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Optimized duty cycle and energy efficient routing protocol in wireless Sensor network

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Abstract

In the development of various large-scale sensor systems, a particularly challenging problem is how to dynamically organize the sensors into a wireless communication network and route sensed information from the field sensors to a target system. Recently, the research focus on energy harvesting routing, a promising routing scheme in wireless sensor networks (WSNs), is shifting toward duty-cycled WSNs in which sensors are sleep scheduled to reduce energy consumption. The prime motivation of our work is to balance the inherent trade-off between the resource consumption and the accuracy of the target tracking in wireless sensor networks. Toward this objective, the study goes through a new energy-efficient dynamic optimization-based sleep scheduling and target prediction technique for large-scale sensor networks. We present Energy efficient prediction based clustering protocol (EEPC) to improve energy efficiency of proactive wake up and also tracking performance. A cluster-based scheme is exploited for optimization-based duty cycled sleep scheduling. At every sampling instant, only one cluster of sensors that located in the proximity of the target is activated, whereas the other sensors are inactive. To activate the most appropriate cluster, we propose a non myopic rule, which is based on not only the target state prediction but also its future tendency. Finally, the effectiveness of the proposed approach is evaluated and compared with the state-of-the-art protocols in terms of tracking accuracy; inter node communication and computation complexity.

Key words: Energy Harvesting, EEPC, Sleep Scheduling, Optimized Duty-Cycle, Clustering Protocol.

1. Introduction

Wireless sensors are widely used to efficiently monitor and report data in various application scenarios. Due to their low cost and their self-configuring capabilities, they can be used in industrial automation systems to improve their efficiency and productivity. As nodes are severely energy constrained, the battery must be used carefully by employing efficient power management techniques. This mode is usually called energy-neutral operation (ENO) in the literature. In order to respect the ENO condition, power managers typically adjust the wake-up period of the node (i.e., its duty-cycle) to the environmental conditions. This method allows for optimizing the quality of service while ensuring the level of reliability required by industrial systems. Since wireless sensor nodes use radio frequency (RF) transmission to exchange data, another major concern that must be taken into consideration when optimizing a WSN system is the radio channel.

Many techniques have already been proposed for on-line duty cycle management or transmission power control. However, they have been developed and analyzed separately. Thus, the mutual interactions and synchronization issues that come with linking them together have not been taken into account until now. In this paper, we propose a global power management approach that optimizes the wake-up period while taking into account the variations of the radio link (i.e., the node transmission power) as well as the environmental conditions (i.e., the harvested energy). This holistic approach allows for analyzing and controlling the global behavior of a wireless sensor node.

The main contributions of our work are:

1. A global power management strategy suitable for industrial wireless sensor networks (IWSN).
2. An original predictive transmission power control algorithm.
3. An accurate system-level modeling environment for an energy harvesting wireless sensor node.
4. A validation of our methodology on a real WSN platform.

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2. Related Works

2.1 Existing System

In spite of the diverse applications, WSNs face a number of unique technical challenges due to their inherent energy and bandwidth limitations, ad hoc deployment, and unattended operation, etc.. Unfortunately, very little previous works on distributed systems can be applied to WSNs, since the underlying assumptions have changed dramatically. Therefore, innovative energy-aware, scalable, and robust algorithms for distributed signal processing in WSNs are highly required. A problem that is closely related is the localized topology control, which maintains energy-efficient network connectivity by controlling the transmission power at each node, or selecting a small subset of the local links of a node.

Since nodes often run on batteries that are generally difficult to be recharged once deployed, energy efficiency is a critical feature of WSNs for the purpose of extending the network lifetime. For major energy harvesting WSN applications, idle listening is a major source of energy waste. To reduce the energy consumption during idle listening, duty cycling is one of the most commonly used approaches. The idea of duty cycling is to put nodes in the sleep state for most of the time, and only wake them up periodically. In certain cases, the sleep pattern of nodes may also be explicitly scheduled, i.e., forced to sleep or awakened on demand. This is usually called sleep scheduling.

2.2 Transmission Power and On-Line Duty-Cycle Management

Two of the most common power management techniques used in WSN are duty-cycling of node activity and RF transmission power control. Transmission power control is highly relevant for wireless sensor nodes and wireless networks in general. By selecting an optimal transmission power level, both power consumption and interferences are reduced. A lot of work on transmission power management and topology control for battery powered sensor nodes has been done in the last few years. Most of this research deals with the topology control of the network. The goal of this technique is to control the topology of the graph representing the communication links between network nodes with the purpose of maintaining some global graph property (e.g., connectivity) while reducing energy consumption. These algorithms are commonly used in network protocols.

Many techniques have already been proposed for on-line duty cycle management or transmission power control. However, they have been developed and analyzed separately. Thus, the mutual interactions and synchronization issues that come with linking them together have not been taken into account until now.

Despite the well-known advantages of communication solutions based on energy harvesting, there are scenarios where the absence of batteries (super capacitor only) or the use of rechargeable batteries is not a realistic option. By assuming low duty-cycle applications, we propose a global power management approach for energy harvesting sensor nodes. Propose a global power management approach for energy harvesting WSN nodes which combines transmission power and duty cycle management and it is also suitable for dynamics and time varying scenarios.

2.3 Global Power Management Approach

This approach is to introduce a transmission power control scheme based on the remaining energy level and the energy-

harvesting status of individual sensor nodes to extend the overall lifetime of wireless sensor networks (WSNs) and balance the energy usage. A global power management approach that optimizes the wake-up period while taking into account the variations of the radio link (i.e., the node transmission power) as well as the environmental conditions (i.e., the harvested energy). Global power management technique that considers the applications constraints to exploit sleep and idle states.

This holistic approach allows for analyzing and controlling the global behavior of a wireless sensor node. Our goal is then to define a global power management strategy that is not only the merge of an on-line duty-cycle management with a transmission power control, but also a unified and efficient adaptation strategy.

The objective of the duty-cycle controller is to find the tasks' execution periods that respect the energy neutral condition, i.e., balance the harvested energy and the consumed energy. As a result, the battery should remain constant over time.

This scheme is to solve the problem of the unbalanced energy consumption and harvesting speed in ambient powered WSNs, which applies a transmission power control scheme to enhance or reduce the communication distance of sensor nodes based on the energy level situation. By applying such a scheme, the sensor nodes with higher remaining energy resource or higher energy harvesting capability will take more responses to the network data packet delivery, while the other nodes will be in an idle state for longer time.

2.4 Drawbacks

- A problem that is closely related is the localized topology control, which maintains energy-efficient network connectivity by controlling the transmission power at each node, or selecting a small subset of the local links of a node.
- The tradeoffs involved in the energy-efficient localization and controlled transmission power by a wireless sensor network but the proposed system lack in target tracking application.
- Lack in optimal energy saving due to individual node control and scheduling.
- It does not use optimization methods, i.e., global power management scheme imposes no performance constraints when reducing the energy consumption. Without performance constraints, it is difficult to configure the protocol toward the best energy performance tradeoff for a specific network environment.

2.5 Proposed System

Our proposed work, present Energy efficient prediction based clustering protocol (EEPC) to improve the efficiency of proactive wake up and enhance the energy efficiency with limited loss on the tracking performance. Energy efficient prediction based clustering protocol is used to track the target and maintain duty cycle based on proactive wakeup for to achieve optimized results. This reduces the energy consumption of sensor nodes and increase the lifetime of the network and also tracking performance is improved than the global power management approach.

EEPC is designed based on proactive wake up: when a node (i.e., alarm node) detects a target, it broadcasts an alarm message to proactively awaken its neighbor nodes (i.e., awakened node) to prepare for the approaching target. To enhance energy efficiency, we modify this basic proactive wake-up method to sleep schedule nodes precisely.

Specifically, EEPC selects some of the neighbor nodes (i.e., candidate node) that are likely to detect the target to awaken.

We utilize two approaches to reduce the energy consumption during this proactive wake-up process:

1. Reduce the number of awakened nodes.
2. Schedule their sleep pattern to shorten the active time.

First, the number of awakened nodes can be reduced significantly, because:

- 1) Those nodes that the target may have already passed during the sleep delay do not need to be awakened;
- 2) Nodes that lie on a direction that the target has a low probability of passing by could be chosen to be awakened with a low probability. For this purpose, we introduce a concept of awake region and a mechanism for computing the scope of an awake region.
- 3) The active time of chosen awakened nodes can be curtailed as much as possible, because they could wake up and keep active only when the target is expected to traverse their sensing area. For this purpose, we present a sleep scheduling protocol, which schedules the sleep patterns of awakened nodes individually according to their distance and direction away from the current motion state of the target.

2.6 Energy efficient prediction based clustering protocol (EEPC)

The propose algorithm predicts the moving region of target in the next time interval, by analyzing current location and unique ID of the target. We take these nodes within the predicted region as waiting-activation nodes and establish dynamic activation strategy. The fewest essential number of sensor nodes within the predicted region will be activated to monitor the target which considers as cluster heads. Thus, the number of cluster head nodes that was involved in tracking the target will be decreased to save energy and prolong the network's operational lifetime. The simulation results demonstrate the effectiveness of the proposed algorithm.

For reducing the number of nodes involved in tracking a target and saving energy, the prediction-based techniques are used to predict the upcoming location of mobile target.

- When a sensor node detects target which broadcast its identity and position as beacon signal, it forwards the target information to its cluster nodes.
- The information contains location, node ID, and moving direction of the target.
- After calculating and predicting the location of target, the cluster head selection done and wakes up all/some nodes nearby the destination or all/some nodes on and around the route of the moving target from current position to the destination.

The EEPC algorithm can reduce the number of nodes that are involved in tracking the target and decrease the missing rate that is caused by the traditional prediction schemes.

- The propose algorithm predicts the moving region in the next time interval by analyzing current location and node ID of the target.
- The moving region is defined as a circle around the current coordinates of the target with a radius of moving range of target in one second (assuming that the sampling interval is one second).
- Assume that the target's moving region in one second is less than a setting value, and then we can prove that the moving region of target in the next time interval must be in the intersection region which combines the communication range of two nodes closest to the target.

- Namely, target location in the next time interval must be in the communication intersection region.
- We take these nodes within the communication intersection region as waiting-activation nodes and establish activation strategy by judging the location relation between the target and the waiting-activation nodes.
- We activate the fewest essential number of sensor nodes within the intersection region to monitor the target, in order to ensure the target can be detected at any time and reduce the number of nodes involved in tracking the target referee as cluster heads which for prolonging the network's operational lifetime.

2.7 Advantages

- The target tracking in WSN is done in efficient way.
- In a duty-cycled sensor network, proactive wake up and sleep scheduling can create a local active environment to provide guarantee for the tracking performance.
- Never miss the target even with abrupt direction changes so tracking performance will increase.
- EEPC reduces the average energy consumed by sensor nodes and thereby increase the lifetime of the network.

3. A System-Level Modeling Approach

3.1 Sensor Network Formation

This contributes to a more systematic understanding and treatment of sensor deployment issues. For this purpose, this studied the existing literature on deployment experience and present a classification of common problems encountered during deployment of sensor networks. A wireless network that is temporarily installed alongside the actual sensor network during the deployment process.

Parameters considered during sensor network formation

- **Transmission range:** nodes communication depends under transmission range which is placed nearly close to each other thus gets better link.
- **Local information system:** Nodes must be grouped under specific feature like battery power, processing capability, bandwidth, memory etc. so according to those, nodes are partitioned using driver methods.
- **Mobility:** Mobility refers the node movement procedure so need to consider the mobility options with limitation in maximum and minimum speed.

According to the critical event monitoring process, sensor network formed under local information system with sleep wake scheduling mechanisms.

3.2 Routing Protocol Design

A routing protocol is a protocol that specifies how routers communicate with each other, disseminating information that enables them to select routes between any two nodes on a computer network, the choice of the route being done by routing algorithms. Each router has a prior knowledge only of networks attached to it directly. A routing protocol shares this information first among immediate neighbors, and then throughout the network. This way, routers gain knowledge of the topology of the network. Design a Routing protocol named as Energy efficient prediction based clustering protocol (EEPC), which is going to implement in OSI layer that need to get and deliver the messages from other layers that make some more changes in supported layers. The routing protocol is implemented in the layered architecture of the GloMoSim simulator.

3.3 Sleep Wake Scheduling

Measurements have shown that the energy that a sensor node spends widely listening amounts to 50%-100% of the energy required for receiving. Furthermore, typically, a sensor node would spend a substantial fraction of the time in the idle state. Therefore, idle listening has been recognized as one of major sources of energy waste in sensor networks and sleep scheduling has been widely studied. The mainstream of research on sleep scheduling can be divided into two approaches. One approach, the “periodical packet-arrival based approach”, assumes periodical packet arrival, thus proposing a periodic active/sleep schedule.

The second approach is “coverage-based approach”, which assumes large density of sensor nodes, thus maintaining the connectivity of the network by a subset of nodes which are ON all the time, while letting the other nodes sleep. There are also various strategies for adaptation of the sleeping schedule, that is ending the ON period according to different criteria, such as the overheard messages, the network topology, the residual energy of the nodes, the most recently updated neighbor sleeping schedule, the database of neighbor nodes’ sleeping schedule, the number of packets queued in the MAC layer, and the waiting time of packets and the length of waiting queue in the previous node.

3.4 Target Tracking Approach

In this module, this quantifies the benefits of our approach in terms of energy consumed and accuracy of tracking for different mobility patterns. The key issues in tracking a mobile target are accuracy of tracking and energy expenditure. The accuracy of tracking is strongly influenced by the number of active sensor nodes. The more sensor nodes that are active, the higher will be the accuracy in tracking. Too few will result in inaccurate tracking. On the other hand, energy expenditure is proportional to the number of active sensor nodes; the larger the size of the active tracking region, the higher the energy consumption. To accurately track the target and minimize energy, a minimum set of sensors nodes need to be active.

3.5 Clustering Scheme

A cluster-based scheme is proposed, where sensors are statically divided into clusters, and each cluster consists of a single Cluster Head (CH) and a bunch of slave sensors. At every sampling instant, only one cluster of sensors is triggered to track the target. When a target enters the wireless sensor network, the CH that detects the target becomes active while other nodes are in sleep mode. Then the active CH selects three sensor nodes of its members for tracking in which one node is selected as Leader node. The selected nodes sense the target and current target location is calculated.

4. A Joint Duty-Cycle and Transmission Power management for Energy Harvesting WSN Nodes

4.1 Duty-Cycle Control Strategy

The objective of the duty-cycle controller is to find the tasks execution periods that respect the energy neutral condition, i.e., balance the harvested energy and the consumed energy. As a result, the of the battery should remain constant over time. In the following, we only consider the transmission task and we use the duty-cycle controller proposed in, called closed-loop power manager (CL-PM).

4.2 A Predictive Transmission Power Controller (PTPC)

The main objective of PTPC is to dynamically adapt the transmission power level to the wireless channel variations.

However, the control law update and the channel estimation technique are fundamentally different in the two approaches. An overview of the controllers interactions as well as the inputs/outputs of the different blocks. As it can be seen, PTPC communicates with the duty-cycle controller (CL-PM) using a system state register that stores all possible transmission energy consumption values.

4.3 Transmission Power Control Law Update

The update of the transmission power control law depends on the channel link state between the BS and the ED. If the link is established, the ED periodically receives a feedback message from the BS. This message is a RSSI average value computed by the BS using TX packets sent by the ED. Then, the update-control-law function (UPC) adjusts the transmission power control law. If the link is broken, PTPC uses a predictive system, shown on the bottom of the control law.

4.4 Channel Contention Management

Our transmission power controller (PTPC) is agnostic with regard to its underlying MAC mechanism. Experimental results that will be discussed in Section V-D, have been obtained using a transmitter initiated cycled receiver (TICER), PTPC architecture initiated cycled receiver MAC protocol. In TICER, the transmitter sends a beacon whenever it wants to transmit a packet to the receiver. Then, it waits for an acknowledgement (ACK) from the receiver before sending packets. In the meantime, the receiver periodically listens to the radio channel waiting for a beacon (i.e., idle listening). In fact, a RSSI value based on the received beacon is sent to the transmitter within the ACK packet. In our setup, the transmitter is the ED and the receiver is the BS. In order to speed-up simulation time, we do not model channel contention mechanism in the simulation framework discussed in Section. As it will be shown in Section V, this optimization has almost no impact since the behavior observed in simulation is very similar to results obtained on real WSN platform.

5. Conclusion

Energy is one of the most critical resources for WSNs. Most of works in the literatures about WSN routing have emphasized energy conservations as an important optimization goal. However, merely saving energy is not enough to effectively prolong the network lifetime. Energy saving in wireless sensor networks has attracted a lot of attention in the recent years and introduced unique challenges compared to traditional wired networks. Extensive research has been conducted to address these limitations by developing schemes that can improve resource efficiency. In this paper, we have summarized some research results which have been presented in the literature on energy saving methods in sensor networks. Although many of these energy saving techniques look promising, there are still many challenges that need to be solved in the sensor networks. Therefore, further research is necessary for handling these kinds of situations.

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