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The Adaptive Node-Selection Mechanism Scheme in Solar-Powered Wireless Sensor Networks

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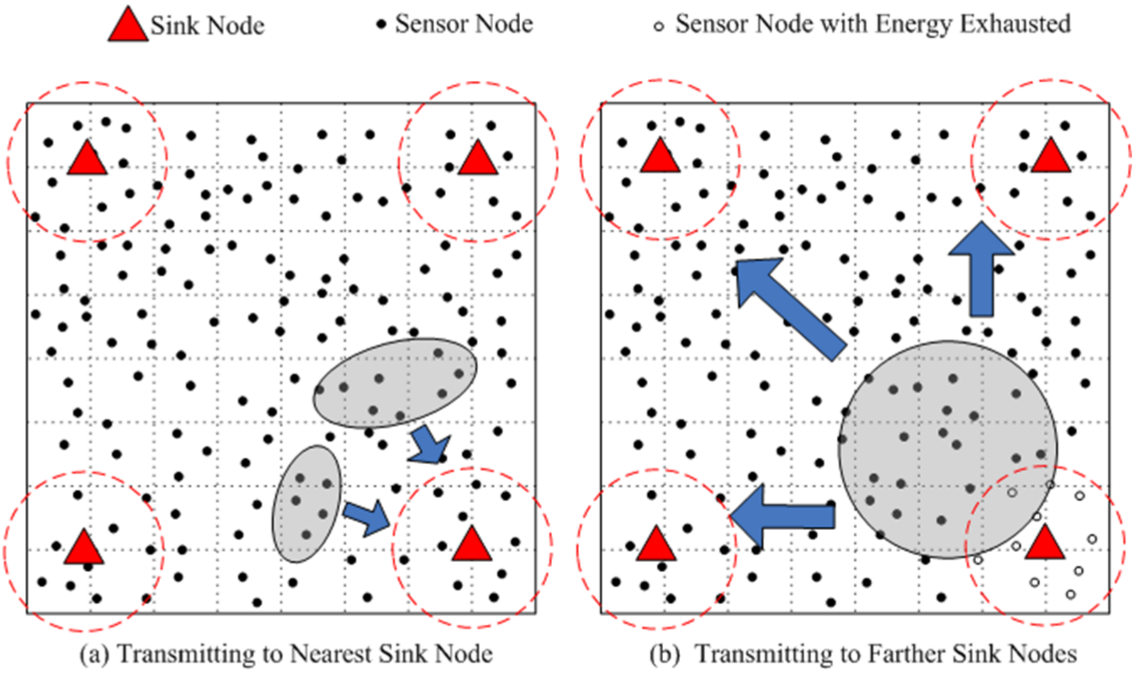
Abstract. *This study proposes a solar power-based adaptive node-selection protocol mechanism for a wireless sensor network to increase the monitor performance of wireless sensors. Using renewable energy, such as solar power, to improve the efficiency of sensors in wireless sensor networks has become a popular topic. Equipping the sensors with solar-powered equipment signifies that the sensors no longer have the limited battery life problem. This design can collect solar power to charge the sensors battery. To solve node-selection problem, an adaptive node-selection mechanism (ANSM) scheme is proposed. The algorithm builds the energy-aware Steiner tree between sensors and sink. This scheme selects the least active node to reduce the overlapping of the sensor coverage but ensure constant coverage of the target area in solar-powered wireless sensor networks. This approach also considers the solar power consuming rate and humidity to solve the solar power problem in various environments.*

Keywords: Sensor Deployment, Scheduling, Node-selection algorithm, Stream Environment, Solar-powered Sensor, Wireless Sensor Network.

1. **Introduction.** Wireless sensor network (WSN) are utilized in a wide range of applications, including military applications and the monitoring of oceans and wildlife. WSN comprise many low-cost devices called sensors, which monitor the status of the environment and send sensing data to the sink node. Because of limitations on the energy supply, available storage space and the computational capacity of the sensor nodes, the data that are transmitted between a sensor node and the sink node must been forwarded by other sensor nodes. For the WSNs, if the network contains sufficient remaining energy then the network has a long lifetime, however, if each sensor spends energy effectively then it is easy to maintain higher remaining sensor power. Decreasing power consumption is achieved by using as few nodes as possible. With more active sensors power consumption is higher. Activating as few sensors as possible guarantees the remaining energy maximization.

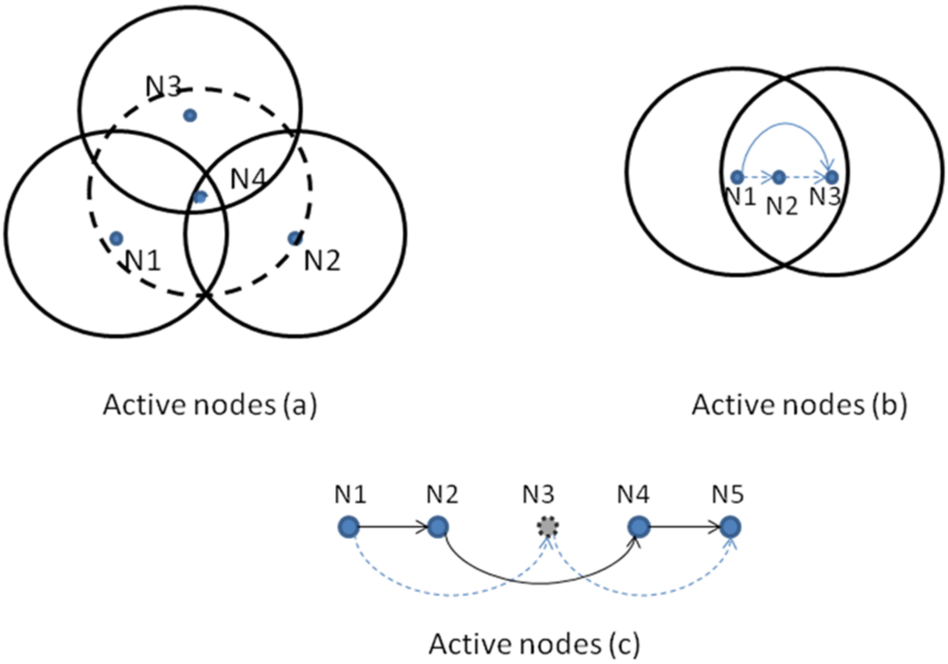
Consider node-selection while scheduling, if the area can be monitored by one node then its not necessary to active another node to sense this area, on the other hand, if the packet can be transmitted directly, its not necessary to cost extra energy to active nodes which play the role of intermediate node to relay the information. Beside of scheduling, another popular technology of power saving is the using of green energy. Nowadays, using renewable energy, such as solar power, to improve the efficiency of sensors in wireless sensor networks has become a popular topic. Equipping the sensors with solar-powered



(a) Transmitting to Nearest Sink Node (b) Transmitting to Farther Sink Nodes

FIGURE 1. The early isolation of the specific sink (EISS) problem

equipment signifies that the sensors no longer have the limited battery life problem. This design can collect solar power to charge the sensors battery. The current battery energy serves as a reference for switching between sleep and active modes. Thus, the sensor detection area can be continually monitored using backup sensors with batteries that can be charged by solar power. In many past researches, the sink selection strategy in multi-sink WSNs is based on Nearest-Sink. However, the kinds of strategy will lead to Early Isolation of Specific Sink problem in asymmetrical data generation environment. More specifically, sensors around specific sink will exhaust energy early due to a large number of data-forwarding. Those algorithms that consider only sensor nodes cause the problem of early isolation of the specific sink (EISS) in an asymmetrical data generation environment. More specifically, sensors around the specific sink will exhaust energy before other sensors because they forward a large number of data. In Fig. 1 (a), the data generation rate in some areas exceeds that in others. If all sensors inside an area that send data to the sink use the nearest sink strategy, then the sensors around the sink in the lower right-hand corner of the figure rapidly exhaust their energy because of the many instances of data-forwarding. The lower right-hand sink is isolated from the WSN when the sensors close to the sink have exhausted the battery. In Fig. 1 (b), the EISS causes many sensors to switch the destination of their forwarded data to a sink that is farther away than the original sink. This situation greatly increases the overall energy consumption of the network and accelerates the isolation for other sinks. Beside EISS problem, node activation of scheduling is necessary in WSNs, but how to select which nodes should be active smartly in each time period is the major problem while scheduling. Fig. 2 (a) shows a simple coverage issue example, node 1, node 2, and node 3 is active in the same time period and the total monitored area from node 1, node2, and node 3 fully overlap the monitor area of node 4. Obviously, then it is no necessary for node 4 to be active in this time period, otherwise it's just increase the energy cost without any coverage profit. Fig. 2 (b) shows another data transmission example. Node 1 can connect to node 3 directly, and node 1 and node 3 are active in the same time period, it's unwise to active node 2



Active nodes (a)

Active nodes (b)

Active nodes (c)

Figure 2. Three example of active nodes-selection

as the relay node of node1 and node 3, it doesn't increase transmission throughput but total energy cost. The other problem of scheduling is how to select node smartly and the standard of node-selection should consider the objective and environment conditions. Fig. 2 (c) shows the important of node-selection, in this example the data is transmitted from node 1 to node 5, if node 3 which can receive the data from node 1 and relay the data to node 5 directly, but node 3 is starving at power at the same time, so it's very importance to consider that the necessity to active node 3 in this time period or sacrifice the totally energy cost but have a stable transmission path by selecting node2 and node4 as the relay nodes.

A solution of power problem of WSNs is embedding the solar-powered module on sensors, the green energy is very popular technology recently, especially the issue of environment conservation, it is the trend to use green energy to substitute the tradition energy source, and the wireless sensor is not the exception in this trend. Solar power is often used in WSNs, because the sun radiation is available easily, low cost and more unlimited than other green energy. But the unstable quality of sun radiation is a general problem even thought solar power is better than other green source. Therefore, three issues will be addressed. The first issue is the EISS problem in multi-sink WSN, the second issue is to select least solar-powered sensors to cover a monitoring area, and the last issue is to address the same problem but in the stream environment. While EISS problem is caused by asymmetrical data generation environment, this problem has great effect on performance as mentioned above. Besides, we want to achieve a low overhead load balancing scheme, so that extra energy consumption can be as low as possible. And this scheme can adapt to any complex data generation in WSNs. We consider the following design goals:

- Dynamic: Design a mechanism in which each sensor can take over another sensors job, and in which sensor nodes have multiple paths.
- Sustainable: Continually monitor the area using different sensors with batteries that can be charged by solar power.

- Adaptive: Design a mechanism that can adapt to environmental changes, such as rain or a lack of sunlight.

The dynamic performance improved using the proposed method which splits the monitoring area into many small fixed grids. The sensor needs GPS equipment to determine its location in the grid, and is capable of covering selected grids. To improve The sustainability improved using additional data as a reference for switching between sleep and work mode, the sensors must send not only monitoring and location data, but also need to seed the current solar power and battery energy. These data serve as a reference for switching between sleep and work modes. To improve adaptability, the adaptive node-selection mechanism (ANSM) scheme is proposed. Therefore, the node-selection problem can be regarded as the minimum Steiner tree problem. The algorithm builds the energy-aware Steiner tree between sensors and sink. This scheme selects the least active node to reduce the overlapping of the sensor coverage but ensure constant coverage of the target area in solar-powered wireless sensor networks. The rest of this paper is organized as follows. In section 2, we give an overview of the existing works about calculation of power consumption, solar-powered wireless sensor networks and scheduling. Section 3 and 4 describes the key elements of the solar-powered wireless sensor networks, including the grids, the information of sensors and the adaptive node-selection mechanism algorithm. Finally, the paper concludes and draws future works in section 5.

2. **Related Work.**

2.1. **Energy consumption.**

To estimate energy consumption, we take the number of transmitted packet into consider. In [1], Zhao shows the existence of "gray areas" where some nodes exceed 90% successful reception while neighboring nodes receive less than 50% of the packets. He shows that the gray area is rather largeone-third of the total communication range. It is advantageous to change the parameters of the MAC protocol based on changing network conditions. Since sensor networks consist of low power volatile nodes, it is likely that links will appear or disappear over time [1]. And several researchers [1] have already shown extensive evidence of radio irregularity in wireless communication. Their main focus is to observe and quantify such phenomena. A multi-hop wireless sensor network exhibits high loss of packets [1], and so it is necessary to ensure that k or more sensors detect an intruder to guarantee the reception of enough detection messages at the base station. Then we use [2] to calculate power consumption, often in the literature generic approximations are used for these terms. However, an explicit expression for eta has been presented in [2] as

$$e_{ta} = \frac{(S/N)_r (NF_{Rx})(N_0)(B\mathrm{W})(4\pi/\lambda)^{\alpha}}{(G_{ant})(\eta_{amp})(R_{bit})} \tag{1}$$

where $(S/N)_r$ is the desired signal to noise ratio at the receiver's demodulator, NFR_x is the receiver noise figure, N_0 is the thermal noise floor in a 1 Hz bandwidth, BW is the channel noise bandwidth, k is the wavelength in meters, G_{ant} is the antenna gain, g_{amp} is the transmitter efficiency, and R_{bit} is the raw channel rate in bits per second. The efficiency of multihop communications can be analyzed for these technologies by extending the model above for the multihop case as shown in [3]. Results of the research show that in most realistic cases, it is worthwhile to maximize transmission power of a radio and minimize forwarding in sensor networks for the best energy efficiency. This is because the amount of energy consumed while listening, receiving, and transitioning to receive mode is similar to that of transmitting, and cannot be ignored in general case, in our stream environment to sense correct value of stream side, the transmitting power should be minimized. The energy estimation model was tested running simulations of an application in two physical deployments. The first deployment consisted on equally separated nodes, while the other deployment presented an optimal deployment given by the work presented in [3].

2.2. **Solar-powered wireless sensor networks.** We consider a discharge-recharge model used in [4]. Assume that each battery of sensors is energy rechargeable. And the time is divided into equal-sized tome slots and all sensors have synchronized clocks. References [4] also examined a scheme where the derived utility depends on the number of active sensors. The sensors are either recharging or transmitting (but not both) and, once completely run out of energy, can only activate themselves when fully recharged. The authors study how sensor nodes should be activated dynamically so as to maximize a utility function based on the coverage area of the sensors. Previous research in the context of sensor networks has discussed the benefit of optimal activation times of deployed sensor nodes. A threshold based activation policy was shown to perform close to the optimal policy for dynamic node activation in [4]. There has been an increased interest in rechargeable sensors in recent years. And in WSNs the node activation question in a rechargeable sensor system is always a popular issue of research has been considered previously in [5]. References [5] considered the sensor in WSNs could be activated even if it is recharged only partially, node activation schedules to provide a better quality of coverage in rechargeable sensor networks, and also consider sensor systems where a sensor could be activate as long as it has sufficient energy, and show that a threshold based node activation policy achieves asymptotically optimal performance with respect to the sensor energy bucket size, under various correlation system models. And in [5], the authors modeled the rechargeable sensors system as a system of finite-buffer queues. In [6], the authors further consider maximizing the system performance, for example, the energy used is always less than the energy harvested so that the system can continue to operate perennially. The authors also studied the scheduling for single sensor with rechargeable energy. We consider a lithium battery for which a linear battery model with relaxation effect is assumed [6].

2.3. **Scheduling.** Span [7] provides coverage and communication by turning on necessary nodes by its algorithm. By the algorithm in SPAN, it saves energy and improve lifetime by deciding the nodes whether to sleep or active as one of the backbone based on local topology information. All active nodes are connected through the backbone. Our node-selection scheme is like SPAN such that each node is either transmitting or not transmitting, which makes it simpler to implement. Some nodes can go to sleep state sometimes, when they are stop transmitting or receiving and saving energy at the same time. There are a lot of research has been conducted into power-aware scheduling, in [8] Y. Yu and V. K. Prasanna model the communication of multiple and single hop wireless channels as additional linear constraints of an Integer Linear Programming (ILP) problem. In [8] presented an optimized technique for energy consumption, that address energy-balanced task allocation. Energy-balanced Task Allocation (EbTA) minimize balanced energy consumption limited by deadline constraints. Therefore communications over multiple wireless channels are modeled as additional linear constraints of an Integer Linear Programming (ILP) problem, and a heuristic algorithm with Dynamic Voltage Scaling (DVS) mechanism is presented. However, the communication scheduling model in [8] does not use the broadcast nature of wireless communication, which can save energy. EbTA are also adjusted to reduce the energy consumption further. However, the 3-phase heuristic approach is only applicable to a WSN with homogeneous sensor nodes so far. The EcoMapS algorithm in [9] is object to minimize the schedule length limited from the energy consumption in single-hop clustered WSNs. However, EcoMapS does not provide execution deadline guarantees for applications. There is another scheduling in WSNs, in [10] a protocol is presented for scheduling the wakeup time of nodes therefore the delay caused by detection can be minimized, for example, each area in the environment is sensed within some finite interval of time. This protocol is useful if there are many redundant sensor nodes in the network and the many sensors cover the same area. The framework in [10] compromises event detection delay and lifetime while maintaining coverage. Data aggregation can be realized as a set of combining the data that comes from many sensor nodes into a set of meaningful information [11]. Low-Energy Adaptive Clustering Hierarchy (LEACH) is a clustering-based protocol that minimizes energy dissipation in sensor networks. LEACH employs the following techniques to reach the design goals stated: (1) randomized, adaptive, self-configuring cluster formation; (2) localized control for data transfers; (3) low-energy media access control (MAC); and (4) application-specific data processing, such as data aggregation or compression. Energy-latency tradeoffs for different routing and scheduling schemes are also studied by Keshavarzian *et al.* [12]. It analyzed different wake-up scheduling schemes and proposed a new scheduling method that can decrease the end-to-end overall delay. The authors of [12] proposed techniques that can significantly enhance the lifetime while ensuring the satisfaction of latency constraints. WSN also allow the base station to send commands/queries to nodes, i.e., forward direction traffic [12]. However, most wakeup scheduling do not consider the spatially-correlated contention, and their performance (energy-efficiency, delay, throughput) can be adversely affected under this specific contention in WSN.

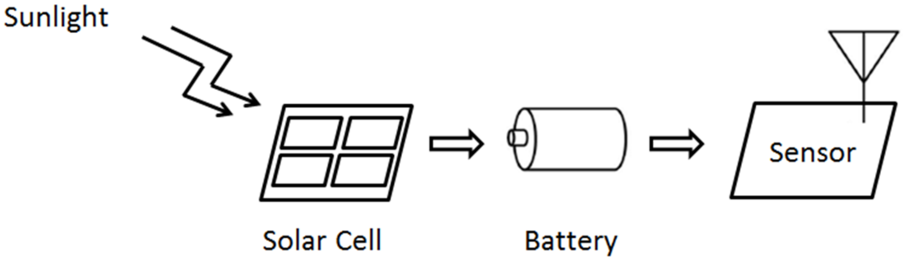


Figure 3. The sensor with solar equipment

3. **System Model.** Previous studies have extended the coverage efficiency of sensors [13], many mechanisms is proposed to extend the lifetime [14][15] and coverage [16][17] of wireless sensor networks. However, several issues remain to be improved and changed. There has been an increased interest in rechargeable sensors in recent years. Using renewable energy, such as solar power, to improve the efficiency of sensors in wireless sensor networks has become a popular topic. Equipping the sensors with solar-powered equipment, as Fig. 3 shown, signifies that the sensors no longer have the limited battery life problem. This design can collect solar power to charge the sensors battery. The current battery energy serves as a reference for switching between sleep and active modes. Thus, the sensor detection area can be continually monitored using backup sensors with batteries that can be charged by solar power.

The survival rate and the covered area from active sensors to effectively monitor each period is improved by this scheme, and assists with reaching the goal of a maximum monitored area with effective power control. For the WSNs, if the network contains sufficient remaining energy then the network has a long lifetime, however, if each sensor spends energy effectively then it is easy to maintain higher remaining sensor power. Decreasing

Table 1. The parameter table for sensors

Parameter	Definition
x_i	The sensor location of longitude.
y_i	The sensor location of latitude.
R_s	The sensor sensing range.
E_c	The working sensor's energy power cost rate.
$E_{ni,j}$	The current battery energy.
$S_{i,j}$	The current solar power charging rate.
$hu_{i,j}$	Humidity of a sensor's surrounding.

power consumption is achieved by using as few nodes as possible. With more active sensors power consumption is higher. Activating as few sensors as possible guarantees the remaining energy maximization. The proposed scheme divides the detection area into smaller pieces according the grid setting and prevents serious overlap in the detection area. This scheme selects the least active node to reduce the overlapping of the sensor coverage but ensure constant coverage of the target area in solar-powered wireless sensor networks. Therefore, the monitoring area can be covered with fewer sensor nodes.

3.1. **Environment description and parameters of sensors.** This study assumes that the wireless sensor network is used to detect ocean pollution or a forest fire. Most of these types of sensors are placed by helicopter or spread randomly in a monitoring area. This study adopts the following assumptions:

- Sensors operate in an outdoor environment, and a sink with a full power supply and Internet access collects data from all the sensor nodes and performs counting tasks, as discussed later. If the monitoring area is under pollution or fire disaster, the sink provides a warning about its location.
- The sensor nodes are placed with random uniform deployment. The sensors have the same sensor sensing range (Rs), which is known before and is unchangeable. The energy power cost of a working sensor node is E_c.
- The solar power rate curve is a Gaussian distribution curve with the highest solar power at 12:00 PM and lowest solar power at 12:00 AM.
- All of the sensor nodes have a chargeable battery, solar-powered equipment, and a humidity sensor to detect the surrounding humidity as $hu_{i,j}$. The solar-powered equipment includes a solar panel that can collect the solar power to charge the battery with an known solar power charge rate into battery $E_{ni,j}$. If the battery is full, the sensor can use solar power directly without going through the battery, to avoid wasting energy.
- The GPS receivers provide x_i and y_i coordinates for all sensors.

The definitions in the single stream case show in Table 1. Note: For $x_i, y_i, E_{i,j}$. and $hu_{i,j}$,all of the i's represent sensor numbers, and all js represent time segments. To improve dynamic performance, the proposed method splits the monitoring area into many small fixed grids, and the distance between each pieces area is $1/\sqrt{2}$Rs to meet the sensing distance. The sensor needs GPS equipment to determine its location in the grid, and is capable of covering selected grids determine which area it covers. Therefore, a backup mechanism or a boundary must ensure that the monitoring area is always under monitoring in case the sensor does not charge as much as expected. Thus, enough sensors must cover the monitoring area with enough node-selection mechanisms, enabling area monitoring until the sensor naturally breaks.

3.2. **Solar-powered sensors.** Solar power is often used in WSNs, because the sun radiation is available easily, low cost and more unlimited than other green energy. But the unstable quality of sun radiation is a general problem even thought solar power is better than other green source. There are many researches which try to improve the utility of solar-powered sensors, including hardware improvement, scheduling, or sun chasing mechanism etc. We consider a discharge-recharge model used in [4]. Assume that each battery of sensors is energy rechargeable. And the time is divided into equal-sized tome slots and all sensors have synchronized clocks. The sensors are either recharging or transmitting (but not both) and, once completely run out of energy, can only activate themselves when fully recharged. The authors study how sensor nodes should be activated dynamically so as to maximize a utility function based on the coverage area of the sensors. The sensors can sense temperature and humidity. We also consider the average temperature variations and humidity. Fig. 4 presents the environmental temperature variation, which is the average temperature variation between May and June 2011 in Tainan City, as recorded by the Taiwan Central Weather Bureau. This study uses the humidity level as the starting raining signal. Three degrees of humidity define as H 0.7 in dry areas such as Tainan City, H 0.8 in regular areas, and H 0.9 in wet areas such as Orchid Island.

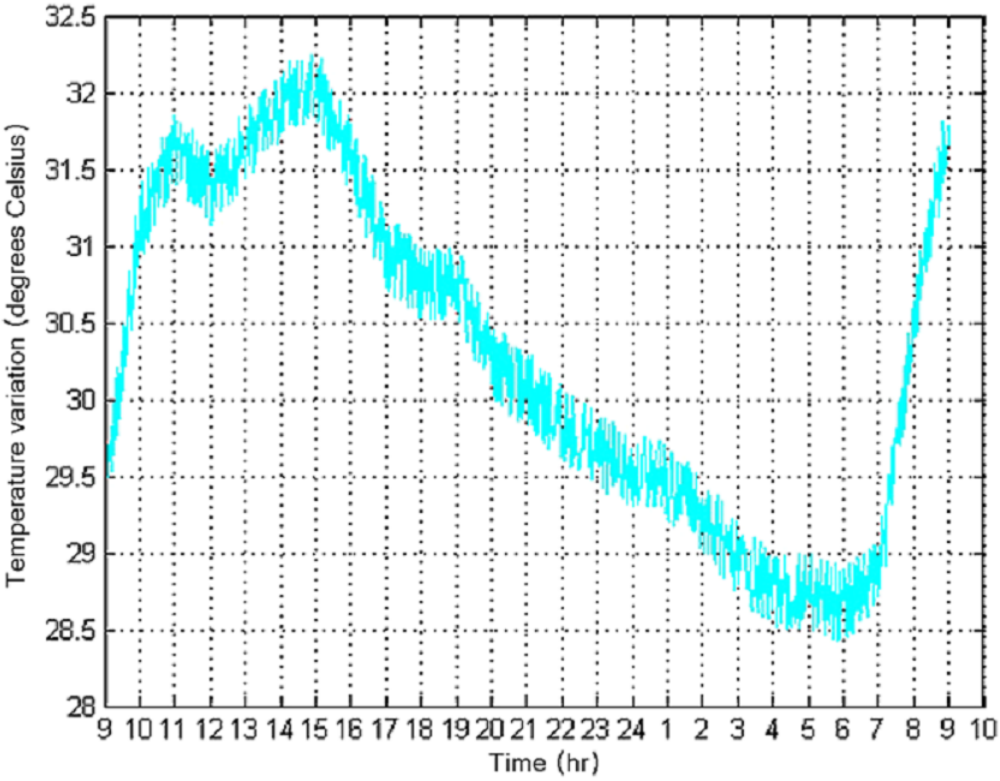


Figure 4. Temperature variation of the environment

The system predicts the amount of energy to be captured in a future epoch. This study assumes that the daily solar power rate curve is a Gaussian distribution curve. With the current solar power rate, the Gaussian distribution curve can be used to predict the amount of energy available and decide whether the sensor has enough power to work in this epoch. The working energy consuming rate C_i, the predicted solar energy S_j, and the solar energy consuming rate R_c. The sensor i decides his follow-up status in next epoch j as follow:

$$E_{i,j} = E_i C_i + S_j * R_c \tag{2}$$

We use humidity as the signal of starting rain. Because the sensor node with enough power can easily wake up, the predicted solar energy S_j becomes zero when the sensors sense that $Hu > H$. It may rain in the future epoch, the status becomes sleep in the next epoch for charge as follow:

$$E_{i,j} = 0, \quad if C_i > E_i \quad and \quad H_u > H \tag{3}$$

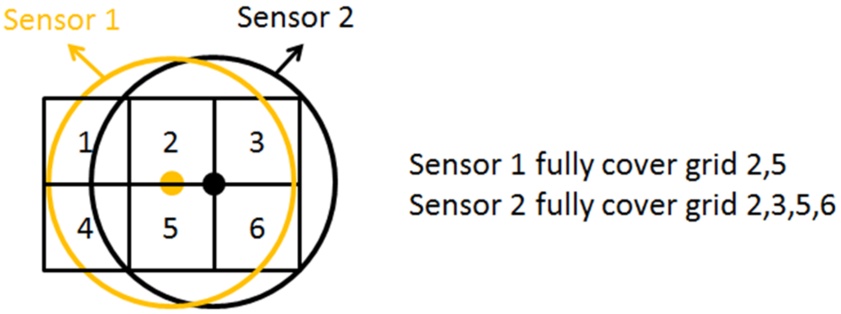


FIGURE 5. The coverage situation of a sensor location on the side line of grid

The sensors can work for a period but may exhaust in future if $C_i > S_j * R_c$, however, some of these sensors are still required to work in this epoch when $E_i + S_j * Rc > C_i$. After this epoch, the sink counts out a list $L_j = E_{i,j}$ of the sensors with the predicted energy.

3.3. **Adaptive node-selection mechanism scheme.** The node-selection problem is this: given a set of sensors, to find a subset whose cover area contains the detection area. The problem is NP-complete. The running time is of order $O(2^N N)$, since there are 2^N subsets and, to check each subset, we need to sum at most N elements. This study proposes a heuristic algorithm, adaptive node-selection mechanism (ANSM) scheme, which divides the detection area into smaller pieces according the grid setting to slave this problem, and the monitoring area can be covered with fewer sensor nodes. The sink calculates each sensor can cover which grids. If the location is on the grid line, there are two different results we can see an example at Fig. 5. The sensor 1 only can fully cover two grids 2 and 5, and the sensor 2 can fully cover four grids 2, 3, 5 and 6. The ANSM scheme uses two rules to make the decision as the follows:

- Rule 1: Select the sensor that can cover most of the grid.
  Assume that the set $M = m_1, m_2, m_3, , m_n$ is representative of the detection area which divided into n grids. The grid $g_k = s_x, s_y, s_z$ means that the grid k can be fully covered by the sensor x, y, and z. The goal is to select a subset:

$$M = m_i, m_j, \ldots, m_k \tag{4}$$

$$= s_a, s_b, s_c, s_a, s_c, s_e, \ldots, s_b, s_f \tag{5}$$

$$= s_a, s_b, s_c, s_d, s_f \tag{6}$$

Therefore, it is essential to select as few sensor nodes which cover more grids as possible to cover the monitoring area, to reduce the total energy consumed.

- Rule 2: Select the sensor with more battery energy $E_{i,j}$.
  A sensor with more $E_{i,j}$ can also be viewed as a sensor with less space for storing solar power. Thus, the other sensors in the same grid will take longer rest to charge their batteries fully. Selecting a sensor with less $E_{i,j}$ causes too many sensors to stay in a low battery energy condition, making it impossible to separate and average the power consumed by sensors in the same grid. According to rule 1, the ANSM scheme picks nodes which cover most grids. According to rule 2, the ANSM scheme then picks nodes with more battery energy $E_{i,j}$ in L. The process repeated until the detection area of the subset M equal the monitoring area of the set M.

3.4. **Minimum Steiner tree.** Connecting all sensors of the subset M' to the sink is similar to find a minimum spanning tree, but the sensors in the subset M' could be disconnected because the subset M' only considers the detection area. To find a Steiner tree helps the network become a connected graph. The problem can be given an edge-weighted graph $G(V, E, e)$, where V is sensor in L_j, edge *e(u,v)* means sensor u and sensor v care connected, e is least energy between *e(u,v)* according to Lj, and a subset $M \in V$. A Steiner tree is a tree in G that spans all vertices of *M'*. Fig. 6 shows that building the Steiner tree with sensors A, B, C and D using additional nodes.

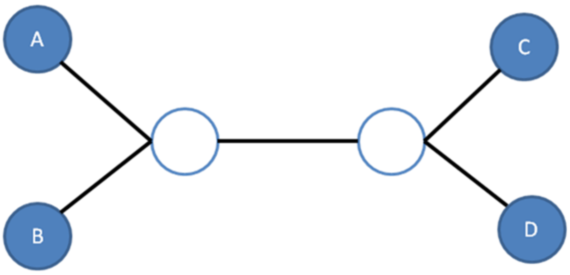


Figure 6. Building the Steiner tree

Therefore, the node-selection problem can be regarded as the minimum Steiner tree problem. The outstanding problem is to calculate the energy weight of each link in the solar-powered wireless sensor network. Consider Fig. 7 for example. In Fig. 7, when sensor E exhausted energy, the neighbors of sensor F cannot transmit or receive data with sensor E. Therefore, the energy weight associated with the edge between sensor E and sensor F is defined as the least energy value. Accordingly, the energy weight of every link is calculated.

The algorithm replaces the distance value with the predicted energy $E_{i,j}$ and builds the energy-aware Steiner tree between sensors and sink. The time complexity of our propose scheme $O(n^3)$ is much less than $O(2_n)$. The details of algorithm are described as Fig. 8.

3.5. **Performance evaluation.** This study compares the proposed scheme, adaptive node-selection mechanism (ANSM), with round-robin (RR) scheme. The RR scheme places the same number of sensors at each grid, which in our simulation is four sensors each grid. These four sensors will work one by one per epoch and rotated into a turn, not consider the overlapping of coverage, solar power, and battery situation.

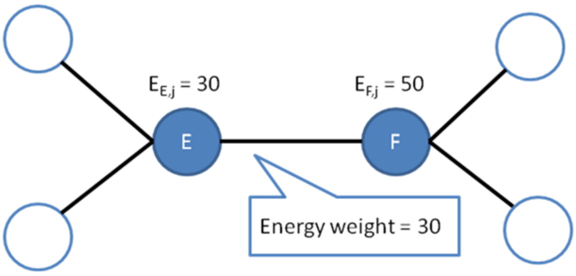


Figure 7. The energy weight associated with the edge between E and F

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input: an edge-weighted G (V,E,e) , M' is a subset of sensors ⊆ V
Output: a Steiner tree, T, for G and M'

Step 1. Construct the complete graph G(M',E',e ) from G and M'
Step 2. Find the minimum spanning tree, T1, of G(M',E',e )
            (If there are several minimum spanning trees, pick an arbitrary one.)
Step 3. Construct the subgraph, Gs, of G by replacing each edge in T1
            by its corresponding shortest path in G.
            (If there are several shortest paths, pick an arbitrary one.)
Step 4. Find the minimum spanning tree, Ts, of Gs.
            (If there are several minimum spanning tree, pick an arbitrary one.)
Step 5. Construct a Steiner tree, T, from Ts by deleting edges in Ts if necessary,
            so that all the leaves in T are Steiner points
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Figure 8. Algorithm of the energy-aware Steiner tree

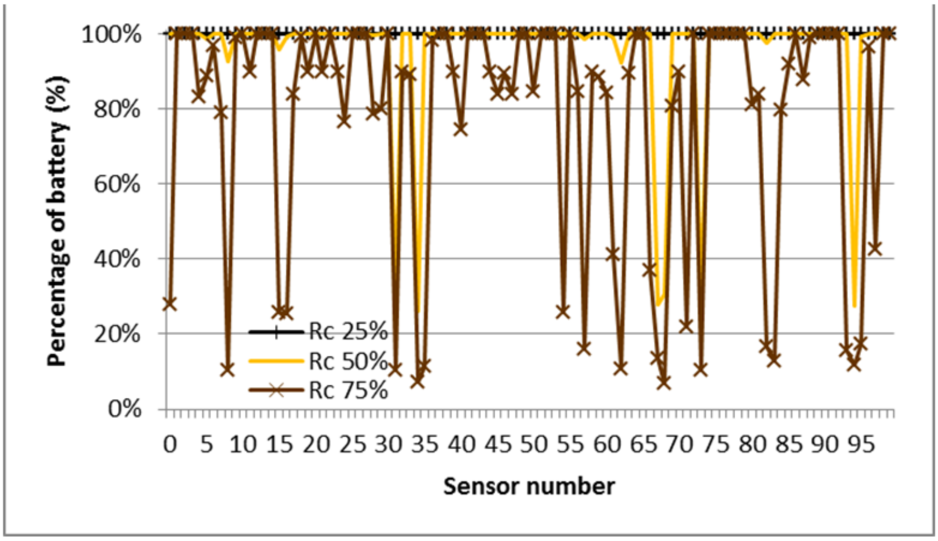

Figure 9. Algorithm of the energy-aware Steiner tree

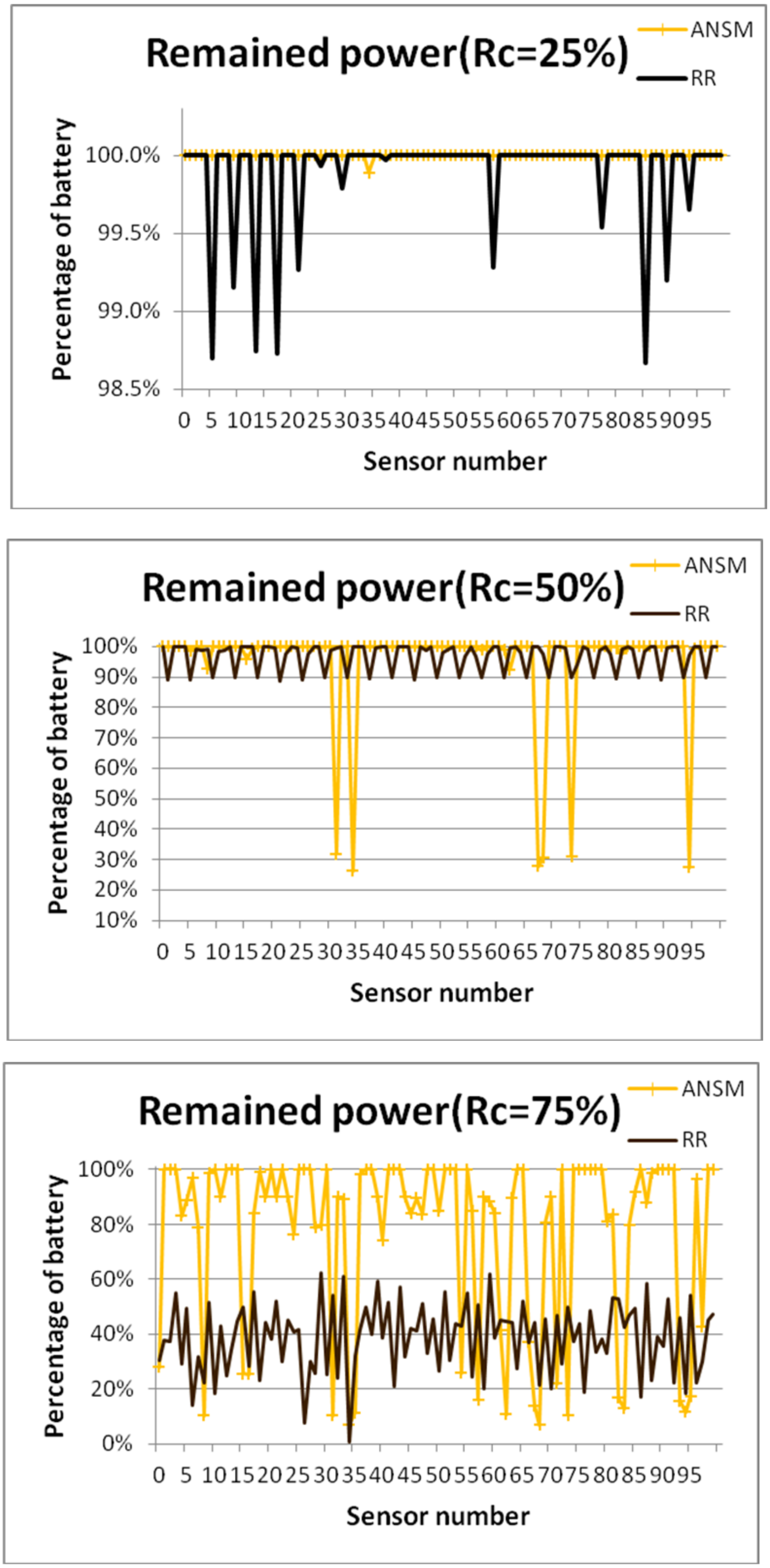

Figure 10. Remained power comparison with RR

Table 2. Simulation Parameters

Number of sensors	100 nodes
Monitor area	2500 m^2
Total grids number	25 grids
Grid side length (L)	10 meters
Sensing range (R_s)	$10\sqrt{2}$ meters
Maximum power of each sensor	25000 Jr
Energy cost per packet	6 Jr
Transmission frequency	30 seconds
Maximum solar power charging rate	1250 Jr per hour
Humidity	0.7

4. Simulation Analysis and Results.

4.1. Simulation environment and parameter setup. The proposed scheme is implemented in the C++ programming language. One hundred sensors are uniformly deployed in the area. The monitoring area is 2500 m2, consisting of 25 grids. Each grid side length is 10 meter, and the sensing range of each sensor is meter. The maximum power in the battery is 25000 Jr. The energy cost per packet for a sensor is 6 Jr. The transmission frequency is one transmission per 30 seconds. The maximum power charged is 1250 Jr per hour. The humidity is 0.7 for Tainan City. The solar energy consuming rate considers three situation 25%, 50% and 75%, and varies from 10% to 75% while comparing with the other algorithm. The running time is 100 days. Table 3 describes the simulation environment.

4.2. Simulation result. In Fig. 9, the remained power of all the sensors is almost all full with energy, because the solar energy consuming rate is so small that the solar power is more than the power we need to work for 100 days. When the solar energy consuming rate comes to 50%, some of the sensors which can cover more grids will work hard to maintain the system, so there is a few sensors remained power drop down. When the solar energy consuming rate is 75%, nearly all of the sensors have to work, so the remaining power of all sensors will become more average lower equally, doesnt like the solar energy consuming rate 50% just a few sensors with lower remained power.

In Fig. 10, there are just a few sensors remained power in RR is lower than ANSM at the solar energy consuming rate 25%, but not above 0.3% so its barely no difference compare with remained power. At the solar energy consuming rate 50%, there are more sensor nodes in ANSM with less power than RR, and because ANSM tends to make more efficiency sensors work more. RR only tends to average the working load but not consider each sensors capability.

At the solar energy consuming rate 75%, we can see the remained power becomes so low at RR because the system cant balance the consuming energy with fewer sensor nodes, but the ANSM is still working as usual. In Fig. 11, the average remained power shows us

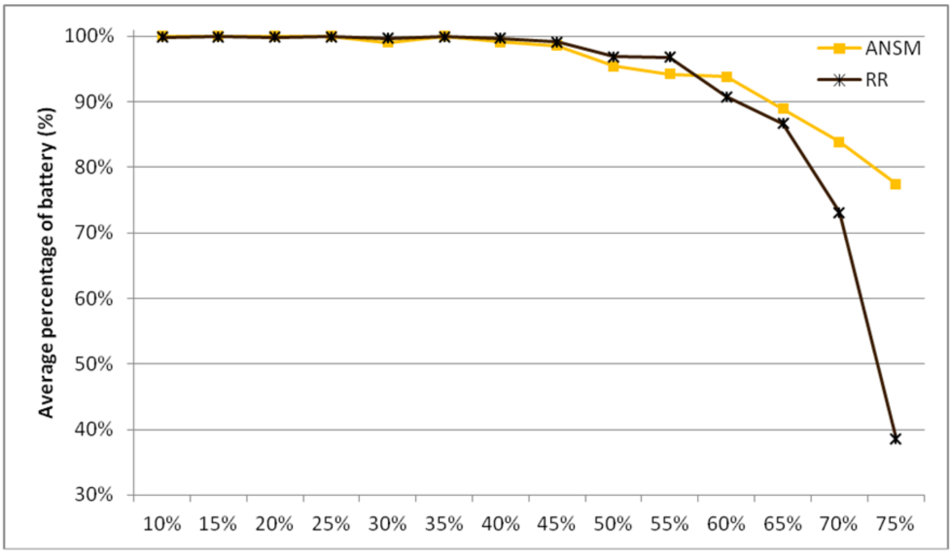

FIGURE 11. Total average performance of remained power comparison with RR

some result. First, when the solar energy consuming rate is lower than 40% that all 100 sensor nodes charge much more energy than the power we need to consume, that makes the battery energy close to 100%. When the solar energy consuming rate is between the number 45% to 57.5%, some sensors in ANSM system start to consume energy faster than 25% until its exhaust, but RR just separate the minus part of solar power into all sensors. Base on the ANSM will use fewer sensors to cover the whole area. When the solar energy consuming rate is more than 57.5, the ANSM average remained power will become more than RR. The curve of ANSM is like the friction, if workload doesnt much enough that fewer effective sensors can handle, it wont separate the workload to the backup sensors. We can also see the line of RR drop much faster than ANSM. Last, we talk about the average of using number of sensor, as Fig. 12 shown. The average number of using sensor number in the RR is always twenty-five. In ANSM, the average number of using sensor number is adaptive and between the number of sixteen to seventeen according to solar energy consuming rate.

5. **Conclusions.** In this work, equipping the sensors with solar-powered equipment signifies that the sensors no longer have the limited battery life problem. We consider the sensing light, temperature and humidity to predict the amount of energy to be captured in a future epoch. We proposed the adaptive node-selection mechanism (ANSM) scheme to solve the node-selection problem. This scheme selects the least active node to reduce the overlapping of the sensor coverage but ensure constant coverage of the target area in solar-powered wireless sensor networks. The simulation proves that the proposed scheme ensures high sustainability.

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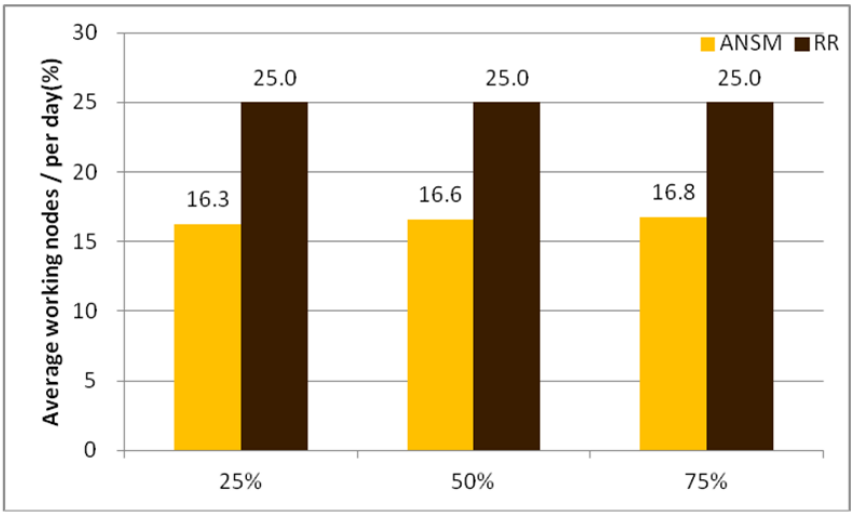

Figure 12. Average number of sensors comparison with RR

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