The received signal intensity for a sensor in the z ring is calculated using

$$\begin{aligned} Sr_z &= St/z^2 \\ &= \sum_{i=1}^{9-z}((9-i)r/z)^2\delta[t_i-i] \end{aligned} . \tag{8}$$

According to Equation (7), we can get the Sr_z = 0 while $i=9-z+1$. In other words, some sensor nodes in z ring will receive the signal intensity Sr_z from 1 to 0 in the t_i period, and the ring number is easily calculated using Equation (8) at this time. For example, while Sr_z =0, we infer that z=9-3+1=7 if i=3. The training and trained algorithms for single sink node and every sensor are shown in Figs. 5a and 5b, respectively. The variable, *mode* is used in the running state for every node. For the sink, there are two modes, TRAINING and DELIVERY. TRAINED and DELIVERY modes exist in a sensor. In the TRAINING mode, the sink will send 9 beacon signals to all sensors, as shown in Fig. 4a. After beacon sending is complete, the sink will switch its mode into DELIVERY. A sensor initially set mode to TRAINED when its power supply is turned on. The sensor will continuously detect the signal *Sr* sent by the sink until the *Sr* level is changed from 1 to 0. The sensor's ring index will then be calculated using Equation (10).

SingleSinkTraining algorithm for sink
Begin
mode = TRAINING;
For i=1 to 9
    transmit the beacon signal St(i) ;
    delay(T_d);
    % Td is a constant number for delay time
End For
mode = DELIVERY;
End Algorithm

Fig.5a Sink training algorithm

SensorTrained algorithm for sensor
Begin
mode = TRAINED;
Synchronize with sink node
While (1)
  detect received signal Sr(i) from $Sink_i$;
  if Sr(i) signal level change from 1 to 0
      then ring index=10-i;
    Exit While
  delay(Td);
End While
mode = DELIVERY;
End Algorithm

Fig.5b Sensor trained algorithm

3.3 Multiple Sink Training Protocol

As shown in Fig. 2b, a multiple-sink structure for WSNs can be regarded as neighboring CSCs crossing internally with adjacent sink nodes apart from 1.73R each other. When every sink node sends out the strongest signal to every ring at the same time, a collision will occur among the overlapping areas in adjacent CSCs. Hence, we design a prevention scheme in which adjacent CSCs send out signals with different intensity signals at the same time. We will illustrate this more detail in the next paragraph.

A special code called C_i is assigned by every CSC_j , where $1 \le i \le 4$ and $1 \le j \le 7$ for discriminating signals, as shown in Fig. 6a. Then C_1, C_2, C_3, and C_4 are used to present four variable revolving signal sequences, described as C_1: [S_1, S_2, S_3, S_4, S_5, S_6, S_7, S_8, 0], C_2: [S_3, S_4, S_5, S_6, S_7, S_8, 0, S_1, S_2], C_3: [S_5, S_6, S_7, S_8, 0, S_1, S_2, S_3, S_4], and C_4: [S_7, S_8, 0, S_1, S_2, S_3, S_4, S_5, S_6] respectively. Figure 6b presents C_2 signal sequences and all sequences are listed in Table 2. Because the CSC_2 is equivalent to CSC_5 a symmetrical location is considered. The symbols C_2, C_3, and C_4 are used to represent the {CSC_2, CSC_5}, {CSC_3, CSC_6}, and {CSC_4 , CSC_7}, respectively. Notice that C_1 is only using in CSC1 not share other due to the sink is located at the center and is adjacent with the others.

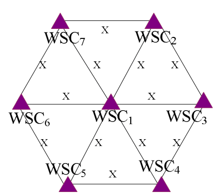

Fig.6a CSC labeling

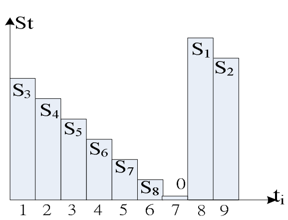

Fig.6b C2 signal sequences

Table 2 Signal sequences for four label types

t_i	1	2	3	4	5	6	7	8	9
C_1	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	0
C_2	S_3	S_4	S_5	S_6	S_7	S_8	0	S_1	S_2
C_3	S_5	S_6	S_7	S_8	0	S_1	S_2	S_3	S_4
C_4	S_7	S_8	0	S_1	S_2	S_3	S_4	S_5	S_6

Based on the single CSC, we revise Equations (6) to (8) to develop our multi-CSC scheme. We define the symbol St_k^p to express the four beacon signal types using the sink node in a period time slot for multiple sink training protocol, where p is an item of the set of {0, 2, 4, 6} and k is an index of the CSC. The initial value of p is set when t_i=1.

$$St^p = \sum_{i=1}^{9-p}((9-i-p)\times r)^2\delta[t_i - i] + \sum_{i=9-p+1}^{9}((i+p-1)\times r)^2\delta[t_i - i]. \tag{9}$$

According to Equation (9), we setup the signal received by z-th ring is Sr_z^p, and the equation for calculating Sr_z^p is listed by

$$\begin{aligned} Sr_z^p &= St^p / z^2 \\ &= \sum_{i=1}^{9-p-z}\left(\frac{(9-i-p)\times r}{z}\right)^2\delta[t_i - i] \\ &\quad + \sum_{i=9-p-z+1}^{9}\left(\frac{(i+p-1)\times r}{z}\right)^2\delta[t_i - i]. \end{aligned} \tag{10}$$

From above equation, Sr_z^p equals to zero while the condition $i=9-p-z+1$ is hold. This means that some sensor nodes in the z ring at t_i will switch the signal Sr_z^p intensity from 1 to 0 when the sensor detects Sr_z^p .We utilize the switching mechanism to develop a calculating ring index scheme. The equation is given using

$$\begin{aligned} &z = 10 - p - i \quad if \quad z > 0 \\ &z = z + 9 \qquad if \quad z < 0 \\ &z = 10 - p - 1 \quad if \quad no \quad signal \quad was \quad detected \end{aligned} \tag{11}$$

3.4 The Algorithm and Simulation of Multiple Sink Training Protocol

The training algorithm for multiple sink WSN is shown in Fig. 7a and 7b. The algorithm is different from the single sink training protocol is beacon code selection for sinks and ring index assignment for sensors. Beacon code selection is referred to Table 2.

MultiSinkTraining algorithm for sink
Synchronize all sink node
Transmit beacon signal type p;
Begin
mode = TRAINING;
For i=1 to 9
    transmit the beacon signal St(i) ;
    delay(T_d);
    % Td is a constant number for delay time
End For

mode = DELIVERY;
End Algorithm
Fig.7a Sink training algorithm

SensorTrained algorithm for sensor
Synchronize with sink node
Receive beacon signal p;
Begin
mode = TRAINED;
Synchronize with sink node
While (1)
detect received signal Sr(i) from $Sink_i$;
if Sr(i) signal level change from 1 to 0
computing ring index z
z=10-p-*i* *if z>0*
z=z+9 *if z<0*
z=9-p *if no signal was detected*
Exit While
delay(Td);
End While
mode = DELIVERY;
End Algorithm
Fig.7b Sensor trained algorithm

Next, we will show the simulation below. First, eight sensor nodes are randomly deployed in each ring as shown in Fig. 8. We supply two variant training codes C_1 and C_2. The C_1 and C_2 sequence signals are [64, 49, 36, 25, 16, 9, 4, 1, 0] and [36, 25, 16, 9, 4, 1, 0, 64, 49], respectively. These signals are sequentially sent by the sinks and then received by each sensor node at t_i, where $1 \le i \le 9$. The sensor node ring index can be computed from the received data.

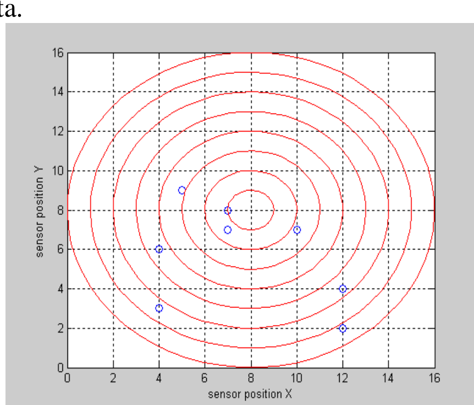

Fig. 8. Eight sensors were deployed randomly in each ring

Tables 3 and 4 show that these signals sequentially send one training code of C1 and C2 are received by each node, respectively. The values in Tables 3 and 4 is calculated using Equation (11). Relative parameters for sensors include PN, X, Y, D, and Z to represent Point Name, x-axis location, y-axis location, and Euler distance, and ring index, respectively. In Tables 3 and 4, the gray rectangle represents that a code is trained complete in a sensor.

Table 3. A CSC receives C_2 code when p=2 and z=10-p

PN	X	Y	D	t1	t2	t3	t4	t5	t6
N1	7	8	1.0	64	49	36	25	16	9
N2	5	9	3.1	6.3	4.8	3.5	2.4	1.5	0.
N3	10	7	2.2	12.7	9.7	7.1	4.9	3.1	1.
N4	4	6	4.4	3.1	2.4	1.7	1.2	0.7	0.
N5	12	2	7.2	1.2	0.9	0.6	0.4	0.3	0.
N6	12	4	5.6	1.9	1.5	1.1	0.7	0.4	0.
N7	7	7	1.4	31.9	24.4	17.9	12.4	7.9	4.
N8	4	3	6.4	1.5	1.1	0.8	0.6	0.3	0.

Table 4. A CSC receives C_2 code when p=2 and z=10-p-*i* (or z=z+9 if z<0)

PN	X	Y	D	t1	t2	t3	t4	t5	t6	t7	t8	t9	z
N1	7	8	1.0	36	25	16	9	4	1	0	64	49	1
N2	5	9	3.1	3.5	2.4	1.5	0.8	0.3	0	0	6.3	4.8	4
N3	10	7	2.2	7.1	4.9	3.1	1.7	0.7	0.1	0	12.7	9.7	3
N4	4	6	4.4	1.7	1.2	0.7	0.4	0.1	0	0	3.1	2.4	5
N5	12	2	7.2	0.6	0.4	0.3	0.1	0	0	0	1.2	0.9	8
N6	12	4	5.6	1.1	0.7	0.4	0.2	0.1	0	0	1.9	1.5	6
N7	7	7	1.4	17.9	12.4	7.9	4.4	1.9	0.4	0	31.9	24.4	2
N8	4	3	6.4	0.8	0.6	0.3	0.2	0	0	0	1.5	1.1	7

3.5 Cell-based Wireless Sensor Networks

We composed one middle size CSC by combining seven CSCs. The hexagon symbol is used to indicate the CSC. We established the layout using a double-column alternating arrangement –C_1, C_3, C_1, C_3, …placed in the 1st column; C_2, C_4, C_2, C_4, …placed in the 2nd column; C_3, C_1, C_3,

C_1, ….placed in the 3rd column; C_4, C_2, C_4, C_2, …placed in the 4th column, as shown in Fig. 8. Similar CSC signal types intersect so the signal intensity of a neighboring CSC will not repeat the same pattern. The architecture is called Cell-based WSNs.

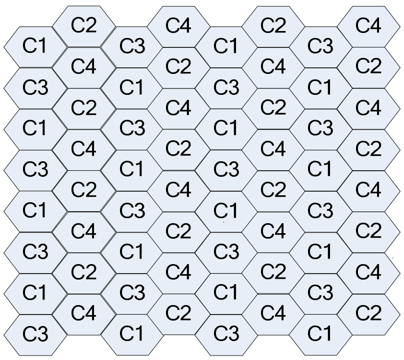

Fig. 9 Cell-based WSN

4. Training Cost

Ring training is a necessary for coarse-grain location in the beginning period. The wider coverage area and less training power energy consumption are better training cost factors. They will be used to improve overall WSN performance. Following we will discuss these elements in detail.

4.1 Ring Numbers Discussion

In Section 3.5, we showed the Cell-based WSN architecture. It extends coverage areas using multiple sink combination. Here, we discuss the relationship between Multiple-Ring-Single-Sink and multiple CSCs in the situation having the same coverage area. A single CSC area deduced from Equation (3) is $Acsc=2.6(kr)^2$. Then the total coverage area of n_s CSCs is

$$A_{ns} = n_s \times A_{csc} = 2.6 n_s (kr)^2 \tag{12}$$

Comparatively, the area of m-rings-single-sink is

$$A_{mr} = \pi \times (mr)^2 \tag{13}$$

where m is ring numbers.

To setup an equal coverage area between the single sink WSN and the multiple sink CSC $A_{mr}=A_{ns}$, we can find the ring numbers m of single node is larger than the ring numbers k of CSC from Equation (14).

$$m = 0.91 k \sqrt{n_s} \tag{14}$$

4.2 Sink Node Training Power Consumption

In this section, we will discuss the sink node beacon signal power consumption using two training modes, single sink power consumption E_s^m and multiple sink power consumption $E_{wsc}^{n_s}$ in a situation having the same coverage area. From Equation (6), we can deduce the required power E_s^m using Equation (15), meant for completing the m rings signal transfer during the time sequence for a single sink WSN with m rings.

$$\begin{aligned} E_s^m &= \sum_{i=1}^{m} (ir)^2 \\ &= \frac{m(m+1)(2m+1)}{6} r^2 \\ &= \frac{2m^3 + 3m^2 + m}{6} r^2 \\ &\approx (0.25(k\sqrt{n_s})^3 + 0.07(k\sqrt{n_s})^2) r^2 \quad . \end{aligned} \tag{15}$$

Then we calculate the power $E_{wsc}^{n_s}$ for a WSN composed of n_s CSCs as Equation (16).

$$\begin{aligned} E_{wsc}^{n_s} &= n_s \sum_{i=1}^{k} (ir)^2 \\ &= \frac{k \times (k+1) \times (2k+1)}{6} n_s r^2 \\ &\approx (0.33k^3 + 0.5k^2) n_s r^2 \quad . \end{aligned} \tag{16}$$

The cost ratio of two training modes $E_s^m : E_{wsc}^{n_s}$ is listed in Equation (17) as shown in Fig. 10. While n_s is equal to 10~100, the ratio $E_s^m : E_{wsc}^{n_s}$ is equal to 2~6.4, that is said more sinks in a CSC can consume less power. Moreover, we can see the ratio is generally stable for various ring numbers.

$$\begin{aligned} E_s^m : E_{wsc}^{n_s} &= \frac{(0.25(k\sqrt{n_s})^3 + 0.07(k\sqrt{n_s})^2) r^2}{(0.33k^3 + 0.5k^2) n_s r^2} \\ &\approx \frac{0.25k\sqrt{n_s}}{0.33k + 0.5} \quad . \end{aligned} \tag{17}$$

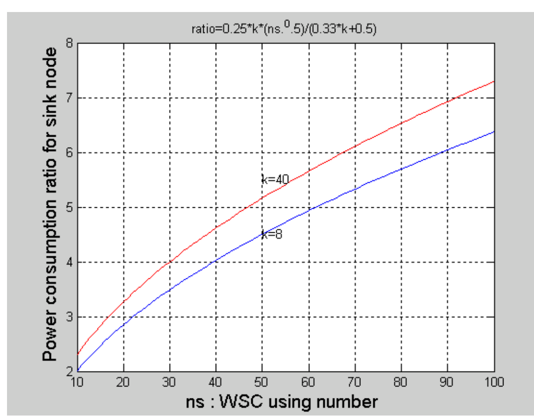

Fig. 10 Sink node training power consumption ratio

5. Data Delivery Power Consumption

After the training phase is completed, the sinks or sensors in WSN will switch their state into the working mode or data delivery mode. A sensor node will deliver its data from the *i-th* ring to its sink node. The required power for an entire WSN will be explained below.

5.1 Delivery Model

First, we show a data delivery scheme in Figure 11.

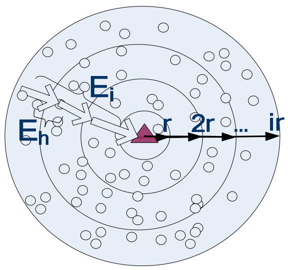

Fig. 11 Power consumption in data delivery mode for a simple WSN

The E_i denote as the total required power is listed in Equation (18). The h is the maximum transfer radius for a single sensor node, c is the environment constant, and E_h is the power consumption for a single hop. The total power consumption for a sensor node in the *i-th* ring transferred to a sink node is proportional to ring numbers i.

$$E_i = i \times (ch_x^{\ 2}) = i \times E_h \quad . \tag{18}$$

5.2 Power Consumption

Assume n sensor nodes deployed uniformly in a simple WSN with m rings, the distribution ratio η_i is proportional to each ring area as Equation (19) - $A_i - A_{i-1}$ is meant for the area of i^{th} ring and A_k is meant for whole ring area.

$$\begin{aligned}\eta_i &= (A_i - A_{i-1}) / A_k \\ &= \pi((ir)^2 - ((i-1)r)^2) / \pi(kr)^2 \\ &= (2i-1)/k^2 \quad .\end{aligned} \tag{19}$$

Let *f(i)* represent a probability mass function (pmf) for one incident, and $f(i) = \eta_i$ is a random process. i is the ring index and is a random variable parameter that changes randomly along with the incident determined by the sensor node location. Taking single CSC k= 8 as example, the sensor node pmf of every ring is drawn in the Fig. 11 in accordance with Equation (19). Further said, the mean value μ can be known by the Equation (20).

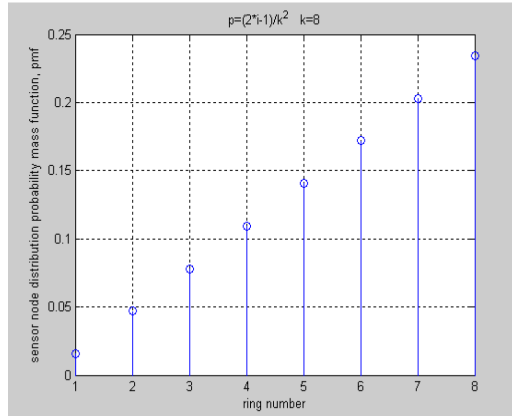

Fig. 12 Sensor node distribution pmf on each ring

$$Let \quad P(X = i) = f(i) \tag{20}$$

$$\begin{aligned}\mu_k &= E[X] = \sum_{i=1}^{k} if(i) \\ &= \sum_{i=1}^{k} i \frac{2i-1}{k^2} \\ &= \frac{1}{k^2} \sum_{i=1}^{k} (2i^2 - i) \\ &= \frac{1}{6k}(4k^2 + 3k - 1) \quad .\end{aligned}$$

Let n sensor nodes be deployed uniformly in a simple CSC and the occurrence probability is ρ, and the mean ring number is μ_k, and the transferring power of single hop is E_h. We can compute the whole average power of transfer E_1 and take Equation (20) to replace μ_k,, as Equation (21).

$$\begin{aligned}E_1 &= n \times \rho \times \mu_k \times E_h \\ &= \frac{(4k^2 + 3k - 1)n\rho E_h}{6k} \\ &\approx (0.67k + 0.5)n\rho E_h \quad .\end{aligned} \tag{21}$$

Expanding this to the applied range; we can obtain the total power E_{ns} as Equation (22) using n_s CSCs.

$$\begin{aligned}E_{ns} &= E_1 \times n_s \\ &= (0.67k + 0.5)n\rho E_h n_s \quad .\end{aligned} \tag{22}$$

Oppositely, setup nxn_s sensor nodes dispread out the single sink node WSN with multiple rings, the whole power E_s of transmission is listed in the Equation (23).

$$\begin{aligned}E_s &= n \times n_s \times \rho \times E_h \times \mu_m \\ &= n \times n_s \times \rho \times E_h \times \frac{1}{6m}(4m^2 + 3m - 1) \\ &\approx (0.67m + 0.5) \times nn_s \rho E_h \\ &\approx (0.67 \times 0.91k\sqrt{n_s} + 0.5) \times nn_s \rho E_h \\ &\approx (0.61kn_s^{\ 1.5} + 0.5n_s)n\rho E_h .\end{aligned} \tag{23}$$

The ratio of two sensor modes –single sink and multiple sink mode, the mean power consumption of transmission ($E_s : E_{ns}$) is listed in Equation (24) and shown in Fig. 12. While n_s is equal to 10~100 for k = 8, the ratio ($E_s : E_{ns}$) is equal to 2.7~8.6, that is said more sinks in a CSC its power consumption is less than a simple WSN.

$$E_s : E_{ns} = \frac{(0.61kn_s^{1.5} + 0.5n_s)n\rho E_h}{(0.67k+0.5)nn_s\rho E_h} = \frac{0.61kn_s^{0.5}+0.5}{0.67k+0.5} \quad . \qquad (24)$$

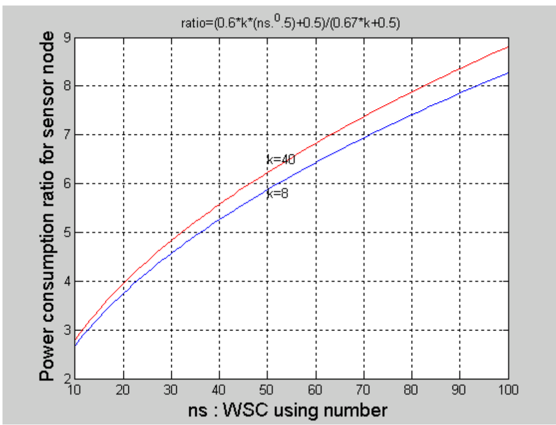

Fig.13. Power consumption ratio E_s:E_{ns} in data delivery mode

6. Conclusions

Using low power technology to quickly train a large number of sensors without GPS equipment deployed in a large geographic environment is very difficult. The corona training protocol is proposed to establish the coarse-grain locations for a WSN, but not to fit a large scale WSN when the number of rings becomes too large. We proposed a deployment scheme using multiple sinks for large-scale WSNs based on suitable ring numbers sink nodes, regarded as a CSC. Overlap technology was been considered to solve sensors deployed in uncovered areas. Training and trained protocols were proposed for single CSC and multiple CSCs to save energy. When multiple CSCs are extended as a cell-based WSN, only four sets of code sequences are needed in our system; hence few resources are required because a reuse mechanism is designed. We analyzed power consumption in training and data delivery modes in this article. For a specific WSN consisting of N CSCs in which each CSC has 8 coronas, the sink node training power consumption ratio for the traditional single-sink scheme compared with our proposed multiple-sink scheme is approximately $0.7\sqrt{N}$ and $0.9\sqrt{N}$ in training and data delivery modes, respectively. A future research direction is lifetime evaluation using variant sensor node distribution in WSNs.

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