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An Energy Efficient Protocol for Target Localization in Wireless Sensor Networks

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***Abstract*—Target tracking and localization are important applications in wireless sensor networks. In these applications, sensor nodes collectively monitor and track the movement of a target. They have limited energy supplied by batteries, so energy efficiency is essential for sensor networks. Most existing target tracking protocols need to wake up sensors periodically to perform tracking. Some unnecessary energy waste is thus introduced. In this paper, an energy efficient protocol for target localization is proposed. In order to preserve energy, the protocol fixes the number of sensors for target tracking, but it retains the quality of target localization in an acceptable level. By selecting a set of sensors for target localization, the other sensors can sleep rather than periodically wake up to track the target. Simulation results show that the proposed protocol saves a significant amount of energy and also prolongs the network lifetime.

***Keywords*—Coverage, energy efficiency, target localization, wireless sensor network.

I. Introduction

In recent years, the advances and developments on wireless communication technologies and embedded systems have enabled the deployment of wireless sensor networks. Wireless sensor networks are composed of a large number of small sized devices powered by batteries and spread over a field where needed to be monitored. Each sensor node is embedded sensing, processing, and wireless communication functionalities. Due to their cost are feasible and flexible, wireless sensor network can be used in a variety of applications such as military surveillance, event detection, target tracking, and environmental monitoring [1].

In sensor networks, a source is defined as a sensor node detecting a target and generating data to report the conditions of the target; a sink is defined as an end user or a base station that collects data from the sources. For a large sensor network, multi-hop data forwarding is typically used to reach a distant destination. The task of deployed sensor networks is to detect specific events (intrusion, mobile targets, alarms, etc.) through the measurement of variations for a given physical parameters (temperature, humidity level, light intensity, etc.) on the time. Therefore, wireless sensor networks are capable of collecting the measurements and processing them based on the conditions set of the filter. The sensors then distribute the collected data through the network, finally reaching the sink.

In target tracking applications, the targets can be classified into two kinds. One kind is external target source, such as intruders from boundary, wildlife in forests, or enemy tanks in battlefield. The other kind is internal target source, such as patients in hospital, animals which have been captured by biology researchers releasing in the wilds, or firefighters in a burning building, which may be equipped with known signaling devices. Interesting events like movement of targets can be monitored. The events happen irregularly with long time intervals. The user might be only interested in the occurrence of a certain event or a set of events. The monitoring sensor network should take different appropriate strategies to adapt to varying active frequencies of events. No matter how often events happen, the networks should maintain a certain degree of coverage as long as possible.

In most cases, sensor nodes are deployed in harsh environments such as disaster area and toxic region. It seems impractical to recharge or renew every battery for each node. Thus, reducing the energy consumption of sensor nodes plays a critical role in prolonging the network lifetime. However existing target tracking protocols are not specifically designed for energy efficiency.

An energy efficient target tracking protocol for localizing the position of targets is developed in this paper. The idea is reducing the number of working sensors for target tracking, and also retaining the quality of tracking results at an acceptable level. The network operations have two modes. In the detection mode, when there are no events of interest in the field, the sensors should be ready to detect any possible occurrences. In the tracking mode, the network should react in response to any moving target and the sensors collaborate in measuring the target's movement. For target tracking, only the area around the target should be covered with certain degree (e.g., tracking target localization using the trilateration approach requires at least three samples), and other area can have lower coverage. It is not necessary to awaken all sensor nodes around the target if there are three or more sensors performing sensing task. The strategy can save more energy, but has not been mentioned in existing target tracking protocols.

The simulation result indicates that the method does not increase the working sensors even if the number of targets increases. In addition, the simulation result also shows that the proposed approach actually prolongs the network lifetime by putting more sensor nodes into sleeping mode.

II. Related Work

Target localization is a high-end application in sensor networks. In order to achieve the goal we should take the following things into consideration. Firstly, the coverage for

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target detection should be ensured in the network. Secondly, a protocol for target tracking should be well defined. Each node should know when to wake up for sensing or forwarding data and when to go to sleep for preserving energy. Thirdly, the distance to the target can be measured and the position of target can be calculated. Coverage problem, target tracking and localization issue in wireless sensor networks have been intensively studied in recent years. And we briefly review related literature here respectively.

A. Network Coverage

Coverage of sensor network has great impact on the quality of target tracking. The coverage problem has been studied extensively, especially combined with connectivity and energy efficiency. In the study of combination sensing coverage and communication connectivity, Wang *et al.* propose a *Coverage Configuration Protocol* (CCP) [2]. CCP can configure a sensor network to any coverage degree and maintain network connectivity at the same time. Each node in CCP collects neighboring information and then decides whether it can go to sleep or not. Under the assumption of disk sensing range, they also prove that coverage implies connectivity if the communication range R_C is at least twice of the sensing range R_S. If $R_C \geq 2R_S$, CCP is sufficient to configure a sensor network with both coverage and connectivity; if $R_C < 2R_S$, they combine their protocol with SPAN [3] to maintain the network connectivity. Zhang and Hou aim at finding the minimal number of sensors that maintain coverage and connectivity [4]. Coverage with minimal overlap is achieved when the locations of any three neighbor sensors form an equilateral triangle with side length as $\sqrt{3}$ times sensing range. Based on the optimal conditions, an *Optimal Geographical Density Control* (OGDC) algorithm is proposed. Huang and Tseng provide a *Perimeter-area Coverage* (PC) algorithm for verifying if the network satisfies *k-coverage* condition, which is true if every location of area is covered by at least k sensors [5]. Wu and Ssu propose an approach to determine the active nodes for full coverage without location information [6]. Wang *et al.* study the coverage problem for target detection and define the sensing region according to detection constraints in terms of false alarm probability and missing probability [7]. They also study the coverage problem for target localization [8]. Based on their results, the disk coverage model requires 4.64 times more sensors for localization compared to detection applications. The number of required sensors for localization is only 1.8 times more than that for detection, when using sector coverage model. But the sensors need to be equipped with multiple directional antennas in the sector coverage model.

B. Localization

Localization provides location information not only for the sensors but also for the targets in the sensor network. Localization algorithms can be classified into two main categories, range-based approaches and the range-free approaches. Range-free approaches are suitable for the applications where the required location accuracy is less critical. Ou *et al.* propose a range-free localization scheme with aerial anchor nodes [9]. The sensor nodes use the information from aerial anchor nodes to calculate their positions. In range-based approaches, the following ranging techniques [10] are used for distance estimation: RSSI [11], ToA [12], TDoA [13] or AoA/DoA [14].

1) RSSI: The RSSI (Received Signal Strength Indicator) technique is based on the fact that the radio signal attenuates exponentially with the increase of distance. According to the receiving power, the distance can be evaluated by translating the power loss with theoretical model.

2) ToA and TDoA: ToA (Time of Arrival) and TDoA (Time Difference of Arrival) techniques evaluate the distance by translating the propagation time between two nodes with known signal propagation speed.

3) AoA: AoA (Angle of Arrival) or called DoA (Direction of Arrival) techniques measure the position by geometric relationships with the angle where signals are received. ToA, TDoA and AoA techniques can typically achieve better accuracy than RSSI techniques, because radio signal amplitude is affected by environmental factors [15].

C. Target Tracking

The problem of tracking targets with sensor networks has received attention from different viewpoints. An information-driven sensor collaboration mechanism is proposed [16]. In this mechanism, measures of information utility are used to decide future sensing actions. Both research papers study tracking schemes based on different binary sensor model [17], [18]. The former sensors provide information such as whether a target is moving towards or away from them. The latter sensors determine whether the target is in their sensing range or not. Yang and Sikdar develop a distributed cluster-based protocol for target tracking sensor networks [19]. Three sensors are used to detect the target in the cluster which the target is moving toward. The next location of the target is predicted using the last two measured locations of the target. Zhang and Cao introduce tree-based tracking approaches in sensor networks [20], [21]. They formalize the tracking problem as a multiple objective optimization problem where the solution is building a convoy tree sequence with high tree coverage and low energy consumption. In order to construct such a convoy tree, global information is required. In addition, considerable energy is spent on computing and communication to maintain a convoy tree. Gui and Mohapatra study both power conservation protocols and sensor deployment schemes [22] that can be integrate with with other target tracking protocols. Du and Lin propose an energy management protocol for target tracking sensor networks [23]. The protocol allows sensors far away from targets going to sleep and guarantees the tracking of target at the same time.

III. System Model

In our system model, we focus on tracking the location of internal target sources. Each sensor is aware of its own position to estimate location information of the target using ranging techniques [11]–[14]. Among those ranging techniques, RSSI technique is applicable to any wireless sensor device without

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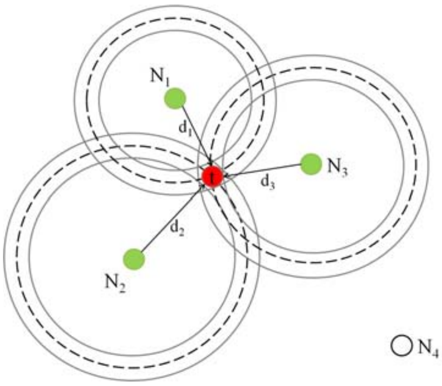

Fig. 1. A target is detected by multiple sensors. Sensor nodes N_1, N_2, and N_3 are activated.

any cost of extra hardware. Thus, it is assumed that sensor can receive a specific signal transmitted from target. Target detection is declared by a sensor if received signal strength exceeds the threshold. In this case, it is said that the sensor is activated. As shown in Fig. 1, where sensor nodes N_1, N_2, and N_3 are activated since received signal strength of each sensor exceeds the threshold. At each data sampling time, the activated sensors forward their positions and measurements with sampling timestamp to the sink rather than compute the target location by cooperative signal processing. Without exchanging time series sampling data among neighbor, it can save more energy and release the computational loading of sensors.

A. Signal Propagation Model

Both theoretical and measurement-based propagation models indicate that average received signal power decreases logarithmically with distance, whether in outdoor or indoor radio channels. Such models have been used in the literature extensively. For instance, the widely used propagation model, *log-distance path loss model* [24], considers the received power as a function of the distance between transmitter and receiver. Since this model is a deterministic propagation model and gives only the average value. Another propagation model, *log-normal shadowing model* [24], is introduced to describe the irregularity of received signal power. That is

$$\begin{aligned} PL(d)[dB] &= \overline{PL}(d) + X_\sigma \\ &= \overline{PL}(d_0) + 10n\log(\frac{d}{d_0}) + X_\sigma \end{aligned} \tag{1}$$

and

$$\begin{aligned} P_r(d)[dBm] &= P_t[dBm] - PL(d)[dB] \\ &= P_0 - 10n\log(\frac{d}{d_0}) + X_\sigma \end{aligned} \tag{2}$$

where $PL(d)$ represents the path loss, $\overline{PL}(d)$ is the mean of path loss, $P_r(d)$ represents the received power, P_0 denotes the initial power transmitted from transmitter, d is separation distance between transmitter and receiver, d_0 is the close-in reference distance which is determined from measurements close to the transmitter, X_σ is a zero mean Gaussian random variable with standard deviation σ. And it is supposed that the initial power transmitted from target is known. For the applications of tracking internal target source, it is not an impractical assumption. Thus, the estimated distance which differs from real distance due to quantization errors and thermal noise can be computed by power strength received from sensors. The expected target transmission range R_T is defined as the signal propagation distance where received signal strength equals to detection threshold without considering the noise from environment.

B. Localization Method

In this paper, the sink has to compute the location of target according the collecting data sampled from sensors. The *lateration* method for determining the position of target is applied. From the estimated distances $\widetilde{d_i}$ and known positions (x_i, y_i) of the sensors, the following equations are derived:

$$(x_i - x_t)^2 + (y_i - y_t)^2 = \widetilde{d_i}^2, \tag{3}$$

for $i = 1 \sim n$, where (x_t, y_t) denotes the location of target. And the following linear equations in the form $Ax = b$ can be derived by subtracting the first equation from above n equations except the first one itself, where

$$A = \begin{bmatrix} 2(x_2 - x_1) & 2(y_2 - y_1) \\ \vdots & \vdots \\ 2(x_n - x_1) & 2(y_n - y_1) \end{bmatrix}$$

$$b = \begin{bmatrix} x_2^2 - x_1^2 + y_2^2 - y_1^2 + \widetilde{d_1}^2 - \widetilde{d_2}^2 \\ \vdots \\ x_n^2 - x_1^2 + y_n^2 - y_1^2 + \widetilde{d_1}^2 - \widetilde{d_n}^2 \end{bmatrix}$$

Finally, the above linear equations can be solved using least-squares approach, and then the location of target (x_t, y_t) can be gotten.

Using *lateration* to get an estimated position at an acceptable level requires at least three measurements from different locations. If the sink only gets one record at the time, the location of sensor which samples the data will be the estimated position. In another case, if the sink has two records sampled from different sensors, the midpoint of two sensors will be the estimated position. Besides, the sink cannot separate one target from other near targets. The target classification problem is not our concern in this paper.

IV. Proposed Scheme

For a target tracking sensor network, the network coverage requirement at the detection mode is far from the one at the tracking mode significantly. The detection mode requires coverage close to full coverage on the whole region. However, the tracking mode requires an intense coverage covered by at least three sensors simultaneously in order to support sink to localize the position of target. Only the area around the target requires high coverage degree at each time. From the perspective of power saving, many studies and measurements have shown that sensor idle listening consumes 50 to 100%

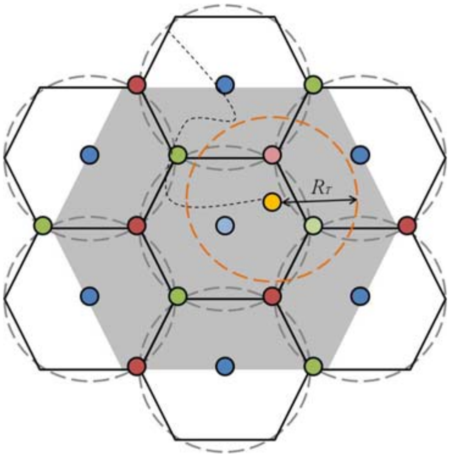

Fig. 2. The targets in the shaded area can be detected by at least three sensor nodes.

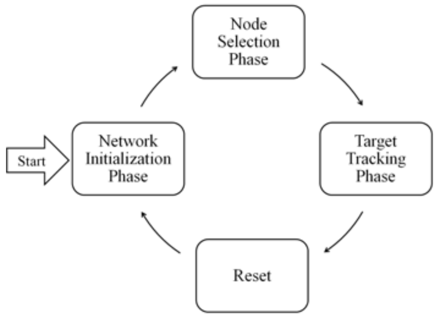

Fig. 3. Phase transition of the proposed scheme.

of the energy required for receiving. Considerable energy is wasted when sensors are in idle mode for most of the time with nothing is sensed. The idea of our proposed method is making most sensors go to sleep to save significant amount of energy. In order not to sacrifice the functionality of target localization, a small number of sensors are chosen to ensure the network coverage for tracking and detection. The sleeping sensors will not wake up until next round begins. To minimize the number of working sensors while preserving network coverage, the optimal deployment pattern has been shown in [4]. But it cannot support enough coverage degree for target tracking. So the pattern is extended to suit the situation as shown in Fig. 2.

In Fig. 2, R_S denotes the sensing range of each node, and the blue, red and green nodes represent active sensors selected to maintain the network coverage for target detection and localization. The yellow node represents the intruder or the target that run into our monitored area. The target under the shaded area can be sensed by at least three sensors. When target is moving under the shaded area, sensors can support enough sampling measurements for sink to localize the position of target. If there are no interesting events in the monitored region, active sensors in blue color are enough for retaining the network coverage for detection mode. The active sensors in red and green color can turn off their sensing component to save energy. In order to recover the coverage for tracking mode immediately, they should still keep their transceiver on.

To achieve the topology shown in Fig. 2, the proposed protocol is divided into three phases as shown in Fig. 3. Firstly, the sensor network is initialized including synchronization and route setup. Secondly, a set of sensors are selected to maintain the network coverage for target detection and localization. Thirdly, the network dynamically adjusts the coverage according to the position of targets. Finally, the whole network begins a new cycle after performing the tracking works for a certain period. The activities which occur during each phase will be described in the following respectively.

A. Network Initialization Phase

In this phase, there are two main functions required to be achieved, including time synchronization and forwarding route creation. Both of them need system wide broadcasting, so combining those two functions into one sending packet can reduce communication overhead. The forwarding route is constructed with minimal hop count route strategy.

At first, sink broadcasts an advertisement message to its immediate neighboring sensors. Each advertisement message contains the packet sending time, the hop count to the sink, and the location of sender. In the packet broadcast from the sink, the hop count is set to 0. Initially, the hop count to the sink is set to infinity at each sensor. After receiving an advertisement message, each sensor will adjust its clock according to the packet sending time and put the message in its buffer. The sensor postpones the transmission of the advertisement message until the back-off timer expires in order to reduce the collision. The sensor only rebroadcasts the advertisement message with updated minimal hop count, new sending time, and location. Before rebroadcasting the advertisement message, the hop count value is increased by 1 and the packet sending time is renewed by the adjusted local clock. If the advertisement message with the actual minimal hop count arrives before the expiration of the back-off timer, the broadcasting of message with a non minimal hop count will be suppressed. The number of broadcasts from each sensor depends on the length of back-off time. Increasing the back-off time significantly decreases the number of broadcasts. However, a long back-off time also increases the total time for the completion of this phase. Thus the back-off time is tuned to be the function of distance between sender and receiver. The farther distance from advertisement sender to received sensor it is, the shorter back-off time sets in the received sensor. The tuning of back-off timer not only speeds up completion of initialization phase, but also reduces the number of broadcasts in the whole network. The algorithm for network initialization phase is shown in Fig. 4.

In the synchronization part, the clock of sensors far from the sink may fall behind the clock of sink due to the delay of propagation and processing. Nevertheless, the lagging of clock does not impact the application of localization operated on the sink. Sensors receiving the same event triggered by target are related in spatial view, so the clock time difference

Definition:
M_R: the received message.
N: the sensor node processing received message.
$A.b$: the value of b stored in sensor A or the value in b field of message A.
$|A - B|$: the Euclidean length between A and B.

Algorithm in Network Initialization Phase

```
When the node receives a message M_R.
while (1) do
    switch(M_R.type)
        case 1: advertisement message
            if(M_R.hop_count + 1 < N.hop_count)
                N.hop_count ← M_R.hop_count + +;
                N.local_clock ← M_R.packet_sending_time;
                set back-off_timer(|M_R.sender_location − N.location|);
        break;
        ⋮
    end switch
end while
```

Fig. 4. Algorithm in network initialization phase.

in those sensors is bounded at once propagation time plus other sending and receiving process time. Sink treats those packets as the same group if the difference of packet sending times does not exceed the threshold.

B. Node Selection Phase

In node selection phase, the goal is determining a set of sensors to maintain the network coverage for target detection and localization. The first step is deciding the starting sensor nodes to drive the whole network. A sink-assisted selection method is utilized to choose starting nodes. At the beginning, sink broadcasts a hello message for collecting the information of neighbor sensors. Sensors that receive the hello message from sink will return a message including their identity, residual energy, and the location of themselves. Then, sink decides the starting nodes based on the residual energy in order to balance the energy consumption. A sensor with higher residual energy has a greater chance to be a starting node.

For satisfying the coverage requirement of different situations (detection mode and tracking mode), the starting nodes are classified into two types. One type is sentry node and the other type is guard node. The former is responsible for the coverage in detection mode and notifies the guard nodes if target goes into the monitored area; the latter helps sentry node to maintain the coverage around target. When sink chooses the sensor with highest residual energy to be starting sentry node, other starting nodes are chosen according to the location of starting sentry node as shown in Fig. 5.

Only two other starting guard nodes are selected by sink. The ideal position of two guard nodes are $(R_T, \theta + \pi/6)$ and $(R_T, \theta - \pi/6)$ respectively in polar coordinate system with origin as the location of starting sentry node. R_S denotes the sensing range of each sensor. The angle θ is generated from a uniform random number in $[0, 2\pi]$. θ should be attached in the selection message for the following steps. If there is no sensor at the ideal location, sink always chooses the nearest sensor to be starting guard node.

The second step of this phase is flooding discovery message from starting nodes. Discovery message is used to find other nodes that cooperate with starting nodes. Sensor nodes process

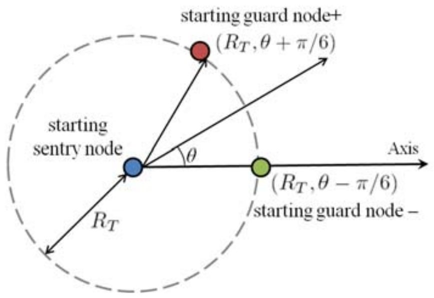

Fig. 5. The ideal places of starting guard nodes according to the location of starting sentry node and random angle θ.

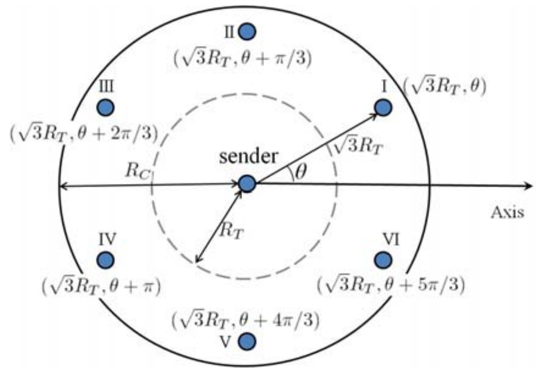

Fig. 6. Six ideal places based on the optimal deployment pattern in sender's view with random angle θ.

discovery message based on their status. There are three states in the status of each sensor: NULL, WORK, and SLEEP. At the beginning of each round, all sensors set their status to NULL state. Sensors change their status into WORK state when they receive a selection message from sink or their selection timer expires. As soon as sensors set their status to WORK state, they broadcast the discovery message that contains the location of sender, the group identity and the angle generated by sink. The starting sentry node and guard nodes select their members separately by the group identity in their discovery message. For instance, a new guard node in guard node$+$ group cannot be selected by the discovery message sent from a sentry node even a guard node in guard node$-$ group.

After receiving a discovery message, sensor sets its selection timer according to the location of sender and the random angle θ. In order to matching the optimal deployment pattern, each sensor calculates the distance between its location and the position of six ideal places in sender's view as shown in Fig. 6. Each sensor selects the minimum value among the six distances and uses the value to set selection timer. The smaller the value is, the faster the selection timer expires. Sensors close to the ideal places have high probability to set their status to WORK state. A sensor may receive discovery messages from different groups and then sets selection timers for different groups. Different selection timers count down in parallel until one of them expires. If a selection timer expires, sensor will become sentry node or guard node based

TABLE I
NODE STATUS IN DETECTION MODE AND TRACKING MODE

Node Type	Detection Mode sensor	Detection Mode radio	Tracking Mode sensor	Tracking Mode radio
sentry node	on	on	on	on
guard node	off	on	on	on
SLEEP node	off	off	off	off

on group identity. When a sensor sets its status to WORK state, it will cancel all the selection timers and ignore discovery messages from any group. Other sensors around the ideal places will become WORK nodes when time goes by. But they are redundant nodes for network coverage. An effective mechanism is proposed to eliminate the redundant nodes. If a sensor receives a discovery message before the selection timer for the same group expires, it will check whether the distance from sender to its position exceeds the sensing range or not. The selection timer will be suppressed if the distance does not exceed the sensing range. Otherwise, the selection timer continues to count. Once the selection timer is suppressed, the sensor loses the chance to become a WORK node in the same group which suppressed timer stands for. In this way, the redundant nodes around the ideal places can be eliminated. When the selection timers for the three node groups are all suppressed, the sensor will set its status to SLEEP state until next round begins. The SLEEP nodes turn off their sensing and radio components to save energy. The algorithm in node selection phase is shown in Fig. 7.

C. Target Tracking Phase

After node selection phase, all sensors set their status from NULL state to WORK state or SLEEP state. Only sensors in WORK state are responsible for the target detection and localization. The network operations have two modes. During the detection mode, no interesting event occurs in the monitored area. Only sentry nodes maintain the coverage for target detection and guard nodes turn off sensing component to conserve energy. If the target moves into the monitored area, the region around the target operates in tracking mode. When a target is detected by a sentry node, the sentry node broadcasts an alert message to its neighbor guard nodes in order to support enough measurements for sink to localize the position of target. After receiving the alert message, guard nodes switch sensing component on and start tracking the target. Table I lists the node status in different operation modes. Finally, when the target moves further away and guard nodes do not receive alert message for a period of time, they switch back to detection mode and turn off the sensing component.

It is assumed that the targets move into the monitored area from boundary. Therefore a method for enhancing the coverage along the boundary without waking up other nodes is proposed here. Sink broadcasts a boundary message which contains the information of boundary area over the whole network. Every sensor in WORK state verifies if its location is inside the boundary area. All WORK nodes in the boundary area turn on the sensing component no matter they are sentry nodes or guard nodes. Other sensors in the center region of

Definition:
M_R: the received message.
N: the sensor node processing received message.
$A.b$: the value of b stored in sensor A or the value in b field of message A.
$|A - B|$: the Euclidean length between A and B.
P_i: the ideal position based on the optimal deployment pattern in sender's view with random angle θ, for $i = 1 \sim 6$.
R_T: the expected target transmission range.

Algorithm in Node Selection Phase

```
When the node receives a message M_R.
while (1) do
  switch(M_R.type)
    :
    case 2: hello message
      create a new message M_N;
      M_N.type ← "information";
      M_N.NodeID ← N.id;
      M_N.energy ← N.energy;
      M_N.location ← N.location;
      send M_N after random back-off time;
    break;
    case 3: selection message
      if(M_R.NodeID = N.id)
        N.group_id ← M_R.GroupID;
        N.angle ← M_R.angle;
        set N.status WORK;
        send discovery message;
    break;
    case 4: discovery message
      if(N.status = NULL)
        N.angle ← M_R.angle;
        if(|M_R.sender_location − N.location| < R_T)
          switch(M_R.GroupID)
            case 1: sentry node
              suppress selection timer of sentry node group;
            break;
            case 2: guard node+
              suppress selection timer of guard node+ group;
            break;
            case 3: guard node-
              suppress selection timer of guard node- group;
            break;
          end switch
          if(all selection timer are suppressed)
            set N.status SLEEP;
            shutdown radio and sensing component;
        else
          switch(M_R.GroupID)
            case 1: sentry node
              set sentry node selection timer as function of
              min(|P_i − N.location|);
            break;
            case 2: guard node+
              set guard node+ selection timer as function of
              min(|P_i − N.location|);
            break;
            case 3: guard node-
              set guard node- selection timer as function of
              min(|P_i − N.location|);
            break;
          end switch
    break;
    :
  end switch
end while
```

Fig. 7. Algorithm in node selection phase.

monitored area turn off their sensing component even they are sentry nodes. When a target is detected by a sentry node in the boundary area, the sentry node informs neighbor sensors in the center region to turn on the sensing component by alert message as original method.

In this protocol, sensors track the target in a simple way. They just report the detection timestamp, their locations and measurements to the sink through the minimal hop count route

Definition:
M_R: the received message.
N: the sensor node processing received message.
$A.b$: the value of b stored in sensor A or the value in b field of message A.
T_k: the time which sensor needs to keep the sensing component on for.

Algorithm in Target Tracking Phase

When the node receives a message M_R.
while (1) **do**
  switch($M_R.type$)
    ⋮
    case 5: alert message
      start sensing component;
      if(sensor belongs to guard node group)
        set sensor timer(T_k);
    break;
    case 6: boundary message
      if(sensor has not sent boundary message yet)
        if($N.location$ in boundary area)
          start sensing component;
        else
          shutdown sensing component;
        send M_R after random back-off time;
    break;
    case 7: forwarding message
      if($M_R.hop\_count > N.hop\_count$ and $M_R.NodeID$ is not in queue)
        $M_R.hop\_count \leftarrow N.hop\_count$;
        add $M_R.NodeID$ in queue;
        set forward_timer(random time);
      if($M_R.hop\_count = N.hop\_count$ and $M_R.NodeID$ is in queue)
        cancel forward_timer;
    break;
  end switch
end while

Fig. 8. Algorithm in target tracking phase.

Definition:
M_R: the received message.
N: the sensor node processing received message.
$A.b$: the value of b stored in sensor A or the value in b field of message A.
$|A - B|$: the Euclidean length between A and B.

Algorithm for Timers

When timer expires.
while (1) **do**
  switch(type of timer)
    case 1: back-off timer
      $M_R.hop\_count \leftarrow N.hop\_count$;
      $M_R.location \leftarrow N.location$;
      $M_R.packet\_sending\_time \leftarrow N.local\_clock$;
      send M_R;
    break;
    case 2: selection timer for sentry node group
      $N.group\_id \leftarrow$ "sentry node";
      set $N.status$ WORK;
      suppress other selection timers;
      send discovery message;
    break;
    case 3: selection timer for guard node+ group
      $N.group\_id \leftarrow$ "guard node+";
      set $N.status$ WORK;
      suppress other selection timers;
      send discovery message;
    break;
    case 4: selection timer for guard node- group
      $N.group\_id \leftarrow$ "guard node-";
      set $N.status$ WORK;
      suppress other selection timers;
      send discovery message;
    break;
    case 5: sensor timer
      shutdown sensing component;
    break;
    case 6: forward timer
      send corresponding M_R;
      remove $M_R.NodeID$ from queue;
    break;
  end switch
end while

Fig. 9. The actions taken when timer expires.

built in the first phase. The detection timestamp obtained from the alert message is used as event identity. Only sensors in WORK state with less hop counts forward the measurements for the sensors with more hop counts. A sensor cancels its forwarding timer if it hears the same measurement with the hop counts equal to its. The advantage of this way is that it defers the complex processing of the sensing measurements to the more powerful sink and reduces the communication overhead. Finally, the algorithm in target tracking phase is shown in Fig. 8, the actions taken when timer expires are shown in Fig. 9 and the types of messages used in our scheme are shown in Table II respectively.

TABLE II
THE MESSAGE TYPES USED IN OUR SCHEME

Type	Content	Purpose
advertisement message	[type, hop count, sender location and packet sending time]	construction of minimal hop count route and synchronization
hello message	[type]	collecting the information from neighbor sensors
information message	[type, NodeID, energy and location]	acknowledgement for hello message
selection message	[type, NodeID, GroupID, angle]	assigning starting nodes of each group
discovery message	[type, GroupID, angle and sender location]	selecting other nodes that should stay awake
alert message	[type and timestamp]	informing other nodes to track target
boundary message	[type and boundary information]	distinguishing boundary area from monitored area
forwarding message	[type, hop count, NodeID, timestamp, location and measurement]	supporting measurements for sink

V. PERFORMANCE EVALUATION

The proposed protocol is implemented with *ns-2* [25] simulator and a series of experiments for performance evaluation are also conducted. The performance of the proposed scheme is also compared with other two schemes: (1) an energy management protocol for target tracking sensor networks —SNEM [23] with minimal hop count routing rather than cell relay routing as original; (2) OGDC [4] algorithm combining proactive wakeup algorithm [22] for target tracking with 40% duty cycle rate in sleep mode. SNEM and OGDC+PW are used to denote the two schemes mentioned above. In the following simulation, all parameters are shown in Table III respectively. The energy model referencing the characteristic of real radio module in [13] is used. The sink is static at the center of simulation area. The target moves across the network from boundary. The mobility of target follows the random waypoint model. The target is always present in the network during most experiments. Four main metrics are used to evaluate the performance of proposed protocol: (*A*) coverage ratio, (*B*) quality of target localization, (*C*) energy consumption and (*D*) network lifetime.

TABLE III
PARAMETER VALUES USED IN SIMULATION

Parameter Setting	
Simulation area	$100 \times 100\ m^2$
Number of nodes	100 - 1000
Sensor deployment	Random (uniform distribution)
Target transmission range	15 m
Communication range	30 m
Maximum target speed	10 m/s
Time of each round	1000 s
Data transmission rate	19.2 kbps
Transmission power	17.76 mW
Receiving power	12.50 mW
Idle power	12.36 mW
Sleep power	16 μW

A. Coverage Ratio

In order to calculate the network coverage, the simulation area is divided into 1×1 grids. A gird is said to be covered if the center of the grid is covered by at least one sensor. Coverage ratio is defined as the ratio of the number of covered grids to the whole grids in network. Due to that the target moves across the network from boundary is assumed. The coverage in boundary area impacts whether the target can be detected or not. The boundary coverage ratio is defined as coverage ratio but the region is limited in the area with specific width from boundary. The boundary coverage ratio with different node populations is shown in Fig. 10. Our approach gets higher coverage ratio in the boundary area when only 100 sensors are deployed, due to the boundary coverage enhancement method mentioned in Section IV-C is used. In our approach, the number of sensors in boundary area with sensing component in operation is more than the number in other two schemes. However, the benefit is not so obvious with the rising of number of sensors. All the schemes approach full coverage after the number of sensor achieves 400.

B. Quality of Target Localization

In order to compute the location of target, each sensor estimates the distance with RSSI ranging technique. To characterize the distance error, the real measurements are used in [26]. The authors derive an error standard deviation of the ranges as a function of the signal strength. And they also show the probability density function of their signal strength measurements fits the Gaussian distribution curve which matches our system model. Thus, their error standard deviation is used when sensor estimates the distance in our simulation. The localization estimation error represents the quality of target localization. It is defined as the Euclidean distance between the real coordinates and estimated coordinates of the target. The average localization error with different node populations is shown in Fig. 11. The mean values and the standard deviation are depicted for different number of nodes. All three schemes compute the location of target using the *lateration* method. In our approach, the average localization error does not increase too much even though the number of measurements delivered to the sink is less than other two schemes. Because our sink receives lesser measurements to localize the target, the

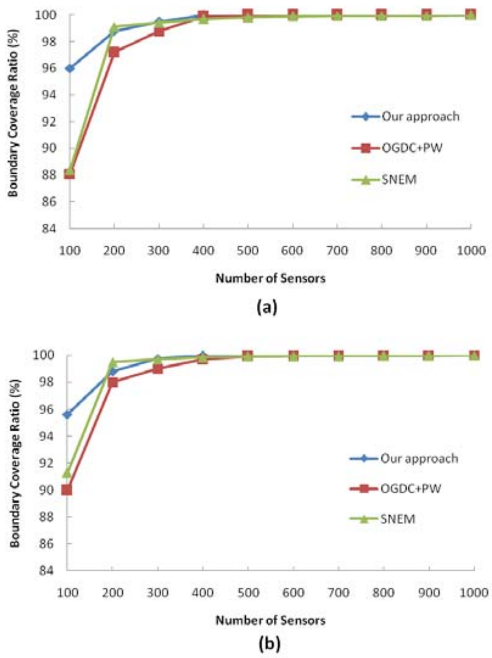

Fig. 10. Boundary coverage with (a) 5m and (b) 10m width boundary area.

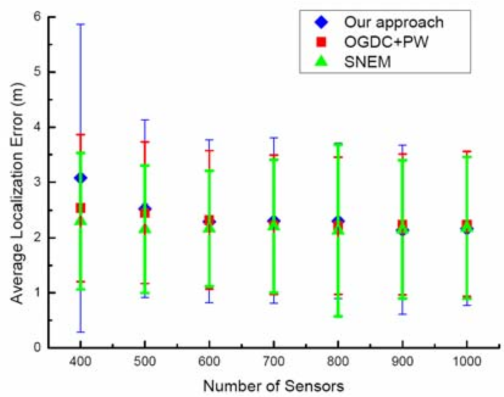

Fig. 11. Variation of the localization error with varying node populations.

standard deviation of localization error is higher than other two schemes. And the accuracy does not improve too much as the number of sensors increases.

C. Energy Consumption

In this experiment, the number of sensor nodes is fixed at 500. And the number of targets varies from 0 to 4. Fig. 12 shows the total energy consumption in the first round when different number of targets moving across the network. Both SNEM and OGDC+PW spend triple times more energy than our proposed protocol even there is no target in the network. The main energy consumption is still on the sensor idle time. In SNEM, sleeping nodes have to periodically wake up for a short time to receive the message. The message is sent by the active node when it detects the target. The summation

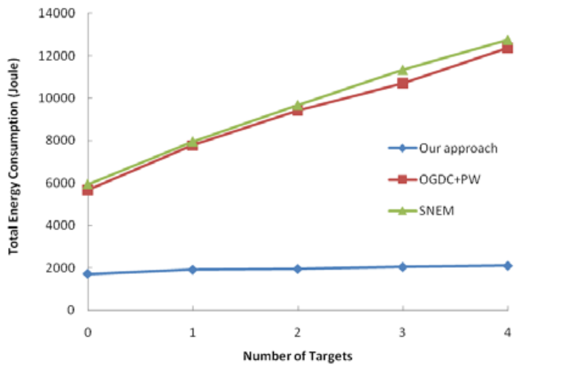

Fig. 12. The total energy consumption in the first round with varying number of targets.

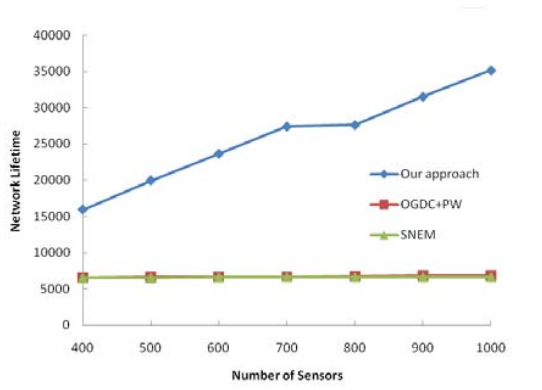

Fig. 14. The network lifetime with varying node populations.

of energy consumed by each sensor for waiting the message contributes most of total energy consumption. In OGDC+PW, sleeping nodes have 40% duty cycle rate to maintain the proactive wakeup mechanism. So each sensor still waste too much on preparing to track target. In our approach, only a small number of sensors are selected for tracking the target. The other sensors can go to sleep and do not wake up until next round begins. Thus, considerable energy is saved. And the number of sensors for target localization is fixed even though the number of targets in simulation area increases. So the total energy consumption increases slightly in our proposed scheme. Both in SNEM and in OGDC+PW, the sensors around the target are awakened to track the target. Therefore, that the number of sensors for target localization is more than ours reflects in the rising of the total energy consumption.

Fig. 13 shows the percentage of working states of nodes in the network. Active state represents that both sensing and radio components are turning on. Ready state denotes that only radio component is on. Sleep state means that both two components are off. Deep sleep state is the same as sleep state but without periodically waking up. The number of active nodes increases as the number of targets raises in the network. And the number of active nodes plus ready nodes is stationary due to only a set of nodes selected for localization and tracking.

D. *Network Lifetime*

Network lifetime is one of the important metrics for evaluating the performance of sensor networks. And the network lifetime is defined from the perspective of services. In this experiment, the sampling rate of each sensor is set to be 1Hz and only one target moves in the network. If the sink receives insufficient (below three) measurements from network twice continuously, then the network is said to be dead. The network lifetime with different node populations is shown in Fig. 14. The main reason why our approach prolongs 2.4 times the network lifetime longer than other two schemes is the same as the reason described in Section V-C. The network lifetime grows longer when the number of sensors increases. The more sensors in the network, the more sets of sensors can share the load of target localization in our approach. However, the other two schemes cannot get the benefit of dense node deployment due to that they use all the nodes around the target for target localization. The network lifetime thus increases little even the number of sensors achieves to 1000.

VI. Conclusion

For prolonging the lifetime of sensor networks, reducing the energy consumption is an important issue. In this paper, an energy efficient protocol for target localization is developed to reduce the waste of energy. The energy conservation and the quality of target localization are trade-offs in sensor networks. Exploiting the features of target localization applications and sensor networks, this protocol keeps the functionality of localization and decreases the number of tracking sensors at the same time. Due to the selected sensors for target tracking and localization, other unselected sensors can conserve their energy by sleeping rather than wake up periodically. The simulation result indicates that our proposed method does not increase the working sensors even the number of targets increases and prolongs the network lifetime by scheduling more sensor nodes in sleeping mode.

References

[1] I. F. Akyildiz, W. Su, Y. Sankarasubramaniam and E. Cayirci, "A Survey on Sensor Networks," *IEEE Communications Magazine*, vol. 40, no. 8, pp. 102-144, Aug. 2002.

[2] X. Wang, G. Xing, Y. Zhang, C. Lu, R. Pless and C. Gill, "Integrated Coverage and Connectivity Configuration in Wireless Sensor Networks," *ACM International Conference on Embedded Networked Sensor Systems (SenSys)*, pp. 28-39, Nov. 2003.

[3] B. Chen, K. Jamieson, H. Balakrishnan and R. Morris, "Span: An Energy-efficient Coordination Algorithm for Topology Maintenance in Ad Hoc Wireless Networks," *ACM International Conference on Mobile Computing and Networking (MobiCom)*, pp. 85-96, Oct. 2001.

[4] H. Zhang and J. C. Hou, "Maintaining Sensing Coverage and Connectivity in Large Sensor Networks," *Ad Hoc & Sensor Wireless Networks*, vol. 1, pp. 89-124, Mar. 2005.

[5] C.-F. Huang and Y.-C. Tseng, "The Coverage Problem in a Wireless Sensor Network," *ACM International Workshop on Wireless Sensor Networks and Applications (WSNA)*, pp. 115-121, Sept. 2003.

[6] T.-T. Wu and K.-F. Ssu, "Determining Active Sensor Nodes for Complete Coverage without Location Information," *International Journal of Ad Hoc and Ubiquitous Computing*, vol. 1, no. 1-2, pp. 38-46, Jan. 2005.

[7] W. Wang, V. Srinivasan, K.-C. Chua and B. Wang, "Energy-efficient Coverage for Target Detection in Wireless Sensor Networks," *ACM International Conference on Information Processing in Sensor Networks (IPSN)*, pp. 313-322, Apr. 2007.

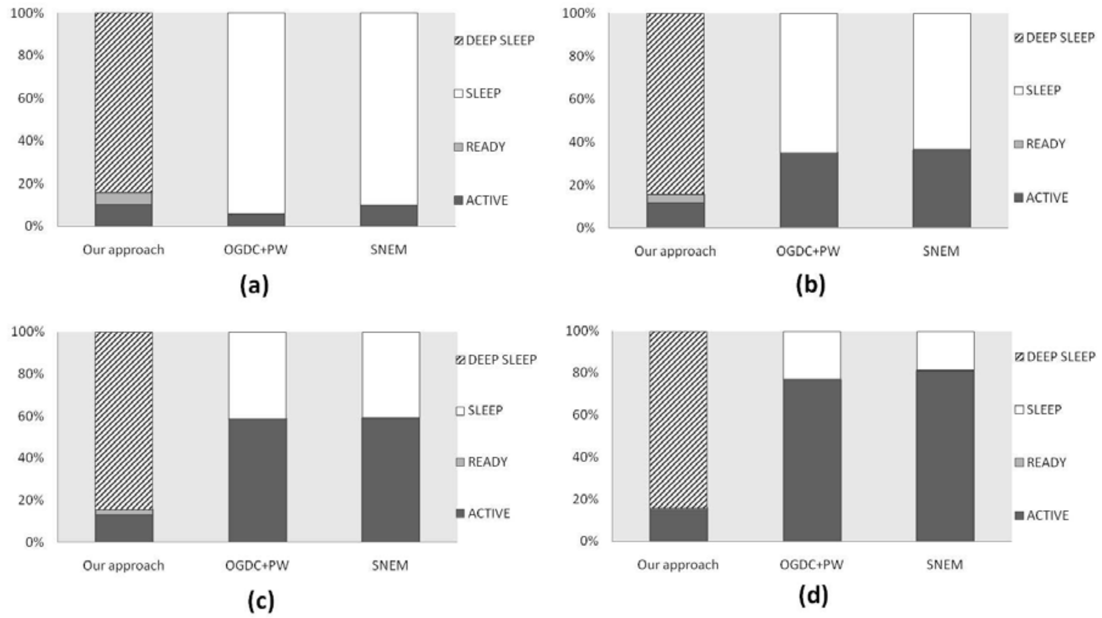

Fig. 13. The percentage of different working states of nodes with (a) no target (b) one target (c) two targets (d) three targets in the network.

[8] W. Wang, V. Srinivasan, K.-C. Chua and B. Wang, "Coverage for Target Localization in Wireless Sensor Networks," *IEEE Transactions on Wireless Communications*, vol. 7, no. 2, pp. 667-676, Feb. 2008.

[9] C.-H. Ou and K.-F. Ssu and H.-C. Jiau, "Range-Free Localization with Aerial Anchors in Wireless Sensor Networks," *International Journal of Distributed Sensor Networks*, vol. 2, no. 1, pp. 1-21, Jan. 2006.

[10] G. Mao, B. Fidan and B. D. O. Anderson, "Wireless Sensor Networks Localization Techniques," *Computer Networks: The International Journal of Computer and Telecommunications Networking*, vol. 51, no. 10, pp. 2529-2553, July 2007.

[11] P. Bahl and V. N. Padmanabhan, "RADAR: An In-Building RF-Based User Location and Tracking System," *IEEE INFOCOM 2000*, vol. 2, pp. 775-784, Mar. 2000.

[12] B. Hofmann Wellenhoff, H. Lichtenegger and J. Collins, *Global Positioning System: Theory and Practice*, 4th ed. Springer Verlag. 1997.

[13] A. Savvides, C.-C. Han and M. B. Strivastava, "Dynamic Fine-grained Localization in Ad-Hoc Networks of Sensors," *ACM International Conference on Mobile Computing and Networking (MobiCom)*, pp. 166-179, July 2001.

[14] D. Niculescu and B. Nath, "Ad Hoc Positioning System (APS) Using AoA," *IEEE INFOCOM 2003*, vol. 3, pp. 1734-1743, Mar. 2003.

[15] M. Broxton, J. Lifton and J. Paradiso, "Localizing a Sensor Network via Collaborative Processing of Global Stimuli," *IEEE Workshop on Wireless Sensor Networks*, pp. 321-332, Feb. 2005.

[16] F. Zhao, J. Shin and J. Reich, "Information-driven Dynamic Sensor Collaboration," *IEEE Signal Processing Magazine*, vol. 19, no. 2, pp. 61-72, Mar. 2002.

[17] J. Aslam, Z. Butler, F. Constantin, V. Crespi, G. Cybenko and D. Rus, "Tracking a Moving Object with a Binary Sensor Network," *ACM International Conference on Embedded Networked Sensor Systems (SenSys)*, pp. 150-161, Nov. 2003.

[18] N. Shrivastava, R. Mudumbai, U. Madhow and S. Suri, "Target Tracking with Binary Proximity Sensors: Fundamental Limits, Minimal Descriptions, and Algorithms," *ACM International Conference on Embedded Networked Sensor Systems (SenSys)*, pp. 251-264, Mar. 2006.

[19] H. Yang and B. Sikdar, "A Protocol for Tracking Mobile Targets Using Sensor Networks," *IEEE International Workshop on Sensor Networks Protocols and Applications*, pp. 71-81, May 2003.

[20] W. Zhang and G. Cao, "DCTC: Dynamic Convoy Tree-based Collaboration for Target Tracking in Sensor Networks," *IEEE Transaction on Wireless Communications*, vol. 3, no. 5 pp. 1689-1701, Sept. 2004.

[21] W. Zhang and G. Cao, "Optimizing Tree Reconfiguration for Mobile Target Tracking in Sensor Networks," *IEEE INFOCOM 2004*, vol. 4, pp. 2434-2445, Mar. 2004.

[22] C. Gui and P. Mohapatra, "Power Conservation and Quality of Surveillance in Target Tracking Sensor Networks," *ACM International Conference on Mobile Computing and Networking (MobiCom)*, pp. 129-143, Sept. 2004.

[23] X. Du and F. Lin, "Efficient Energy Management Protocol for Target Tracking Sensor Networks," *IFIP/IEEE International Symposium on Integrated Network Management*, pp. 45-58, May 2005.

[24] T. S. Rappaport, *Wireless Communications: Principles and Practice*, 2nd ed. Prentice Hall, 2001.

[25] The Network Simulator — ns-2, http://www.isi.edu/nsnam/ns, 2009.

[26] M. L. Sichitiu and V. Ramadurai, "Localization of Wireless Sensor Networks with a Mobile Beacon," *IEEE Conference on Mobile Ad-hoc and Sensor Systems (MASS)*, pp. 174-183, Oct. 2004.