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An Energy Aware-Based Complete Coverage and Connectivity Scheme in Clustered Wireless Sensor Network

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Abstract

Keeping the network coverage and maintaining high connection are the goal of the wireless sensor networks (WSN). Therefore, network coverage becomes the focus of research, then an Energy aware-based complete coverage and highly connectivity scheme is proposed in this paper, which named EACC. In EACC scheme, firstly, the relationship between overlapping area of two sensor nodes' sensing area and distance between them is analyzed, and results show that overlapping area is non-linearly reduced with the increase of distance. Secondly, each cluster head (CH) makes use of the coverage area and residual energy of nodes to determine whether the node is the active node or sleep node. Moreover, in order to maintain the connectivity, any one node is in another node communication range. Finally, compared with similar schemes, extensive simulations results show that EACC scheme outperforms other schemes.

***Keywords**: Wireless sensor networks; Coverage ratio; Energy consumption; Connectivity; Sleep*

1. Introduction

Nowadays, wireless sensor network (WSN) are considered as an effective tools to monitor and track applications, such as seismic monitoring, health care monitoring, and crop monitoring. WSN consists of low power, low cost, limited battery power sensor nodes. These sensor nodes are capable of collecting some information, and processing it, storing the information. If necessary, sensor nodes will communicate with other sensor nodes until the collected data reaches sink node.

Every sensor node has sensing capability through which it can sense the data within a limited area called sensing radius. The sensing data is may processed and sent to sink node by communication. Therefore, both sensing data from environment and sending the data to the sink node are considered in WSN, it involves two key issues that network coverage and connectivity in the desired area (Misra, S.*et al*, 2012).

In general, coverage of sensor nodes is considered as how well sensor nodes monitor the specified environment. Basically, the coverage is divided into area, target and barrier coverage. In area coverage, all point of the given entire area is in the sensing range of at least one active node (Arora P A. 2014). For network lifetime, numbers of active sensor nodes are as small as possible to save energy. Target coverage is considered as set of discrete points in the given field of interest. Any target area is covered by active sensor nodes, which can't be less than one (Kar S, 2013). Target coverage is usually used in military applications. Barrier coverage refers to observing the movement of mobile objects that enter into the boundary of a given field of interest (Saipulla A, Cui J H, 2014).

Keeping network coverage is basic requires of WSN. The purpose of research is that requirement of network coverage is satisfied by the least amount of active node. How to maximize the sensing area coverage ratio of perception area with minimum number of

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sensors is area coverage' problem (Bang Wang, 2011). It is a critical key for many applications such as battlefield surveillance, wildlife monitoring in the forests, *etc*. The area coverage problem becomes a bit more complicated in WSN since that we need to determine the active sensing nodes (Tian D, 2012.). In addition, the overlap coverage area should be reduced to be as minimum as possible. Scheme of solving the problem should be energy-efficient to prolong the network lifetime.

There are most research in addressing the area coverage problem. Different approach-based existing solutions in literature are proposed by researchers. None of these works consider to evenly distribute energy level of the nodes to increase network lifetime. They only try to minimize the number of nodes to conserve energy. However, existing solutions do not always ensure the enhanced network lifetime.

Therefore, for randomly deployed wireless sensor networks, the Energy aware-based complete coverage and connectivity (EACC) scheme is proposed in this paper. In EACC, a cluster head (CH) selects active member sensing nodes based on nodes' covered area and residual energy values. The proposed EACC is neither fully distributed nor centralized. In fact, each CH controls its member nodes in a centralized way.

The key contribution of work are summarized as follow:1) each CH runs EACC scheme to solve area coverage problem, and diminish redundant coverage among intra-cluster, 2) relationship between Euclidean distance of sensor nodes and overlapping area of them is analyzed, analysis results show that overlapping area is indirectly affected by distance.

2. Network Model and Assumptions

In cluster WSN, there are N sensor nodes in an area of A. Cluster WSN has a sink node that collecting sensed data from sensor nodes. Using GPS, each sensor i has a fixed and known location, even $i = 1, 2, \cdots, N$. Every sensor node is uniquely identified by its ID, which we assume an integer number. The realistic assumptions are summarized as follow:

◆ Sensing and communication range: R_s, R_c devote sensing range and communication range of sensor node respectively. Each sensor node is homogeneous in terms of sensing and communication range, as shown in Figure 1(a) and (b).

◆ Euclidean distance: for sensor nodes i and j, Euclidean distance is devoted by $d(i, j)$.

◆ Connecting neighbors: for sensor nodes i and j, if $d(i, j)$ is less than R_c,namely, $d(i, j) \le R_c$, two sensor nodes i, j are said to be connecting neighbors. As shown in Figure 1(a), $R_c = R_s$,then $R_c < 2R_s$ is given in Figure 1(b). Therefore in Figure 1(a), due to $d(i, j) = R_c$, $R_c = R_s$, nodes i and j are connecting neighbors. Similarly, in Figure 1(b), sensor nodes i and j are neighbors relationship. Besides as shown in Figure 1(b), due to sensor node *h* and *g* are inn communication range of *j*, they are connecting neighbor. Therefore, a connecting neighbor must be one-hop neighbor of a sensor node.

◆ Sensing neighbors: if $d(i, j) < 2R_s$, sensor nodes i and j are said to be sensing neighbors, as shown in Figure 1(a), sensor node i and j are sensing neighbor as $d(i, j) = R_s$.Similarly, as shown in Figure 1(b),sensor node *h* or *g* a sensing neighbors of sensor node i, as $d(i, j) < 2R_s$ and $d(i, k) = 2R_s$.

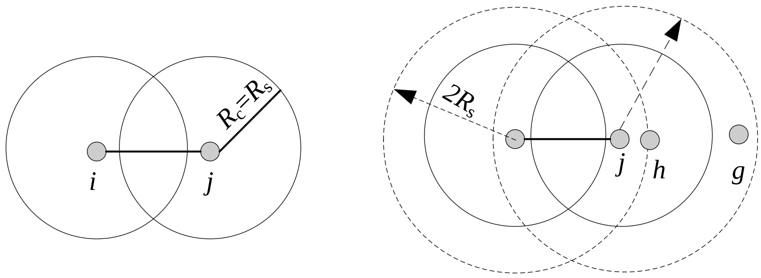

Figure 1. Sensor Node Model

In WSN, A sensor node has multiple tasks such as sensing data from environment, processing data and communicating with other node. This tasks have been done at the cost of energy consumption. Therefore, conservation of energy of sensor nodes is critical important consideration of coverage algorithms. In this paper, sensor nodes have different states (Yi Wang, Guohong Cao, 2011). Different state of node means that the node has different tasks. The state determine the whether 'OFF' or 'ON' its hardware.

If the sensor nodes need to complete a particular task, it turns on related hardware, turn off the unrelated hardware. By this means, it can save some energy. Therefore, in EACC scheme, three different states of sensor nodes are as following:

- Inquiring

At the beginning, each sensor node is in inquiring state. Once deployed sensor nodes, all nodes are in the state. When a node is in inquiring state, it turns on its communication module, correspondingly, and turns off sensing and processing module. Then,it waits until it received the Hello message transmitted by CH. Of course, CH is ready to receive information transmitted by sensor node.

When sensor node has received the Hello message, it will ready to join a cluster. If receiving multiple messages from different CHs, the sensor node send its location information toward CHs and still is inquiring state until it received a reply message transmitted by CH, then its state is changed to ACTIVE or SLEEP state, which is determined by the received information. In fact, consumption energy in inquiring state is less than communication unit.

- Active state

The sensor node in active state needs to take processing, sensing and communicating task. When sensor node enters active state, it turns on its sensing unit, then it is begin to do actual work. Accordingly, both the processing and communicating units are triggered. The former is responsible for sensing data, and have obtained raw analog data, then analyze those data, and determines to relay those data or discard. The latter is responsible for forwarding data toward other nodes. Due to various tasks in active state, most energy is used in active state.

- Sleep state

In sleep state, sensor node turns off its all units except transceiver, and enters a maximum power saving mode. In this state, node does not need to do anything. In order to save energy, sensor node is as far as possible to maintain the state a long time.

3. EACC Scheme

3.1. Euclidean Distance between Overlapping Area

As above assumption, sensing discs of all sensor nodes are R_s, which is a constant. As shown as Figure 2, for sensor nodes i and j, the overlapping area of them is only related to distance between them. Sensing areas of i and j is overlapping. Next, the proof process is given as following.

Since sensor nodes are deployed in a random way, it may result in two activated sensors' sensing area overlapping. The overlapping area depends on distance between them. As shown as Figure 3, sensor nodes i and j, overlapping area of sensing area is twice the shaded part S_{arc}, as shown as equation:

$$S_{arc} = S_{oapb} - S_{oab} \tag{1}$$

Where S_{oapb} is the area of segment 'OAPB'. S_{oab} is area of the triangle 'OAB'.

$$S_{oapb} = \frac{1}{2} r^2 \theta \tag{2}$$

Where θ is angle between OA and OB, namely, $\theta = \angle AOB$.

$$S_{oab} = \frac{1}{2} r^2 \sin\theta \tag{3}$$

Therefore, equation (2) and (3) is substituted into (1), we get:

$$\begin{aligned} S_{arc} &= S_{oapb} - S_{oab} \\ &= \frac{1}{2} r^2 \theta - \frac{1}{2} r^2 \sin\theta = \frac{1}{2} r^2 (\theta - \sin\theta) \end{aligned} \tag{4}$$

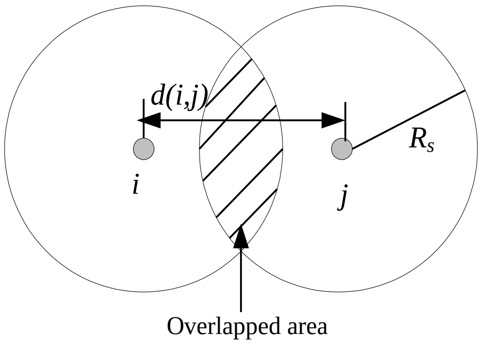

Figure 2. The Overlap of Area of Two Sensor Nodes

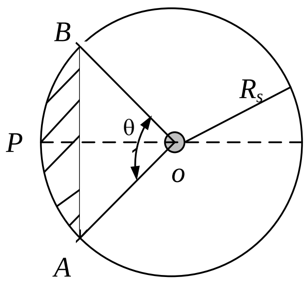

Figure 3. The Overlap Area contributed by a Node

In triangle OBM, according to analytical geometry knowledge,

$$\begin{aligned} &\cos\left(\frac{\theta}{2}\right) = \frac{OM}{OB} = \frac{d(i,j)}{2R_s} \\ &\Rightarrow \frac{\theta}{2} = \cos^{-1}\left(\frac{d(i,j)}{2R_s}\right) \Rightarrow \theta = 2\cos^{-1}\left(\frac{d(i,j)}{2R_s}\right) \end{aligned} \tag{5}$$

Therefore, the equation (4) is changed by substituting the equation (5) into the equation (4).

$$\begin{aligned} S_{arc} &= \frac{1}{2} R_s^2 \left(\theta - \sin\theta\right) \\ &= \frac{1}{2} R_s^2 \left[2\cos^{-1}\left(\frac{d(i,j)}{2R_s}\right) - \sin\left(2\frac{d(i,j)}{2R_s}\right)\right] \end{aligned} \tag{6}$$

Notice that equation (6), when a radius R_s of the sensing disk of sensor node is given, overlapping area S_{arc} of sensor nodes i and j solely depends on distance $d(i,j)$. Further, the overlap area of the sensing areas of two sensor nodes decreases non-linearly with Euclidean distance between the two nodes. Next, the proof process is given.

$$\begin{aligned} S_{arc} &= \frac{1}{2} R_s^2 \left(\theta - \sin\theta\right) \\ &= \frac{1}{2} R_s^2 \left[2\cos^{-1}\left(\frac{d(i,j)}{2R_s}\right) - \sin\left(2\frac{d(i,j)}{2R_s}\right)\right] \\ \Rightarrow S_{arc} \big/ R_s^2 &= \frac{1}{2}\left[\frac{-1}{\sqrt{4R_s^2 - d^2(i,j)}} - \frac{d^2(i,j) - 4R_s^2}{\sqrt{4R_s^2 - d^2(i,j)}}\right] \end{aligned} \tag{7}$$

Differentiating S_{arc} with respect to $d(i,j)$:

$$\begin{aligned} \frac{1}{R_s^2}\frac{dS_{arc}}{dd(i,j)} &= \frac{1}{2}\left[\frac{1}{\sqrt{4R_s^2 - d^2(i,j)}}\frac{d^2(i,j) - 4R_s^2}{R_s^2}\right] \\ \Rightarrow \frac{dS_{arc}}{dd(i,j)} &= \frac{1}{2}\frac{d^2(i,j) - 4R_s^2}{\sqrt{4R_s^2 - d^2(i,j)}} = -\frac{1}{2}\sqrt{4R_s^2 - d^2(i,j)} \end{aligned} \tag{8}$$

Equation (8) shows the relationships between overlapping area S_{arc} and $d(i,j)$ is nonlinear. When the distance is increased, the overlapping area S_{arc} is decreased. Therefore, in order to reduce the overlapping area S_{arc}, we can increase the distance, namely, S_{arc} is minimized by maximizing distance $d(i,j)$.

3.2. Active Sensor Node Selection by CH

In a given clustered WSN, the EACC scheme is proposed to maximize the field area coverage in such a way that the network lifetime is enhanced. On the other hand, the uncovered and overlapped area in network is minimized. In EACC scheme, every CH decides sensor nodes' state in a central way. To minimize coverage overlapping area and uncovered regions in the cluster, number of active sensing nodes is optimized.

In a cluster, each CH determines its member state. Assume that C_{ch}^u is a set, which includes all nodes in cluster u, and A_{ch}^u is subset of C_{ch}^u, which include sensor nodes in active state in cluster u. At first, A_{ch}^u is null. Each CH makes a decision its active sensor nodes based on its residual energy and overlapped area. For all $i \in C_{ch}^u$, A_i^u is the total area covered by sensor node i. ANO_i^u is the area of non-overlapped region covered by sensor node i. $AO_{i,j}^u$ is the overlapped area of sensor node i and j. Firstly, the integrated metric is defined for sensor node $i \in C_{ch}^u$, as follows.

$$AE_i = \omega_1 \times \frac{ANO_i}{\pi R_s^2} + \omega_2 \times \frac{E_i}{E_0} \tag{9}$$

Where, πR_s^2 is the total area covered by sensor node i. E_0 is the initial energy of sensor node i. E_i is the residual energy of sensor node i. Both ω_1 and ω_2 are the weight factors.

Note that equation (9), it measures the value of the metric AE_i as a weighted linear combination of two sub-metrics $\frac{ANO_i}{\pi R_s^2}$ and $\frac{E_i}{E_0}$. Therefore, metric AE_i helps us to select the sensor that has higher residual energy and the sector having non-overlapped area, which in turn increase the network lifetime as well as decrease the coverage redundancy by judiciously choosing the active sensor nodes.

Next, the CH firstly generates a list γ, which is a descending order sorted list of sensor nodes by the AE_i value. Then, the CH detects whether the first entry sensor node in γ meet the equation (10). If yes, the sensor node is moved to the active set A_{ch}^u, as shown as equation (11). Simultaneously, the other entries for that sensor nodes are removed from the list γ.

$$AO_{i,j} \le \delta \tag{10}$$

$$A_{ch}^u = A_{ch}^u \text{n} \langle i \rangle, i \in C_{ch}^u \tag{11}$$

Where, δ is the overlapped threshold value. The value of the threshold δ may need to be increased (e.g., $\delta = \delta + \delta$ dynamically in the second round if the CH communication sector is not fully covered even if all the entries of γ are checked in the first round.

Once selecting a new active sensor node, CH will check whether its communication region is fully covered or not. If yes, CH stop running the algorithm. The total communication area of CH is CA_{ch}:

$$CA_{ch} = \frac{\pi}{2} R_c^2 \tag{12}$$

Each time CH selects a active sensor node to add in the A_{ch}^u, its corresponding non-overlapping covered area is added to previously computed area using equation (13).

$$A_{ch}^{cur} = A_{ch}^{prev} + ANO_{i,s} \tag{13}$$

Where A_{ch}^{prev} is the covered region of CH before adding the node i in active list γ. A_{ch}^{prev} is the covered region after activating the node i.

The process of adding new sensor nodes in the active list γ is continuing until the condition holds, which is given in equation (14).

$$A_{ch}^{prev} \le \omega \times A_{ch} \tag{14}$$

Where ω is a weighted, which depends on the portion of the region of CH that we want to cover. The flow chart of active sensor node selected algorithm is shown as Figure 4.

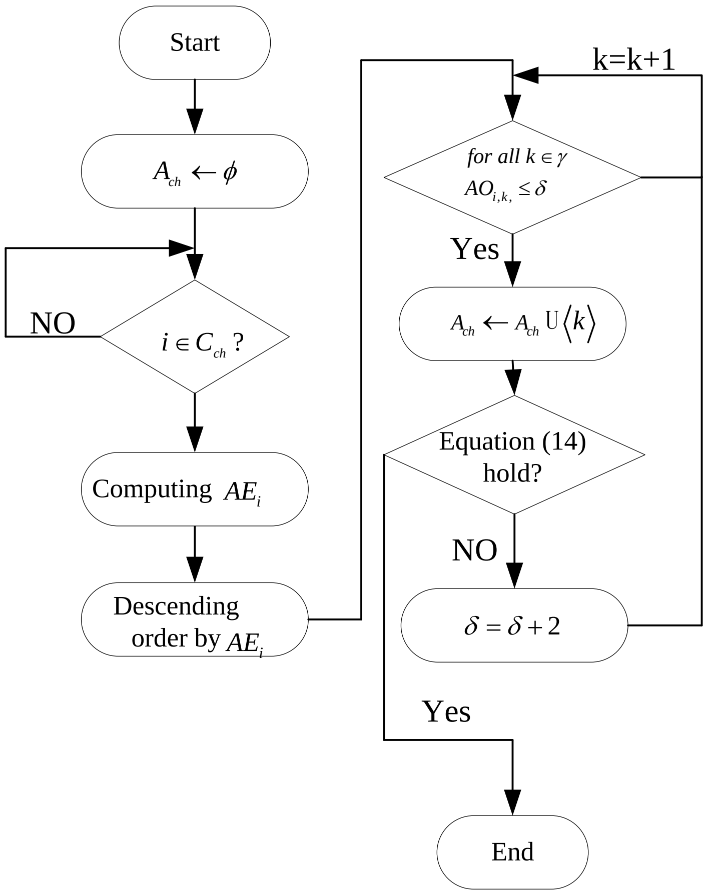

Figure 4. The Flow Chart of Active Sensor Node Selected Algorithm

4. System Simulation and Performance Analysis

4.1. Simulation Environment

The simulation has been carried out in ns3. The number of sensor node is from 100 to 900 in a region of $1000m \times 1000m$. They are uniformly deployed in the region. The sensing radius R_s =50m and communicating radius R_c =100m. The initial energy of sensor node E_0 =5J. Simulation time is 1000 seconds. The experiments were totally repeated for 10 times and the average value is points in each graph. The simulation results are shown as Figure 5 and 6. We study the performances of the proposed EACC scheme with two state-of-the-art solutions ECSS (Energy Conservation node Self-Scheduling)(Yuanyuan Zeng,Naixue Xiong 2010) algorithm and NLAC(Network Lifetime Aware area Coverage)(Selina S,Fernaz N,2015).

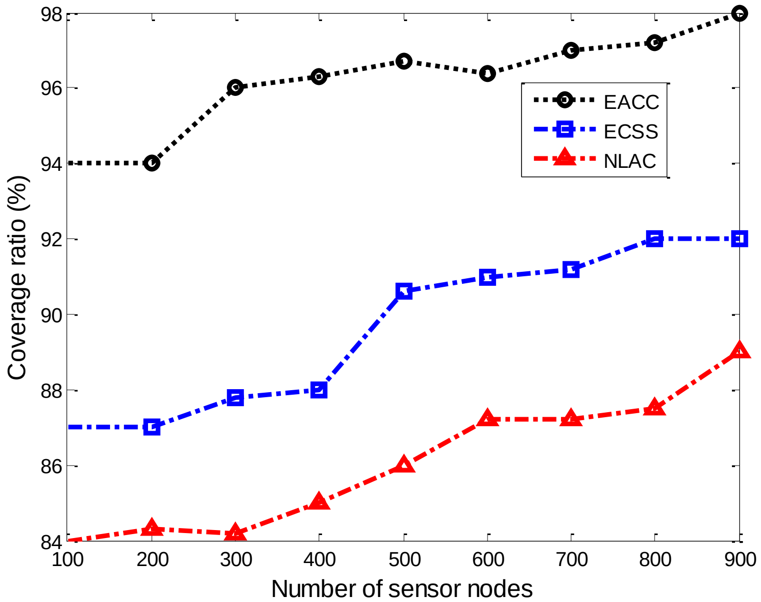

Figure 5. Coverage Ratio with Different Sensor Nodes

From the graphs in Figure 5, we consider coverage ratio to be a metric, which is computed by ratio of sensing covered area and total area. Proposed EACC achieves relatively higher accuracy compared to NLAC and ECSS. EACC gives better performance. The reason is that CH is considered to be a coordinator that determine the active sensor nodes to ensure its sensing coverage. It aggregates information with others. In ECSS and NLAC, individual sensors are responsible to take decisions, and it is not consideration in overall way. Therefore, they are unable to realize maximized coverage. In contrast, the proposed EACC achieve a better performance, which owe to CHs. In EACC scheme, CHs is considered to be a coordinator to decide sensor nodes' state and make an optimal decision. So that overlapping area is minimized.

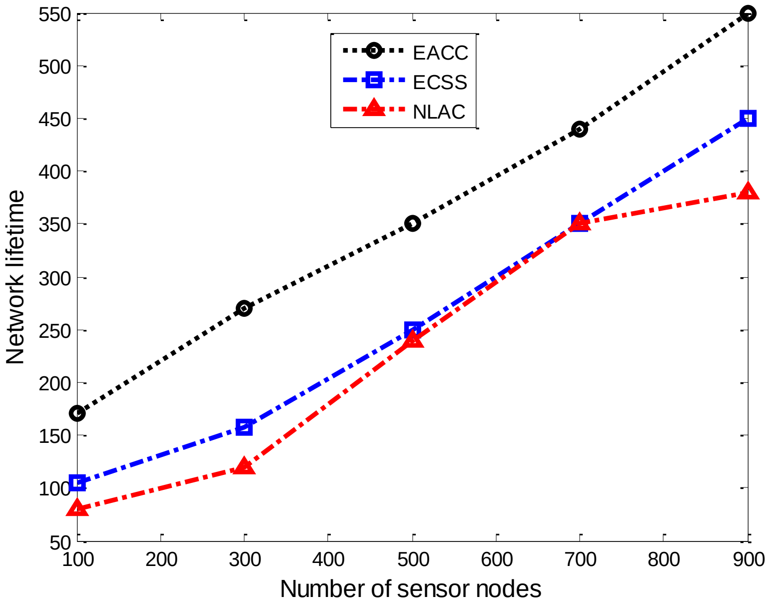

Figure 6. Network Lifetime with Different Sensor Nodes

The network lifetime behavior of the algorithms EACC, ECSS and NLAC are shown in Figure 6. As known as Figure 6, when number of sensor nodes is increased, network lifetime is linearly improved in three schemes. The reason is very simple. The more number of sensor nodes is, the more network energy is, therefore, network lifetime is accordingly long. However, compared with ECSS and NLAC schemes, the proposed EACC scheme outperform in terms of network lifetime. The reason is that network overhead is reduced by clustering algorithm. More explicitly EACC selects active nodes based on their residual energy, and thereby, enhances lifetime significantly. Thus, in ECSS and NLAC schemes, energy level have been not taken into consideration. But in EACC the energy level of nodes are considered and hence, there is balanced energy consumption.

5. Conclusions and Future Work

For cluster wireless sensor network, the EACC scheme for improving coverage is proposed in this paper. It is capable of maintaining the network coverage while minimizing the energy consumption of the network by activating only a subset of nodes, with the minimum overlap area. EACC scheme meet network coverage requires with minimal energy consumption. CHs are taken as a coordinator to determine sensor nodes' state. Some nodes is active state, thus other nodes is sleep state. Each CH first selects the active nodes and their sensing directions within its covering region to ensure a fully covered communication region. The residual energy-aware selection of sensing nodes helps EACC to achieve balanced energy consumption of network nodes and thereby extending the network lifetime significantly. Finally, simulation results show that coverage ratio is up to about 95% in EACC scheme.

In future, we will pay attention to extend the work to solve *k*-coverage problem and provide mathematical analysis on the correctness and accuracy of the coverage algorithms.

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