AN IMPROVED ENERGY EFFICIENT APPROACH FOR WSN BASED TRACKING APPLICATIONS

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ABSTRACT

Tracking systems using a high number of low cost sensor nodes have been proposed for use in diverse applications including civil, military, and wildlife monitoring applications. In tracking applications, each sensor node attempts to send the target's location information to a sink node. Deploying a tracking system with a high number of sensor nodes results in the following limitations: high packet dropping rate, high congestion, transmission delay, and high power-consumption. Data aggregation schemes can reduce the number of messages transmitted over the network, while prediction schemes can decrease the number of activated beacon nodes in the tracking process. Consequently, data aggregation and prediction approaches can reduce the energy consumed during the tracking process. In this paper, we propose and implement an energy efficient approach for WSN-based tracking applications by integrating both a novel data aggregation method with a simple prediction approach. Three metrics are utilized for the evaluation purposes: total number of messages transmitted in the network, overall power-consumption, and the quality of the tracking accuracy. The proposed system is simulated using the NS2 simulation environment.

KEYWORDS

Tracking, Localization, ZigBee network, Data Aggregation, and Prediction.

1. INTRODUCTION

The node localization and tracking applications that have received much attention recently in the area Wireless Sensor Networks (WSNs) have focused on the need to achieve high localization accuracy without incurring a large cost, the form factor, and power consumption per node. The authors focused on localization and energy network standard issues in [1, 2] respectively. In this paper, we focus on the power consumption issue for tracking applications.

Tracking systems including numerous low-cost sensor devices have been used in many applications including those for the military, emergencies, wildlife monitoring, and border security. Each sensor node is equipped with one or more sensors for detecting physical characteristics, a battery as an energy source, a processor for performing computations, and a wireless transceiver for two-way communications. The communication range for each sensor node is limited and therefore, sending a message from a beacon node to the sink node normally results in a series of hops through the network. Each one of these hops produces a consumption of energy power, which is limited, and therefore results in failures within the network as soon as the sensor nodes run out of energy.

One of the most critical technical issues which has to be addressed in developing sensor networks for target tracking applications is the conservation of energy. Sensor nodes are usually supported by batteries which could be difficult to replace. A few existing researches [3, 4, 5] focused on the data aggregation concept for tracking applications using WSNs. Thus, in this paper, we study the problem of how to reduce the communication and power consumption for tracking applications by focusing on the research challenge related to the data aggregation and prediction techniques in WSNs for real-time surveillance applications.

The idea of utilizing a data aggregation scheme with a prediction approach is to reduce the overheads of mobile computing systems.

Our contributions lie in the following features: 1) We present and compare several data aggregation and prediction schemes for target tracking sensor networks, and point out how a power-efficient tracking system might be designed; 2) We propose an energy efficient approach for WSN-based tracking applications; 3) Our proposed system is validated through simulation experiments; 4) Trade-offs are investigated between tracking efficiency and network lifetime.

This paper is divided as follows: In Section 2, the related data aggregation and prediction methods are presented. In Section 3, several aggregation strategies are designed and implemented while Section 4 presents the simulation setup. The proposed aggregation strategies are evaluated in Section 5, and finally, Section 6 offers a conclusion and suggestions for future work.

2. RELATED WORK

Target tracking systems require a high number of messages to be transmitted over the network from beacon nodes to a sink node. In this section, we present various research works which have focused on data aggregation and prediction techniques and which are applicable to wireless sensor tracking systems. We divide the discussion into two approaches: an energy efficient approach and a tracking through sensor networks approach.

2.1 Energy efficient approach

Power consumption is a critical issue in designing a tracking application for WSNs as data aggregation and prediction methods can reduce the power consumption for the whole WSN. In this section, we briefly describe previous data aggregation and prediction methods.

Several existing researches focus on data aggregation methods, as the work presented in [3] which includes investigating four diverse aggregation strategies for tracking applications, concentrating on the trade-offs between the amount of communication in the network and tracking accuracy. The implemented strategies aim to reduce the total number of messages transmitted over the network while offering reasonable tracking accuracy by aggregating the localization information from beacon nodes.

The proposed work in [4] involves a data aggregation technique in a real-time surveillance application focusing on timeliness, power consumption and information availability. It was agreed that tracking solutions with data aggregation method can reduce the amounts of energy consumed. Three aggregation methods are presented in [5]: in-network, grid-based and hybrid schemes. The proposed hybrid scheme tries to combine features from both previous techniques, and also offers low time delay.

Prediction systems using a WSN are actively researched and addressed in several works. For example, the works proposed in [6, 7, 8] includes investigating several basic energy-saving methods for target tracking in sensor networks.

2.2 Tracking approach

Target tracking and localization in sensor networks have been dynamically researched and studied in several works. For example, the works presented in [9, 10, 11, 12, 13, 14] focus on diverse aspects of tracking using sensor networks, such as tracking accuracy, real-time implementation, network standard, and the required application. The work presented in this paper is based on the binary detection method.

The work proposed in [15] includes a novel method for tracking the movement of people or vehicles in outdoor environments based on acoustic sensor devices. The presented work includes identifying each target with its unique acoustic signature, a feature sound pattern or a set of frequencies unique to that target. The work presented in [16] offers a binary sensor model, where each sensor's value is converted constantly into one bit of information. Additionally, the solution proposed in [17] includes a tracking method for use in networks with binary proximity sensors. The presented method finds a straight line which estimates the path of a target during a short period of time, and uses a line to find out the target's current position.

3. THE PROPOSED MODEL

The proposed system tries to optimize power consumption by minimizing both the sampling frequency rate and the number of nodes involved in target tracking, while offering reasonable localization accuracy. In this section, we first define the system requirements for target tracking applications and identify three performance metrics. Then, we investigate several data energy-saving strategies to meet these requirements. A system design is illustrated in detail next.

3.1 System requirements and metrics

In this section, we define the application requirements and identify numerous parameters needed for energy-saving schemes. The information of interest regarding the mobile targets includes: position p, direction d, and velocity v. As soon as this is information found, only a small set of sensor nodes are activated while other sensor nodes stay in sleep mode.

Requirements: consider a network $R = \{b_1, b_2, ..., b_n\}$ with a total number of beacon nodes n, and $M = \{m_1, m_2, ..., m_z\}$ with a total number of mobile targets z. nb represents the total number of observer nodes which sense the mobile target m. $ns = n - nb$ is the total number of beacon nodes in sleep mode. The application requires the sensor network to report the mobile target's location to the sink node with low power consumption and reasonable positioning accuracy.

Problem Definition: knowing the requirements for the mobile tracking application, we need to develop energy-saving strategies in order to minimize the overall power consumption while maintaining realistic tracking accuracy.

Performance Metrics: three performance metrics have to be taken into consideration: first, the total amount of messages transmitted over the network; second, the overall power-consumption needed by the tracking application; and third, the tracking accuracy for mobile targets through a distributed WSN.

3.2 Energy-saving strategies

The main goal of this paper is to design and implement different energy saving approaches in order to reduce the total number of messages which need to be transmitted over WSNs, while achieving reasonable tracking accuracy.

Table 1. Parameters definitions

Parameter	Name	Definition
ob	Observer node	A beacon node which senses any mobile target
s	Sink node	A node which need to be informed about the targets' positions
sf	Sampling frequency rate	How often the sink node has to be informed about the targets' position
l_k	Leader node	A node which has the role of aggregating the collected localization information
v	Velocity	The mobile target's speed
P	Power consumption	The total power consumed over a period of time

In this section, we propose 4 energy efficient strategies. The first three strategies are aggregation-based, while the latest strategy includes a simple energy-efficient prediction system integrated with an aggregation approach in order to reduce the power consumption for the whole WSN. Table 1 includes definitions for several parameters.

Strategy One (Naive): All beacon nodes in the network have to be in active mode in order to sense the mobile target. Beacon nodes which sense the presence of the mobile target m_j broadcast $\{p_i, q_i(t)\}$ to the sink node, where p_i is the position of beacon node i, and q_i is the quality of the observation at time t. There is no local processing or data aggregation in this strategy. The sampling frequency rate is ($sf = 2$).

Strategy Two (Differential-based): Like the previous strategy, all beacon nodes stay in active mode. Once the mobile target m_j enters the beacon node's detection range b_i, b_i then reports the observation to the sink node. From this time, it is assumed by the sink node that the beacon node b_i can observe the mobile target m_j. As soon as the mobile target m_j leaves the detection range for sensor b_i, then b_i reports this to the sink node. The observer node b_i broadcasts $\{p_i, q_i(t), \Delta t\}$, where Δt is the total duration time for tracking the mobile target m_j by the beacon node b_i. In this strategy, the sink node is responsible for computing the location of each mobile target. The sf is presented in Equation 1. The same idea for this strategy is proposed in [3].

$$sf = \frac{tr}{v} \tag{1}$$

where tr, v are the transmission range, and velocity respectively.

Strategy Three (Leader-based): In this strategy, a leader node has to be elected each time in order to aggregate the relevant location information and transmit the latest position information to the sink node. Unlike in the previous strategy, as soon as any mobile target m_j enters the sensor's range b_i, b_i reports this to the leader node instead of the sink node. The leader node l_k aggregates the position information collected from the beacon nodes $\{b_i, b_{i+1}, ..., b_w\}$, where w is the total number of observer nodes which cover the mobile target m_j, and informs the sink node. As soon as the mobile target m_j moves away from any beacon nodes' range b_i, then b_i will report this to the leader node. The leader node l_k will then re-compute the target's position and report that to the sink node. The sampling frequency rate is presented as follows:

$$sf = \frac{tr}{v} - agt \tag{2}$$

where agt is the time needed to collect the localization information from observer nodes.

Strategy Four (Prediction-based): This strategy includes the aggregation strategy 3 with a simple prediction system in order to reduce the power consumption of the whole network. Most of the energy is consumed during the idle period waiting for possible targets. Beacon nodes should spend a minimal time in the active mode and stay in sleep mode as long as possible. Therefore, a large amount of energy is saved if the system does not require all the beacon nodes to be activated for the whole tracking period.

The prediction system works by computing the velocity and direction of each mobile target, based on the localization information collected from the observer node. The leader node has to make these computations and then activate only the essential beacon nodes required to track the mobile targets; other beacon nodes stay in sleep mode.

3.3 System Design

The main stages are presented in this section for the 4th strategy as it offers the lowest power-consumption, as will be shown in the evaluation section.

1. Initial Activation: We divide the beacon nodes, based on the activating mode, into two main types: sentry and non-sentry nodes. Sentry nodes include a small number of beacon nodes which have to stay active all the time in order to sense any approaching mobile target. Non-sentry nodes are end-device nodes which stay in sleep mode until they are woken up by a leader node. In this phase, all beacon nodes stay in the sleep mode when there are no targets to be tracked in order to save power.

2. Target Detection: Unlike localization sensors which are used in traditional tracking systems, binary systems use binary sensors which offer 1-bit of data, representing the presence or absence of the mobile target in the sensing range. Binary sensors are unable to produce any other information, such as distance to the beacon node or direction of arrival.

The mobile target position q is estimated through the binary sensor as $q \in \{0,1\}$, where $q=0$ when the target is out of the beacon node's detection range, and $q=1$ when the mobile target is within the range of the beacon node. A centroid method is used to find the final position for each mobile target.

3. Group Aggregation: The proposed system is designed to work with a ZigBee network standard. Therefore, every end-device node in each group belongs to one, and only one, router node. The proposed model includes dividing the wireless sensor area into small groups. Each group includes a number of end-devices and one or more router nodes; the group is represented by a single leader node which has the responsibility of aggregating the localization reports from observer nodes, and transmitting the target's position to the sink node.

Each group can be in either the active or the inactive state at a specific point in time. The active group includes activating all the beacon nodes in that group, while the inactive state includes deactivating the beacon nodes in that group.

4. Group Leader to Sink Report: After the group aggregation, the leader node aggregates the collected readings from end-device nodes and reports a single message to the sink node. The aggregation function is typically simple as it needs only to find out the average of the mobile target's position based on the location information collected from observer nodes.

The sink node is responsible for computing the mobile target's trajectory. A Kalman filter is used to establish the mobile targets' trajectories. This is a recursive filter that assesses the state of a dynamic system from a series of noisy measurements. The Kalman filter takes advantage of the dynamics of the target to remove the consequences of noise and to offer a good estimation.

5. Prediction and Activation: Tracking based on a single beacon node offers low localization accuracy; agroup of sensors have to be collaborated in order to track and locate the target's position. End-device nodes need to be activated as soon as one of the group's members detects a mobile target. Before activating a set of beacon nodes, a prediction method has to be applied first in order to predict the future movement of the mobile target and then activate the right set of beacon nodes. This stage includes three main phases: A) Prediction mechanism, B) Activation mechanism, C) Recovery mechanism.

4. IMPLEMENTATION

In the previous section, we outlined the design and development of an energy-efficient WSN-based tracking system. Simulation experiments were carried out in order to evaluate the proposed strategies. This section presents the simulation environment, and the network topology. The proposed model was evaluated using an NS2 simulator.

4.1 Network topology

Our simulation model includes 145 beacon sensor devices in a $120 \times 120m^2$ monitored area. The sensing coverage for end-device nodes is 15 meters and is 30 meters for router device nodes.

The proposed tracking system is implemented using ZigBee network standard. ZigBee is a low-power, low-data rate, and low-cost wireless communication standard which aims to be used in home automation and remote control applications. The ZigBee network includes three main roles: coordinator, router and end-device nodes. The coordinator has the role of starting and controlling the network. The router is responsible for routing messages between nodes and provides backup in case of network congestion or device failure. The end-device has the ability to transfer and receive messages.

In our simulation, we used these three components. The coordinator node works as a sink node to collect information from router nodes while router nodes have the responsibility for routing messages between nodes; in addition, each router node might work as a leader for a period of time. End-device nodes collect the localization information about the mobile target and transmit their readings to the router node. Each end-device node can talk to only one router within on hop. ZigBee network uses the Ad-hoc On Demand Distance Vector (AODV) routing protocol.

5. SYSTEM EVALUATION

In order to produce a long-term tracking system that meets the requirements of several applications, power-efficiency is both essential and critical. In this section, we evaluate the total number of messages, power-consumption and tracking accuracy.

5.1 Total number of messages

In this section, the total number of messages is evaluated for the first three strategies. In the first strategy, the observer nodes transmit a single message to the sink node every 2 seconds. The total number of messages nm_{loc} which need to be transmitted over the network is presented in Equation 5. The sampling frequency rate is quite high, as the sink node needs to be informed about the mobile target's location every 2 seconds, hence $sf = 2$.

Fewer messages are transmitted in the second strategy as the observer nodes have to transmit their readings only when the mobile target enters and leaves their detection range. The total number of messages is presented in the following equation with sampling frequency rate $sf = \frac{tr}{v}$

$$nm_{loc} = \frac{nb \times ft}{sf} \qquad (5)$$

where nb and ft are the number of observer nodes and the final time respectively.

In the third and fourth strategies, each observer node transmits its localization report to a leader node and then a leader node aggregates the localization information from observer nodes and transmits a single report to the sink node. Two types of message need to be transmitted: local and global. Local messages include the total number of messages nm_{loc} which needs to be transmitted among observer and leader nodes, as presented in Equation 6. These messages do not reach the sink node as they are required to be transmitted to the leader node. Global messages include the total number of messages nm_{glb} which reaches the sink node from leader nodes, based on the AODV routing protocol. For both equations, the sampling frequency rate is $sf = \frac{tr}{v}$, Figure 1 presents the total number of messages which needs to be transmitted for each strategy.

$$nm_{\mathrm{glb}} = \frac{ft}{sf} \qquad (6)$$

5.2 Power consumption

In the previous section, we evaluated the total number of messages transmitted over the network. Each transmitted packet requires a specific amount of energy; therefore, reducing the total amount of messages transmitted over the network will reduce the total power consumption. In this section, we evaluate the total energy consumed over a period of time for each strategy.

The first strategy offers the worst power-efficient solution, as the sampling frequency rate is high, while the second strategy achieves a reasonably power-efficient system, as the sampling frequency rate is lower than the first strategy. The power consumption E in both strategies is represented in the following equation:

$$E = p + \left((n - nb) \times p_{act} \right) \tag{7}$$

$$p = \left(\left(nm \times p_{tx} \right) + \left(nm \times p_{rx} \right) \right) \times h \tag{8}$$

where p, p_{rx}, and p_{tx} are the power needed to transmit a number of messages nm, the transmission power, and the reception power respectively.

All the position information is transmitted to a leader node in the third strategy; the leader node aggregates the collected information and transmits a single packet to the sink node. The power consumption in the third strategy is based on the target speed and is represented in the following equation:

$$P = p_{nm} + \left((n - nb) \times p_{act} \right) \tag{9}$$

where p_{act} is the power needed for sensor nodes in active mode for every 1 time unit.

The first 3 strategies show that most of the energy is consumed while the beacon nodes are in the active mode. The third aggregation strategy reduces the power consumption for the observer nodes but a high level of energy is still consumed during the waiting process. The fourth strategy includes minimizing the power consumption by deactivating beacon nodes that are away from the mobile target.

In the fourth strategy, only the beacon nodes which sense the mobile target are in the active mode; other beacon nodes have to stay in sleep mode. The power consumption is represented in the following equation:

$$P = p_{nm} + \left(ns \times p_{act} \right) + \left((n - nb) \times p_{drm} \right) \tag{10}$$

where p_{drm} is the power needed for sensor nodes in sleep model for every 1 time unit.

Figure 3 shows the power consumed for each strategy within 3 minutes of tracking time.

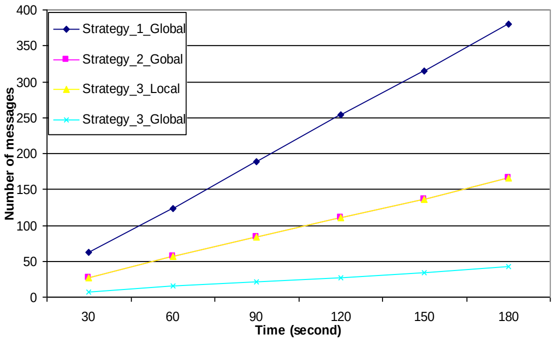

Figure 1: Total number of messages for three strategies

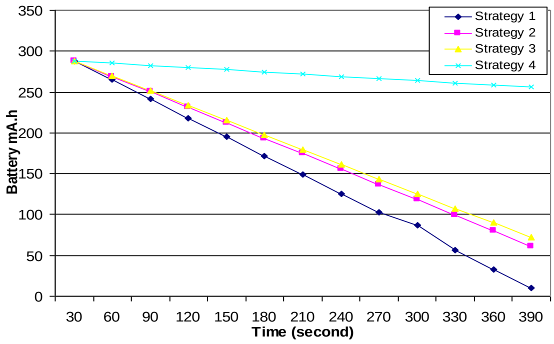

Figure 2: Power consumption for three strategies

5.3 Tracking accuracy

The accuracy of each strategy is evaluated in this section. Figure 4 presents the tracking trajectory (dotted line) for the third strategy.

6. CONCLUSION

This paper shows the results of a study concerning tracking, through WSNs, multiple mobile targets simultaneously travelling at different speeds, concentrating on the trade-offs between the amount of messages which need to be transmitted to the sink node, power consumption and tracking accuracy. In this paper, we have proposed, implemented and evaluated several energy-efficient schemes for tracking applications. The data aggregation and prediction methods offer power-efficient solutions for sensor networks and achieve good tracking accuracy.

The proposed approach in this paper integrates both the data aggregation and prediction approaches for wireless sensor tracking applications. A novel aggregation strategy is proposed in Strategy 3 and integrated with a simple prediction system in order to reduce the power consumed during the tracking process. Our future work includes implementing the proposed system on real sensor networks and testing the efficiency of tracking multiple mobile targets through a WSN while achieving low power consumption.

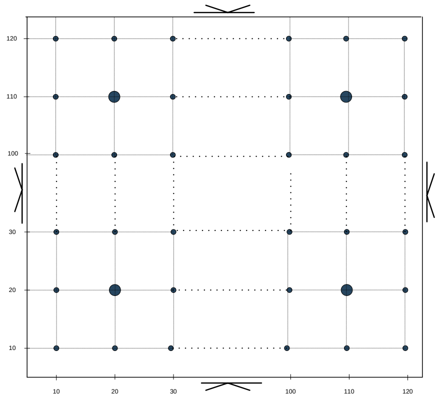

Figure 3: Sensor network topology

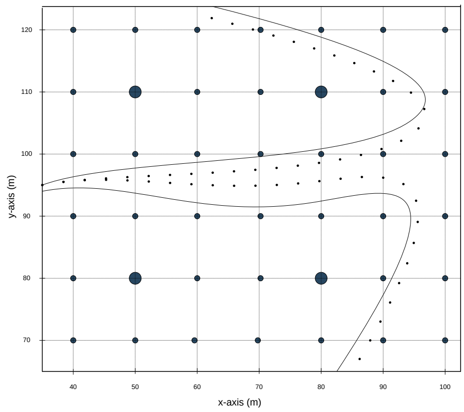

Figure 4: Approximated trajectory for Strategy 3

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