A Cluster-based Approach for Collaborative Target Tracking in Wireless Sensor Networks

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Abstract

Target tracking is an important application of wireless sensor networks (WSNs). A primary criterion of wireless sensor networks is the energy efficiency. This paper proposes a cluster-based approach for collaborative single target tracking in dense wireless sensor networks. In this approach, the sensor nodes collectively monitor and track the movement of the target. This involves detecting, clustering and localization of target. Detection of target is initiated by the phenomenon emitted by the target. Sensor nodes are dynamically clustered based on received signal strength. The function of Leader sensor node is to compute the location of target, based on the information obtained from other sensor nodes in its cluster. An Energy-based target localization algorithm is used to localize the target. This paper focuses on tracking error and energy management involved in tracking the target.

Keywords - Wireless sensor networks, Target tracking, Collaborative signal processing, Target localization, Phenomenon, Clustering.

1. Introduction

Wireless sensor networks (WSNs) consist of a large number of intelligent sensor nodes with sensing, processing and wireless communicating capabilities. These sensor nodes collectively monitor environmental conditions, such as temperature, sound, vibration, and so forth as explained in [4] and [3]. WSN can be employed in applications ranging from environmental monitoring and battlefield surveillance to condition based maintenance applications. Among the tasks of these applications, target tracking and localization are most frequently involved.

One of the application of target tracking is tracking the position of vehicle in battlefield surveillance system [12]. Determination of target location at successive time instants is integral to tracking. In target tracking, there are three important steps to be followed. First, detecting the phenomenon emitted by the target. Second, dynamic clustering of sensor nodes for tracking the target [15]. Based on their functionality, the sensor nodes are classified into leader nodes and neighboring nodes. Leader nodes are responsible for communicating the information to the user nodes by collecting information from neighboring sensor nodes. Since, there are strict energy constraints in sensor nodes, energy management can be obtained using this approach. This helps in optimization of energy consumption in sensor nodes. Third step is estimating the location of target. This is performed by using an energy based collaborative target localization algorithm.

Initially the existing leader sensor node and other neighboring nodes in its cluster are involved in tracking the target. Finally, target location information is fused in the newly elected leader sensor node. In order to optimize the target location, steepest descent search algorithm [10] is used.

2. Related work

The specific sensor network functionalities are the generation of track information and the delivery to a collector/sink. This paper only concerns with the track information generation which can be deemed as high-level event acquisition, as compared with raw data acquisition. A classification of existing approaches is based on a variety of different physical measurements. Two most common methods for target localization are the time delay-based and energy-based approaches. While time delay-based approaches such as TOA/TDOA (Time of Arrival/Time Difference of

978-0-7695-3267-7/08 $25.00 © 2008 IEEE
DOI 10.1109/ICETET.2008.241

Arrival) [7] are susceptible to estimation errors in time synchronization, on-set detection and echo effect. Moreover accurate synchronization of relative sensors at present is too expensive. This method is less affected by noises as a result of cross correlation but requires more computation. So, energy-based approaches are more robust in these aspects. Hence, this paper adopts energy-based approach as the localization method.

For target tracking in sensor networks, Leader nodes (Cluster heads) play an important role. Zhao *et al.* proposed the IDSQ (Information Driven Sensor Querying) in [5], where a leader sensor node is intelligently selecting the best neighbor node to perform sensing and serve as the next leader. A cost function was employed by jointly considering the energy expenditure and information gain. Based on a similar idea, in [1], Wang *et al.* applied the Baysian SMC (Sequential Monte Carlo) methods to the problem of optimal sensor selection and fusion in target tracking. These approaches require that individual sensor nodes process detailed information about all nodes in neighborhood, such as the location and residual energy level, which limits the protocol scalability.

Brooks et al. proposed location centric CSP (Collaborative Signal Processing) approaches for target tracking sensor networks in [11], where a selected region instead of an individual sensor node is activated. But clustering of nodes is not considered, which can further reduce the energy consumption. Efficient methods for exchanging information between the nodes, and collaborative signal processing (CSP) between the nodes to gather useful information about the physical world are two critical problems underlying successful operation of sensor networks.

3. Assumptions

The proposed system can only be used for single target tracking. Radio range of sensor nodes should be two times larger than the sensor nodes as explained in [8]. This introduces constraint in maximum target moving velocity. Various model assumptions are made for simulating the system.

3.1. Radio propagation model

Two-ray ground reflection model [6] is used as radio propagation model in detecting the target. This model considers both the direct path and a ground reflection path. This model gives more accurate prediction at a long distance than the other propagation models. The received power at distance d is predicted by

$$P_r(d) = \frac{P_t . G_t . h_t^2 . h_r^2}{d^4 . L} \tag{1}$$

Where ht and h_r are the heights of the transmitter and receiver antennas respectively. G_t , G_r are transmitter and receiver gains of sensor nodes. P_t denotes the transmitted power of the sensor node. L is the system loss which is assumed to be one.

3.2. Sensor network model

A typical sensor network consist of components like sensor nodes, user nodes, target [14]. The communication between the sensor node and user node is done through the wireless channel and phenomenon (or) sensor channel is used for target and sensor.

3.3. Sensor node deploying model

Node deploying model follows a Poisson distribution model. Sensor nodes are deployed in grid topology (or) random topology and the movements of target nodes in the sensing region are defined at various intervals of time.

4. System overview

The proposed target tracking system can applied for dense wireless sensor networks. Initially, sensor nodes are deployed in the surveillance region. Sensor nodes are deployed in a specific topology. Locations of the sensor nodes are known a priori. The location may be artificially specified during the deployment or determined by the WSN self localization algorithms as introduced in [9]. Target enters into the sensing region with constant velocity by emitting a phenomenon. This phenomenon is produced in terms of broadcasting packets to other neighboring sensor nodes.

Detection is initiated by leader node when the received signal strength exceeds the threshold level of sensor as explained in [2]. After detecting the phenomenon(or) event, the dynamic clustering algorithm can be applied to the sensor nodes for tracking the target. Finally, target location information fusion is done at newly elected leader sensor node based on estimated signal level. In this step, old leader sensor node and other sensor nodes sends the estimated location to newly elected sensor node. Based on this, target location is estimated by using energy based localization algorithm Optimization of target location obtained by using the steepest descent search algorithm[10].

This procedure is repeated until the target disappears from the surveillance region.

5. Proposed system architecture

The architectural design of the target tracking system is shown in Figure 1, where the major components are identified. Sensor nodes are deployed based on the grid width and height of the region specified, number of sensor nodes. The moving target enters into the region where the sensor nodes are deployed and initiates the sensing. By using the target tracking algorithm, the tracking of target is made. The sensor nodes goes into various states, thereby performing energy saving operations. This can be applied to more number of nodes using dynamic clustering algorithm to obtain power consumption. Finally, the tracked information is sent to the user nodes.

The proposed approach for target tracking in wireless sensor networks consist of various modules. They are scenario generation, detection of target, dynamic clustering of nodes, energy based target localization, optimization of target location, estimation of target error and energy consumption.

The detailed description of various modules and sub-modules are as follows.

5.1. Scenario Generation

Initially the sensor nodes are deployed in surveillance region. Locations of the sensor nodes are known a priori. The location may be artificially specified during the deployment or determined by the WSN self localization algorithms as introduced in [9].

Target enters the sensing region with emission of particular type of phenomenon like acoustic signals, vibrations, light etc. Maximum velocity of target is constrained to the sensing and radio range of sensor nodes. Appropriate channels are allotted for communication between the target and sensor node and also between user node and sensor node.

5.2. Target detection

Target detection is based on the strength of the signal received by the sensor nodes from the target [2]. Detection uses minimal a priori information about the target. During detection, average of the signal power is detected over a window of pre-specified length. The output of the detector is sampled at a pre-specified rate. The window duration and sampling rate are determined by target characteristics, such as the signature bandwidth and the expected signature duration in the particular sensing modality.

An event (or) phenomenon is detected, when the estimated signal strength exceeds a threshold range of sensor. Due to the inherent signal averaging, the noise component in the signal may be modeled as a Gaussian random variable whose mean and variance can be determined from the statistics of the background noise. If the detector output is below the current threshold, the signal is assumed to consist of noise only and these measurements are used to update the threshold.

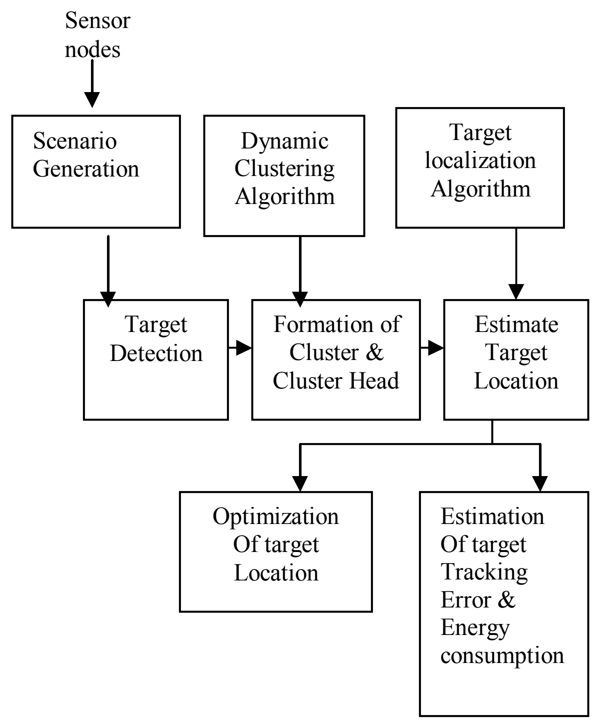

Figure 1. Overall architecture of target tracking system

5.3. Clustering of sensor nodes

Sensor nodes are clustered in order to facilitate collaborative data processing in target tracking-centric sensor networks. Dynamic clustering algorithm [15] is used to cluster the sensor nodes. The cluster architecture consists of cluster heads (or) leader nodes and several neigh boring nodes.

The attributes of each cluster includes the size of a cluster, the area it covers, and the members it possesses. This approach considers the sensor network as a heterogeneous, hierarchical sensor network that is composed of (a) Sparsely deployed high-capability sensors called CHs (Cluster Heads) or Leader nodes and densely populated low-end sensors whose function is to provide sensing information to CHs upon requests.

In this approach , there are various steps to be followed to perform clustering and provide communication between the sensor nodes as explained in [8]. They include the following important tasks

1) Election of Leader node 1.
2) Selection of sensor nodes for tracking the target.
3) Selection of sensor nodes for information fusion at newly elected leader node 2.
4) Updating the old track information at various time instants.

The task of leader node includes the following steps:

1) Broadcasting a packet that contains the energy and the extracted signature of the detected signal to sensors.
2) Receiving replies from sensors for clustering process.
3) Estimating the location of the target based on localization of target.
4) Sending the result to user nodes.

5.3.1. Election of Cluster Head. In the first step of dynamic clustering, a CH volunteers to recruit sensors to form a cluster if its detected signal strength exceeds a predefined threshold. One fundamental design issue to consider is which CH(s) should be elected to form a cluster if more than one CH detects simultaneously signals with the strength exceeding the threshold. Note that if two or more clusters are active simultaneously, packets exchanged in one cluster may interfere/collide with those in the other cluster(s). Ideally, the CH that is closest to the target (or the CH with the largest SNR ratio) should be elected. Since the communication cost of deterministic leader election is very high, a two-phase, random delay-based broadcast mechanism [15] is used to implicitly determine the active CH. This mechanism has two phases. In the first phase, an energy packet that carries only the signal strength information is broadcast. In the second phase, a signature packet that contains the detailed signature information is then broadcasted. Both packets are subject to the same random back-off delay value.

5.3.2. Selection of nodes for tracking. A set of sensor nodes are selected for tracking the target based on sensing measurement of sensor node at particular time. Assuming that Ns (neighboring CH1) be the set of sensor nodes have detected the target at time t. Selected nodes for tracking are denoted by N_t. Let, A_t denote the set of N_t nodes. It is expressed as.

$$A_t = \left\{ i \mid E_i(t) > E_{th,i}, \left\| L_i - L_{CH1} \right\| < \text{Range} \right\} \quad (2)$$

Where $E_i(t)$ and $E_{th,i}$ denotes the sensing measurement and detection threshold of sensor node i at time t, L_i and L_{CH1} are the location coordinates of sensor node i and cluster head 1 respectively. Range denotes the radio transmission range.

5.3.3. Selection of nodes for information fusion. This involves selecting set of nodes from N_t, which denotes the set of nodes participating in tracking the target. These nodes are selected based on the detected information about the target. Let us denote these set of nodes as A_{ft}. A_f is considered as subset of A_t. It means that all sensor nodes involved in tracking does not participate in information fusion about the target. Information fusion is done at a newly elected leader node (or) Cluster head (CH2). Sensor nodes are selected based on the received signal level, energy level of the nodes, sensing range.

5.3.4. Updating track information. During the fusion of track information at newly elected leader sensor node (CH2), old leader sensor node (CH1) send the information regarding the previous target location at various time instants. The track information also includes the profile of target. Let T_{track} denote the time interval between two consecutive target location estimation. At time t + T_{track}, the node CH2 takes the role of CH1, and the above procedure is repeated until the target disappears in the surveillance.

5.4. Localization of target

In this approach, energy based target localization [16] is used. The localization problem is constrained within two dimensions, that is, the target is assumed to be positioned in a plane. The location of target is expressed in terms of (x, y) coordinates. $\| \cdot \|$ represents the vector 2-norm. It is expressed in equation (3).

$$\left\| [x, y]^T \right\| = \sqrt{x^2 + y^2} \quad (3)$$

When a signature of phenomenon is propagating, it essentially propagating energy emitted from the source. Physically, energy of vibration is proportional to the square of vibration amplitude. Following equation (4), energy decays in a manner that is inversely proportional to the square of the distance from the source.

$$\frac{k.E_s}{\left\| L_s - L_m \right\|^2} = E_m \quad (4)$$

where k is a coefficient, L_s and L_m are the location coordinates of the source (target) and the sensor nodes. E_s is the source energy at L_s and E_m is the energy propagated to L_m. Since absolute energy cannot be measured, only relative energy is measured. It is denoted in equation (5).

$$E_{mr} = \frac{E_m}{E_{mr}} = \frac{\|L_s - L_r\|^2}{\|L_s - L_m\|^2} \qquad (5)$$

The target position can be estimated by combining several equation similar to equation (6), (7) and (8).There are two unknowns in the equation; therefore it seems two such equations are sufficient to determine the target position. However, note all the Ps satisfying Equations forms a circle in a plane. Solutions of two such equations correspond to the intersections of two circles, which usually corresponds to two solutions to Equations (6), (7) and (8). Therefore a third equation is needed to uniquely determine the target position. That is to say, at least four leader sensor nodes are needed to collaboratively localize the target by 3 such equations

$$\|L_s - L_{m1}\|^2 E_{m1} - \|L_s - L_{m4}\|^2 E_{m4} = 0 \qquad (6)$$

$$\|L_s - L_{m2}\|^2 E_{m2} - \|L_s - L_{m4}\|^2 E_{m4} = 0 \qquad (7)$$

$$\|L_s - L_{m3}\|^2 E_{m3} - \|L_s - L_{m4}\|^2 E_{m4} = 0 \qquad (8)$$

For calculating the solutions of equations , four sensor nodes are selected that report the highest energy level. This procedure is repeated for each cluster.

5.5. Optimization of target location

Target location is optimized inorder to obtain exact solution for equations (6), (7), (8). Gradient based steepest descent search method [10] is adopted. Its computation expense is comparatively low and converges fast to the solution. The optimization equation is given in equation (9), in order to find out the value of Ls.

$$\min\ J(L_s) = \sum_{j=1}^{3}\left[\|L_s - L_{mj}\|^2 E_{mj} - \|L_s - L_{m4}\|^2 E_{m4}\right]^2$$

(9)

5.6. Estimation of target tracking error and Energy Consumption

Target error is estimated based on comparison of location obtained from this approach with the true locations. Energy consumption of sensor nodes is calculated based on the energy consumption on each sensor node. Energy consumed is calculated based on the initial energy in the sensor nodes, number and size of packets transmitted, number and size of messages exchanged between nodes.

6. Simulation results

In this section, the proposed approach is evaluated using SensorSim[14] (which is built upon *ns-2*[13]). The surveillance area is 150*150 m^2. The radio transmission range is set to be twice the acoustic detection range. The simulated results are shown in figure 2. In this, after applying the clustering and target tracking algorithm, the CHs and other neighboring nodes are differentiated by change of colours during tracking.

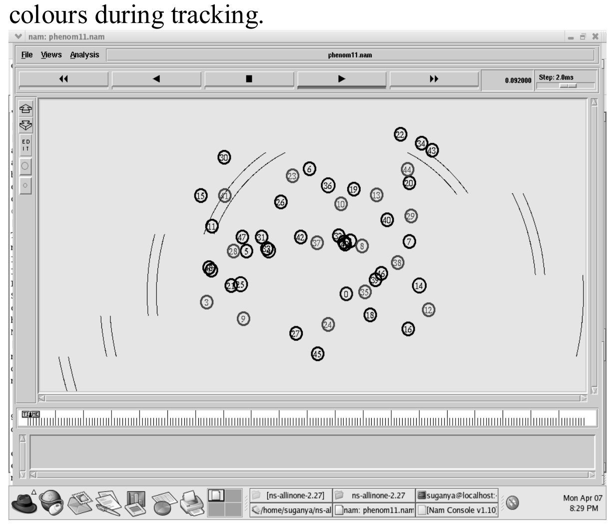

Figure 2. Detection and tracking target in grid topology

The simulation is performed for various topologies with different density of nodes. The performance metrics like packets overhead, messages transmitted and received in tracking , energy consumed and remaining in the sensor nodes are evaluated using the proposed approach are shown in figure 3 and figure 4. The energy consumption is also less in the sensor nodes.

Total packet overhead involved in clustering and Localization is calculated based on the packets transmitted and received between the nodes. Using the proposed approach, the packet overhead is less when compared with other existing approaches.

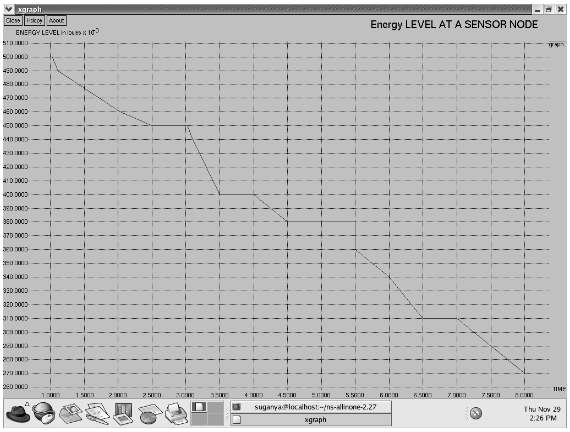

Figure 3. Energy Level in sensor node

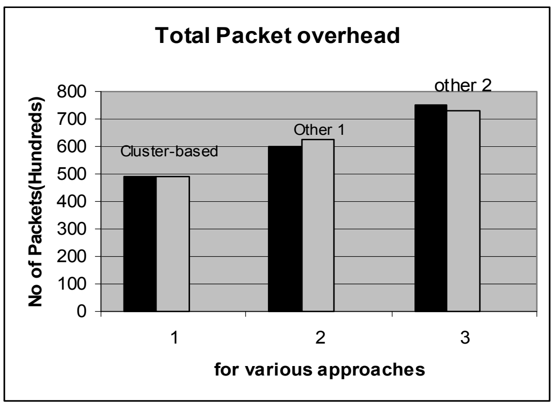

Figure 4. Total Packet Overhead

7. Conclusion

This proposed approach provides better estimation of target location. This also results in efficient energy management since collaborative information processing approach is used . This can be extended to tracking multiple targets which involves classification of targets for various

8. References

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