An Enhanced Coverage Control Protocol for Wireless Sensor Networks

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Abstract

Wireless sensor networks (WSNs) of limited power need to utilize reasonable coverage control protocol to reduce overall energy consumption by turning off redundant sensors while maintaining the required coverage quality. However, the two most well-known off-duty eligibility rules of coverage control protocols (Ottawa and CCP) are either unnecessary or insufficient conditions which consequently lead to redundant sensors or blind points. In this paper we propose a necessary and sufficient off-duty eligibility rule which can guarantee no blind points incurred while maintaining the number of on-duty nodes to a minimum. Based on this rule, a novel coverage control protocol denoted as Enhanced Coverage Control Protocol (ECCP) is presented. Simulation results demonstrate that ECCP can conserve the network’s energy with less on-duty sensors than Ottawa, and preserve the coverage quality more accurate than CCP. Therefore, ECCP is an efficient and reliable coverage control protocol with no redundant sensors and blind points.

1. Introduction

A wireless sensor network [1] is composed of a large number of low-cost and low-power tiny sensor nodes, which form to a multi-hop, self-organizing and wireless communication network. Energy source provided for sensors is usually battery power, which has not yet reached the stage for sensors to operate for a long time without recharging. Moreover, the sensors are usually intended to be deployed in remote or hostile environment, such as a battlefield or desert; it is undesirable or impossible to recharge or replace the battery power of all the sensors. However, long system lifetime is expected by many monitoring applications. Therefore, energy efficient design for extending system lifetime is one basic principle to the design of a large wireless sensor network.

Besides, sensor networks need to maintain sufficient coverage quality to capture the timely changing targets. Sensing region (coverage region) of a node is generally abstracted to a circular area, which uses the sensor node’s location as the center and sensing range as the fixed radius. A point is covered (monitored) by a node if the Euclidian distance between them is less than the sensing range of the node. A target region (monitored network) has a coverage degree of K (i.e., being K-covered) if every location inside the region is covered by at least K nodes. Moreover, the region being K-covered is full covered. Coverage degree is usually a measure of quality of service [2]. The higher the coverage degree is, the better the covered effect of monitored network is. In addition, blind points or sensing voids are the points that can not be full covered inside the target region. To sensor monitored networks, the existence of blind points is intolerable and a direct result of reducing the quality of network coverage. Thereby, it is a hot issue about avoiding blind points while maintaining the required sensing coverage degree with saving energy consumption in wireless sensor networks [3].

In most cases, sensor nodes are deployed densely and their sensing region are overlapped by adjacent nodes, which lead to a large number of redundant nodes. If the node’s sensing region is full covered by its neighbors, it is a redundant node. Researches [2, 3] indicate that, only a small number of nodes in active can guarantee the degree of coverage while most else can be turned off to conserve energy. Generally, it is the lowest power consumption when the node is turned into sleeping. Therefore, if we can schedule sensors to work alternatively with the redundant nodes into sleep state, the density of on-duty nodes can be reduced, contributing to the network’s overall energy consumption reduced and the system lifetime prolonged correspondingly. In wireless sensor networks, that is called the Node Scheduling Scheme or Coverage Control Protocol. Importantly, a basic requirement for coverage control protocol is to maintain the required sensing coverage quality while turning off redundant sensors. That means active nodes need to keep the coverage degree with no sensing voids and a minimal number of on-duty sensors. In coverage control protocols, judging whether a node’s sensing...
region is full covered by its neighbors is a key, which is called Off-duty Eligibility Rule.

At present, there are some coverage control protocols which are based on the node density control, such as Xu’s GAF [4], Gui’s Mesh [5] and Ye’s PEAS [6]. However, these density control protocols could neither guarantee the coverage degree, nor support designated coverage degree. In addition, the two most well-known coverage control protocols in literature are Ottawa [7] and CCP [8]. Because the Ottawa considers a limited number of neighbors, leading to too many redundant nodes still in the network, its off-duty eligibility rule is a sufficient but not necessary condition of estimating redundant nodes; thereby Ottawa can not reduce network’s power consumption efficiently. Besides, the CCP off-duty eligibility rule is working by judging intersection points of the node’s neighbors in its sensing region at least K-covered by other neighbors to estimate redundant nodes. But the rule could misjudge to power off the non-redundant nodes, which causes blind points in the network; hence, CCP rule is a necessary but insufficient condition of judging redundant nodes. Clearly, the present off-duty eligibility rules of coverage control protocols are all either unnecessary or insufficient conditions of estimating redundant nodes.

In this paper, based on the literature [8], we present an Enhanced Coverage Control Protocol (ECCP). The ECCP off-duty eligibility rule can completely eliminate the redundant nodes with no blind points caused by algorithm, so that ECCP rule is a necessary and sufficient condition of judging redundant nodes and ECCP protocol is an efficient and reliable coverage control protocol. Simulation results demonstrate that, ECCP has the following advantages over the relevant work in the past:

- ECCP rule is a necessary and sufficient condition of estimating redundant nodes. ECCP is more accurate than CCP to judge whether the nodes are redundant or not, while ECCP does not cause coverage blind points.
- ECCP is more efficient than Ottawa, since it brings the active nodes and the average coverage degree to a minimum. Therefore, ECCP is more efficient to reduce the network’s overall energy consumption and prolong the system lifetime.

In the rest of this paper, we first formulate the problem and show that the sufficient condition derived in [8] (Proposition 1) does not hold true in Section 2. Section 3 proposes a necessary and sufficient off-duty eligibility rule. Section 4 introduces an enhanced coverage control protocol ECCP. Extensive simulation results are presented in Section 5. The paper concludes in Section 6.

2. Problem Formulation

2.1. Network Model and Problem Definition

![Sensors Coverage Model](image)

In Figure 1, we define a convex region A as target monitored network. The sensors are deployed randomly. Node’s sensing model is used by Boolean Sensing Model [6, 7], that means each node has a fixed communicating range $R_e$ and a fixed sensing range $R_s$. Since $K$-coverage ensures $K$-connectivity when $R_e \geq 2R_s$ [8], we also define this restriction in our paper. Based on the above, we present the following definitions:

**Definition 1: Euclidean Distance.** A point $p(x, y) \in A$, a node $v(x, y) \in A$, their Euclidean distance is defined as $|pv| = \sqrt{(x-x)^2 + (y-y)^2}$; a node $v(x, y) \in A$, a node $u(x, y) \in A$, their Euclidean distance is defined as $|uv| = \sqrt{(x-x)^2 + (y-y)^2}$.

**Definition 2: Sensing Region.** A node $v$, we define its sensing region as $\text{C}(v) = \{\text{point } p | |pv| \leq R_s\}$; and the border of its sensing region as $\text{Ch}(v) = \{\text{point } p | |pv| = R_s\}$.

**Definition 3: Neighbor Set.** The neighbor set of node $v$ is defined as $\text{SN}(v) = \{\text{active node } u | |uv| \leq 2R_s$ and $u \neq v\}$. 

**Definition 4: Inside Intersection Set.** The set of intersection points between node $v$’s neighbors inside its sensing region is defined as $\text{SI}_L(v) = \{\text{point } p | p \in \text{Ch}(v) \text{ and } x, \text{we } \text{SN}(v), x \neq w \text{ and } p \in \text{C}(v)\}$, shown as rounded points in Figure 1.

The basic principle in coverage problems [9] is to make a maximal number of off-duty sensors as well as maintaining network’s K-coverage. In theory, for estimating that a node is eligible to sleeping or not, it is necessary to judge whether the node’s sensing region is K-covered by other nodes. (i.e., whether every point in the node’s sensing region is K-covered by other nodes). If its sensing region is K-covered by its neighbors, the node is eligible to sleep, otherwise it remains active.
However, if we determine whether the node eligible to sleep or not base on the information that whether every point in a sensor region is $K$-covered by other nodes, the complexity of the algorithm will be considerably huge. Therefore, it is necessary to adopt efficient off-duty eligibility rule. By these rules, it is not only to estimate whether a node is eligible to sleep or not, but also to ensure coverage quality and minimize complexity of the algorithm.

2.2. Insufficient Condition of CCP

In [8], Wang proposed a theorem (as Theorem 1) which defined a necessary and sufficient condition of a convex region $K$-covered by a set of sensors:

**Theorem 1**[8]: A convex region $A$ is $K$-covered by a set of sensors $S$ if 1) there exist in region $A$ intersection points between sensors or between sensors and $A$’s boundary; 2) all intersection points between any sensors are at least $K$-covered; and 3) all intersections points between any sensor and $A$’s boundary are at least $K$-covered.

In Theorem 1, “intersection points between sensors” mean the intersection points of their sensing circles; “intersection points between sensors and $A$’s boundary” mean the intersection points between sensing circles and target region’s boundary.

Based on this theorem, Wang presented a CCP off-duty eligibility rule which estimates whether a node’s sensing region is $K$-covered by other sensors by using a few points. The CCP rule contains two propositions:

**Proposition 1**: A sensor is eligible for turning off if all the intersection points inside its sensing circle are at least $K$-covered.

**Proposition 2**: If a sensor is eligible for turning off, all the intersection points inside its sensing circle are at least $K$-covered.

In the two propositions, “the intersection points inside its sensing circle” mean the intersection points between the node $v$’s neighbors inside $v$’s sensing region, as the set $SI_I(v)$.

CCP assumes the Proposition 1 is right. As shown in Figure 2, considering 1-coverage, in Figure 2(a) node 4’s neighbors’ intersection points inside its sensing region can be all covered by other neighbors, so node 4 is eligible to turning off. Meanwhile in Figure 2(b), the intersection point A and B inside node 4 cannot be covered by node 4’s other neighbors, thus node 4 is ineligible and should be active instead.

However, as shown in Figure 3(a), point P inside the node 4 is a sole intersection point, which is covered by node 3, accordingly based on the CCP eligibility rule, node 4 should be eligible to turn off. But once node 4 goes to sleep, it will cause blind region as shown in Figure 3(b), thus the node 4 should not be eligible to turn off, that means the CCP rule could be misjudgment in some cases.

The **misjudgment** leads to the nodes turned off which should not be eligible, on account of the CCP rule’s insufficient condition to judging wrong. Thus, it is obvious that the assumption of CCP’s Proposition 1 does not hold true. Meanwhile, it is easy to prove that the Proposition 2 is correct. Accordingly, Proposition 1 and Proposition 2 in [8] are necessary but not sufficient conditions of estimating redundant nodes. They could be misjudgment to turn off non-redundant nodes, and it will lead to blind points which can not be tolerant for the monitored network. Therefore, CCP and its off-duty eligibility rule are neither sufficient nor reliable for estimating redundant nodes.

![Figure 2. An example of CCP off-duty judgment](image)

3. Off-duty Eligibility Rule

According to the last section’s problem description, CCP rule just considers the points in the set $SI_I(v)$ to execute the off-duty eligibility rule. Whereas, based on Theorem 1, it is also required to introduce the following two sets:

**Definition 5**: Node Border Intersection Set. The set of intersection points between node $v$’s neighbors and the border of its sensing region is defined as $SI_B(v)$: $\{point p| p \in Cb(u), u \in SN(v) \text{ and } p \in C(v)\}$, shown as quadrates points in Figure 1.

**Definition 6**: Region Boundary Intersection Set. The set of intersection points between the border of
node v’s sensing region and the boundary of target region A (as Ab) is denoted as SL_E(v) = \{point | p ∈ Ab and p ∈ C(v)\}, shown as rhombic points in Figure 1.

In this work, in order to overcome the shortage of CCP rule, we need to involve the three sets of intersection points, SI_I(v), SI_B(v) and SI_E(v) to estimating redundant nodes. And Theorem 1 can not be used to estimate redundant nodes directly, based on Theorem 1 sequentially, we propose a novel necessary and sufficient off-duty eligibility rule, which avoids the insufficiency of CCP rule.

**ECCP Off-duty Eligibility Rule:** A sensor is eligible for turning off if and only if all the intersection points inside its sensing region and in border of its sensing region are at least K-covered.

**Proof:** In this rule, a intersection point p inside node v’s sensing region is denoted as p ∈ SI_I(v), coverage degree sd_I(p|v) denotes how many v’s other neighbors cover a point p ∈ SI_I(v); A intersection point p in border of node v’s sensing region is denoted as p ∈ SI_E(v) or p ∈ SI_B(v). sd_B(p|v) denotes how many v’s neighbors cover a point p ∈ SI_E(v) or SI_B(v); Then, we define SI(p|v) = \{p | (p ∈ SI_I(v) or p ∈ SI_E(v) or p ∈ SI_B(v)) and p ∈ C(v)\}, and sd(p|v) as sd_I(p|v) or sd_E(p|v) or sd_B(p|v) correspondingly.

Accordingly, ECCP Off-duty Eligibility Rule is denoted as: ∃p ∈ K( p ∈ SI (p|v) ∧ sd (p|v) ≥ K ↔ node v is eligible into the off-duty), so we need proof that this proposition is correct.

**Sufficiency (Section “if”):** Countervidence. Suppose that node v is ineligible to sleep, it indicates that coverage degree of v’s sensing region C(v) is at most K-1 and can not reach K, i.e., ∃p ∈ K( p ∈ C(v) ∧ sd(p|v) ≥ K), which equals ∃p ∈ K( p ∈ C(v) ∧ sd(p|v) ≥ K). In addition, we have the Known Condition: all the intersection points inside v’s sensing region and in border of its sensing region are at least K-covered, i.e., ∃p ∈ K( p ∈ SI(p|v) ∧ sd(p|v) ≥ K). So based on Theorem 1, v’s sensing region C(v) is at least K-covered, which means ∃p ∈ K( p ∈ C(v) ∧ sd(p|v) ≥ K). Clearly, it is a contradiction between Supposition and Known Condition. Hereby, the supposition is not valid.

**Necesity (Section “only if”):** if node v is eligible into sleeping, it shows that sensing region C(v) of v is at least K-covered by its neighbors, i.e., ∃p ∈ K( p ∈ C(v) ∧ sd(p|v) ≥ K). So based on Theorem 1, all the intersection points inside v’s sensing region and in border of its sensing region are at least K-covered.

ECCP rule judges whether a node is off-duty eligible or not by checking whether all the intersection points inside its sensing region and in border of its sensing region are at least K-covered. As illustrated in Figure 1, a convex region A is supposed as target region, and a node v is required to estimate. Based on the above coverage model, the specific ECCP algorithm for ECCP rule are as follows.

**ECCP Algorithm (integer K)**

\[
begin
/*find all intersection points inside or on the border of C(v)*/
SI = \{p | p ∈ SI_I or p ∈ SI_B or p ∈ SI_E\};
/*find all coinciding sensors*/
SC = \{uv | \nuv = 0\};
if (|\nu| = 0)
   return INELIGIBLE;
end if
/*consider every p’s coverage degree where p is a intersection point between v’s neighbors*/
for (each point p ∈ SI_I)
   /*compute p’s coverage degree*/
   sd_I(p) = ||m | m ∈ SN(v), m ≠ x, w and p ∈ C(m)||;
   if (sd_I(p) < K) return INELIGIBLE;
end for
/*consider every p’s coverage degree where p is a intersection point between v’s neighbors and the border of v’s sensing region*/
for (each point p ∈ SI_B)
   /*compute p’s coverage degree*/
   sd_B(p) = ||m | m ∈ SN(v), m ≠ u and p ∈ C(m)||;
   if (sd_B(p) < K) return INELIGIBLE;
end for
/*consider every p’s coverage degree where p is a intersection point between the border of node v’s sensing region and the boundary of target region A*/
for (each point p ∈ SI_E)
   /*compute p’s coverage degree*/
   sd_E(p) = ||m | m ∈ S(v) and p ∈ C(m)||;
   if (sd_E(p) < K) return INELIGIBLE;
end for
return ELIGIBLE;
end
end for
end
end for
end
end for
end
end for
end
end

4. Enhanced Coverage Control Protocol

In wireless sensor networks, each node determines its eligibility using the off-duty eligibility rule to reduce its energy consumption based on the information about its sensing neighbors, and may switch state dynamically when its eligibility changes. The alternation of node’s state should not only balance each sensor’s energy but also avoid blind points caused by conflicts of nodes’ turned-off in simultaneity. Therefore, the coverage control protocol is necessary in the node scheduling scheme. In this work, Enhanced Coverage Control Protocol (ECCP) is proposed based on ECCP off-duty eligibility rule.

In ECCP, each node can be in one of three basic states: SLEEP, ACTIVE and LISTEN. In the SLEEP state, the node sleeps to conserve energy. In the
ACTIVE state, the node actively senses the environment and communicates with other sensors. Each node periodically enters the LISTEN state to collect messages from its neighbors and reevaluates its eligibility to determine its new state.

Besides, since each node changes its state independently based on local information, the conflict is considerable potential. For example, eligible nodes are off-duty at one time and blind points may appear; besides when an active node is turned off, there may be multiple nodes take over its work at the same time, which causes redundancy. In order to avoid such blind points or redundancy, the two important transitional states JOIN and WITHDRAW are proposed in ECCP. Figure 4 indicates the state transition of ECCP.

![Figure 4. The state transition of ECCP](image)

When a network is deployed, all nodes are initially in the ACTIVE state, and each node broadcasts a Hello message at a random interval $T_a$.

In ACTIVE state: When a node receives a Hello message from one of its communication neighbors, first, it updates its sensing neighbor table by broadcasting. Then, it finds out the set of intersections between its neighbors inside its sensing region, and the set of intersections between neighbors and the border of its sensing region. It also gets the set of intersections between the border of its sensing region and target region’s boundary. Finally, it executes the ECCP off-duty eligibility rule to determine that whether all of the three sets above are $K$-covered by other neighbors. If it is eligible, it starts a withdraw timer $T_w$ and enters the WITHDRAW state, otherwise it continues to be an ACTIVE node.

In WITHDRAW state: When withdraw timer $T_w$ expires, it broadcasts a Withdraw message, starts a sleep timer $T_s$, and enters the SLEEP node. If a Withdraw message from a communication neighbor is received before the withdraw timer $T_w$ expires, the node executes the ECCP off-duty eligibility rule. And if ineligible, it cancels the withdraw timer $T_w$ and returns to ACTIVE state; otherwise it remains in WITHDRAW state.

In SLEEP state: When the sleep timer $T_s$ expires, a node in the sleep state turns the radio on, starts a listen timer $T_l$, and enters the LISTEN state.

In LISTEN state: If the listen timer $T_l$ expires, a node broadcasts a Join message and enters the ACTIVE state. When a Join message from neighbors is received before join timer $T_j$, a node determines its eligibility to turn off or not by using ECCP off-duty eligibility rule. If it is ineligible, it starts a join timer $T_j$ and enters the JOIN state; otherwise it continues to be a JOIN node.

In ECCP, both the join timer $T_j$ and withdraw timer $T_w$ are randomized to avoid collisions among multiple nodes that decide to join or withdraw. The values of $T_j$ and $T_w$ affect the efficiency of ECCP directly. For example, the shorter $T_j$ and $T_w$ are, the quicker response to variations in coverage is, meanwhile, the quicker decrease to network’s overall energy consumption is, and the shorter the system lifetime is. Besides, both timers are also related to the density of nodes in the network. For example, for a denser network where a node has more neighbors, if $T_j$ and $T_w$ are too short, a node does not have enough time to collect the Join or Withdraw messages from its neighbors, which leads to wrong estimation for active or sleep while reducing the protocol’s efficiency and its reliability; otherwise, if $T_j$ and $T_w$ are too long, it is the same result that the protocol’s efficiency and its reliability are debased.

5. Experimentation

In this section, we present some results of simulation experiments as the performance evaluation of our protocol and rule.

5.1. Simulation Environment and Parameter

Our environment is performed on the Coverage Simulator (CS) provided by [7]. The target region used for testing in all experiments is 50m×50m if not specified otherwise, and the sensing range is 10m for all sensor nodes. We assess the experiments about
ECCP and its off-duty eligibility rule by changing the coverage degree \( K \) and the number of deployed nodes in the network, while all the results are on average based on ten runs with different random network topologies. We compare the performance of ECCP to the Ottawa [7] and CCP [8], including the following three parameters:

1. **The number of blind points caused by protocol**: An efficient precise node scheduling scheme first should be able to ensure the target region full covered, that is no coverage blind points. Sequentially, the number of blind points caused by protocol is a key to measure a coverage control protocol good or bad.

2. **On-duty node number**: With maintaining the requested coverage quality of the target network, the least on-duty sensors can reduce the network’s overall energy consumption and prolong the system lifetime.

3. **Average coverage degree**: Under the requested coverage quality and coverage degrees, the less average coverage degree is, the less redundant node is, and the lower network’s overall energy consumption is, the longer system lifetime is.

### 5.2. Results and Performance Evaluation

#### 5.2.1. Number of Blind Points

Figure 5 presents that the number of blind points caused by ECCP, CCP and Ottawa respectively in different requested coverage degrees (1, 2 and 3) and the numbers of deployed nodes from 10 to 100. When the number of deployed nodes is less than 50, the number of blind points in the network caused by CCP rule is much more, and sensing voids reach 1% to 5% of overall target region, which is intolerant to the monitored network; however, no matter what coverage degree \( K \) is, the number of blind points is zero caused by ECCP and Ottawa.

Especially, the less the number of deployed nodes is, the more misjudgment and blind point caused by the CCP is; nevertheless, when the deployed node number is a little, the network does not suffer from blind points caused by ECCP all the time. This is because ECCP rule and its protocol eliminate misjudgment (the node is turned off, which should be active) which is on account of the CCP rule's insufficient condition. In addition, Ottawa rule is a sufficient condition to estimate sleep eligibility, so there is also no blind points. This experiment result demonstrates that ECCP rule is a necessary and sufficient condition of estimating redundant nodes without blind points.

#### 5.2.2. On-duty Node Number

Figure 6 shows the on-duty node numbers computed by ECCP rule, CCP rule and Ottawa rule respectively, under different requested coverage degrees (\( K=1 \) and \( K=2 \)) and different numbers of deployed nodes (from 10 to 100 and 100 to 600). The result testifies that ECCP rule can compute less on-duty node numbers than Ottawa rule, and when the number of deployed nodes is over 50, the numbers of active nodes are basically stable calculated by ECCP rule (around 20 under 1-coverage and 35 under 2-coverage); whereas the number of active nodes used by the Ottawa increases when the number of deployed nodes increases. Consequently, ECCP can give fewer nodes to achieve the requested coverage quality than Ottawa, with more efficient to reduce power consumption and extend the network lifetime. Besides, as shown in Figure 6, the number of active nodes for ECCP is more than 1% to 3% of that for the CCP protocol. This is because ECCP rule eliminates the...
misjudgment, which is owing to the CCP rule’s insufficient condition of estimating redundant nodes.

5.2.3. Average Coverage Degree

![Figure 7. Comparison of Average Coverage Degree](image)

As Figure 7 shown, in the 1-coverage, experiment selects deployed node numbers from 100 to 600 and compares network’s average coverage degree generated by ECCP, CCP and Ottawa protocol. The average coverage degree of ECCP remains around 2 in all numbers of deployed nodes as same as CCP. In contrast, the Ottawa protocol results that an average coverage degree is between 5 and 6, and increases with the number of nodes. When the requested coverage degree is $K=1$, the average coverage degree closer to 1 indicates that there are less redundant nodes. In summary, this experiment shows that our ECCP can preserve coverage with fewer active nodes than Ottawa. That in turn will consume less power than Ottawa protocol, and thus extend the lifetime of the network.

5.3. Experiment Summarization

The above simulation results indicate that ECCP off-duty eligibility rule is a necessary and sufficient condition of estimating redundant nodes. ECCP is more reliable than CCP in [8] on account of no blind points, so ECCP rule is a sufficient condition of judging redundant nodes. Compared to Ottawa in [7], ECCP rule is a necessary condition of evaluating redundant nodes, since it brings the active nodes and the average coverage degree to a minimum with maintaining the required sensing coverage quality. Accordingly, ECCP is more efficient to reduce the network’s overall energy consumption and prolong the system lifetime.

6. Conclusions

In this paper, we propose a necessary and sufficient coverage control protocol ECCP for wireless sensor networks. It is theoretically proved that the off-duty eligibility rule in ECCP protocol is a necessary and sufficient rule, which guarantees full coverage to target area and no blind point with a minimal number of on-duty sensors. Simulation results demonstrate that, ECCP off-duty eligibility rule has been greatly improved than CCP rule, thanks to the elimination of blind points caused by algorithm. It is better to utilize ECCP rule for coverage control protocol, since it is a necessary and sufficient condition to judge redundant nodes, and more accurate to determine node into sleeping or not than some other rules (e.g. rule of CCP or Ottawa). Meanwhile, ECCP can be more efficient to reduce the network’s overall energy consumption and prolong the system lifetime than Ottawa protocol. In conclusion, ECCP protocol is a reliable and efficient coverage control protocol. In the future, we will research coverage control problem when a node’s sensing region is not assumed as a circular model.

References