Organization of Energy Efficiency in Wireless Sensor Network
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ABSTRACT
Wireless Sensor Network (WSN) has specific constraints and stringent requirements in contrast to traditional wired and wireless computer networks. Due to the wide potential applications of wireless sensor networks, this topic has attracted great attention. The strict energy constraints of sensor nodes result in great challenges for energy efficiency. Because of limitation in energy and selection of best route, for the purpose of increasing network remaining energy a node with most energy level will be used for transmission of data. The most part of energy in nodes is wasted on radio transmission, thus decreasing number of transferred packets in the network will result in increase in node and network lifetimes. This paper proposes an energy-efficient organization method. The organization of wireless sensor networks is formulated for target tracking. The destination route is achieved by collaborative sensing with multi-sensor fusion. The sensor nodes implement sensing tasks are awakened in a distributed manner. Thus, by using this we can be minimized energy consumption in wireless sensor network.

Keywords—Wireless Sensor Network, Energy Efficiency, Collaborative Sensing, Distributed Sensor Node Awakening

I. INTRODUCTION
For environmental and industrial monitoring and surveillance purpose, wireless sensor networks (WSNs) are widely used in various applications. For a given sensing area, sensors are distributed and detect an unknown target or event locally. Sensor nodes are typically powered by batteries with a limited lifetime and, in most cases, the batteries cannot be recharged. The energy problem in wireless sensor networks remains as one of the major barriers preventing the complete exploitation of this technology. Due to the limited battery capacity, the energy efficiency of a WSN is an important issue. Sleeping and awakening of sensor nodes are supported in power-aware hardware design. As a typical WSN application, target tracking should be addressed as an energy efficiency problem. Prior target position estimation can be used to organize the awakening and routing of WSN, so that the energy efficiency can be improved. Based on the forecasted results, energy-efficient organization of sensor nodes can be performed to optimize the energy consumption of a WSN.

This paper proposes an energy-efficient organization method for WSNs. Equipped with multisensors, sensor nodes can produce range and bearing measurements. The energy-efficient organization approach includes sensor node awakening and dynamic routing. A distributed awakening approach is presented to save and scale the operation energy consumption.

II. PRELIMINARIES OF THE ENERGY EFFICIENT ORGANIZATION
The two-dimension sensing field is filled with randomly deployed sensor nodes. Their positions are provided by a global positioning system (GPS). A sink node is located in the centre of the sensing field. Sensor nodes sense collaboratively within a specified sensing period. As the historical target positions become available, the sink node can forecast the target position of the next sensing period.

(i) Multi-Sensor Model
It is assumed that each sensor node equips two kinds of sensors, one pyroelectric infra-red (PIR) sensor and one omni-microphone sensor. Sensor nodes obtain the bearing observations with the PIR sensors, while the
range observations are produced by the omni- microphone sensors. For each sensor node, it is assumed that the two sensors have the same sensing range $R$. The coordinates of the sensor node and target are denoted by $(x_i', y_i')$ and $(x_{\text{target}}, y_{\text{target}})$ respectively. Then the true bearing angle is calculated as:

$$\beta_i' = \arctan \left( \frac{y_{\text{target}} - y_i'}{x_{\text{target}} - x_i'} \right)$$  \hspace{1cm} (1)

and the true range value is calculated as:

$$r_i' = \sqrt{(x_{\text{target}} - x_i')^2 + (y_{\text{target}} - y_i')^2}$$  \hspace{1cm} (2)

Both sensors have zero-mean and Gaussian error distribution. The standard deviation of bearing and range observations is $\sigma_\beta$ and $\sigma_r$, respectively. The observations produced by the sensor node $i$ is:

$$\beta_i = \beta_i' + w_\beta$$  \hspace{1cm} (3)

$$r_i = r_i' + w_r$$  \hspace{1cm} (4)

where $w_\beta$ and $w_r$ are the corresponding Gaussian white noise.

(ii) Energy Model

For the scalability of energy consumption in WSN, all the components of the sensor node are supposed to be controlled by an operation system, such as microOperating System (µOS).

There are four main parts of energy consumption source that should be consider during sensor node operation- processing, sensing, reception and transmission. The processing energy is spent by the processor with memory. It is assumed that when the processor is active it has constant power consumption. The embedded sensors and A/D converter are adopted as there is any sensing task, and the corresponding power consumption is a constant. When the reception portion is turned on, the sensor node keeps listening to the wireless channel or receiving data. Therefore, when sensor nodes $i$ transmits data to sensor node $j$, the power consumed by transmission portion is:

$$P_{tx} = \alpha_1 r_d + \alpha_2 d_{i,j}^2 r_d$$  \hspace{1cm} (5)

where $r_d$ denotes the data rate, $\alpha_1$ denotes the electronics energy expended in transmitting one bit of data, $\alpha_2 > 0$ is a constant related to transmission amplifier energy consumption, $d_{i,j}$ is the Euclidean distance between the two sensor nodes.

III. COLLABORATIVE SENSING

Due to the redundancy of sensor node deployment in WSNs, the target can be detected by a group of sensor nodes simultaneously. Observations of sensor nodes are merged for higher detection accuracy.

(i) Target Localization with Multi-sensor Fusion

It is assumed that the coordinates of the target are $(x_{\text{target}}, y_{\text{target}})$ at one sensing instant of the WSN. The target can be detected by $N_i$ sensor nodes. Sensor nodes can produce the bearing observations $\beta_i$ and range observations $r_i$, where $i = 1, 2, \ldots, N_i$. For sensor node $i$, the matrix representation of the observation equation can be derived from (3) and (4):

$$\Gamma_i = H(X) + W_i, \ W_i \sim N(0, \Psi)$$  \hspace{1cm} (6)

where $X = [x_{\text{target}}, y_{\text{target}}]^T$ is the true target position, $\Gamma_i = [\beta_i, r_i]^T$ is the observation vector, $H_i$ is the observation matrix, $W_i$ is the observation error vector, $N$ means the normal distribution function, and $\Psi = \text{diag}[\sigma_\beta^2, \sigma_r^2]$.

(ii) Adaptive Target Position Forecasting

When the current target position is obtained, the historical target is also available in the active sensor nodes so that target forecasting can be performed. In the twodimension field, the target position is presented by Descartes coordinates.

One direction of the target trajectory $\{Y_k | k = 1, 2, \ldots, N_i\} \in \mathbb{R}$ is considered for this discussion. The problem is to estimate the target position $Y_{N_i+1}$ in the next sensing period. The same forecasting approach can be implemented in the other direction.

The ARMA model is adopted here due to its outstanding performance in model fitting and forecasting. This model contains two terms, (i) the autoregressive (AR) term and (ii) the moving average (MA) term. In the AR
process, the current value of the time series $y_k$ is expressed linearly in terms of its previous values \( \{ y_{k-1}, y_{k-2}, \ldots, y_{k-p} \} \) and a random noise $a_k$. This model is defined as a AR process of order $p$, $\text{AR}(p)$. It can be presented as :

$$ y_k = \phi_1 y_{k-1} + \phi_2 y_{k-2} + \ldots + \phi_p y_{k-p} + a_k \quad (7) $$

where $\{ \phi_i | i=1,2,\ldots,p \}$ are the AR coefficients. In the MA process, the current value of the time series $y_k$ is expressed linearly in terms of current and previous values of a white noise series $\{ a_k, a_{k-1}, \ldots, a_{k-q} \}$. This noise series is constructed from the prediction errors. This model is defined as a MA process of order $q$, $\text{MA}(q)$. It can be presented as :

$$ y_k = a_t - \theta_1 a_{k-1} - \theta_2 a_{k-2} - \ldots - \theta_q a_{k-q} \quad (8) $$

In the autoregressive moving average process, the current value of the time series $y_k$ is expressed linearly in terms of its values at previous periods $\{ y_{k-1}, y_{k-2}, \ldots, y_{k-p} \}$ and in terms of current and previous values of a white noise $\{ a_k, a_{k-1}, \ldots, a_{k-q} \}$.

**IV. ENERGY-EFFICIENT ORGANIZATION METHOD**

With the forecasted target position, WSN performs distributed awakening to enhance the scalability of the energy consumption.

**Distributed Sensor Node Awakening** - Sensor node awakening is considered with the forecasted target position. To prolong the lifetime of WSN, we exploit a sensor node awakening approach. Operation modes of sensor node are defined as follows:

1) **Sleep**: It has the lowest power consumption as all the components are inactive. Only the timer driven awakening is supported, that is, the processor component can be awakened by its own timer. The power consumption is defined as 5 mW.

2) **Idle**: Only the processor component is active in this mode. All the other components are controlled by the operation system. The power consumption is defined as 25 mW.

3) **Sense**: The processor and sensor components are active. In this mode, sensor nodes can acquire the target observations. The power consumption is defined as 40 mW.

4) **Rx**: The processor is working and the reception portion of RF circuits is turned on. Sensor nodes can receive request or data. The power consumption is defined as 45 mW.

5) **Rx & tx**: The processor is active while both the reception and transmission portions of RF circuits are turned on. Sensor nodes can receive and transmit information. The power consumption is defined as $(45 + P_{tx})$ mW, where $P_{tx}$ is the power consumption of transmission.

Then, sensor node awakening strategy can be exploited according to the defined operation modes. Each sensor node controls its operation modes separately. For a sensor node in idle mode, if there is no target in its sensing range, it will get into tx mode. Thus, the broadcasting information of the target position can be obtained from the sink node. Note that this target position is the target position estimation forecasted in the last sensing period. That is because the target localization is not accomplished yet, while the sensor node should go to sleep as soon as possible. Then the sensor node goes to sleep mode with the estimated sleep period number. If the sensor node in idle mode detects any target, it goes into data acquisition sensing mode. After that, the data is transmitted for data fusion in the rx & tx mode. Then, the forecasted target position is acquired. Also, the sensor node which finishes the sensing task goes to sleep mode, adopting the estimated sleep period number.

For each sensor node, we define the shortest distance to the WSN boundary as $d_{\text{max}}$. Then the sleep time is:

$$ t_{\text{sleep}} = \begin{cases} T & d_{\text{min}} \leq v_{\text{max}} \cdot T + R_s \\ \frac{d_{\text{target}} - R_s}{v_{\text{max}}} & d_{\text{min}} > v_{\text{max}} \cdot T + R_s \end{cases} $$

(9)

where $T$ denotes the sensing period, $R_s$ is the sensing range of sensor node, and $v_{\text{max}}$ is the maximum target velocity.

**V. CONCLUSIONS**
As mentioned already, a main problem with wireless sensor networks is energy. Considering the energy consumption in Wireless Sensor Network, this paper proposes an energy efficient organization method based on collaborative sensing and adaptive target estimation. Sensor nodes which are equipped with bearing and range sensors utilize the maximum likelihood estimation for data fusion. Hence, targets can be localized by collaborative sensing while the localization error is evaluated. The future target position is derived from the forecasted results and is adopted to organize the sensor nodes for sensing. Here, the energy efficient organization method includes the distributed sensor node awakening and adaptive routing scheme. Sensor nodes can go to sleep when there is no target in its sensing range and it can be awakened once there is potential sensing task. Besides, probabilistic awakening is introduced to prolong the sleep time of sensor nodes. More importantly, the energy efficiency of WSN is guaranteed by the distributed sensor awakening.

REFERENCES