Energy Efficient Shift-Based Sleep Scheduling Mechanism for WSN Deployment in Rescuebots

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Abstract
A trend in today’s technology is the deployment of wireless sensor network in mobile robotics for emergency surveillance and rescue systems. The field of robotics can be enhanced when deployed with sensors. In this a critical issue is how to increase the lifetime of the network. A sleeping mechanism for putting the idle sensors to sleep is necessary. First we design a 3-tier hybrid network architecture to support the deployment of WSNs in mobile robots. Then we propose a shift-based sleep scheduling mechanism in which the sensors are in sleep for half-a-time and wakeup in the other half. Our research creates virtual circles in the sensing environment and the sensors are put to sleep based on shifts. The experimental results show that our scheme performs well compared to other existing sleep scheduling algorithms.

Keywords: Shift-Based Sleep Scheduling; Mobile Robots; Rescue Systems; Wireless Sensor Networks; Emergency Surveillance; Rescue Systems.

INTRODUCTION
Mobile robots are the major demand in this dynamic world. The future search and rescue systems will involve complex autonomous mobile robots undertaking complex tasks at risky environments in a large scale. Mobile robotics are the best alternative for intelligent systems in which the environment is totally unsafe where search dogs or wall mounted cameras cannot be used. In the areas of emergency surveillance and rescue systems robots support reliability and robustness of the system. However, in the rescue campaign it is necessary to identify and control the movement of mobile robots. In such cases, wireless sensors can be developed for increasing the sensing capabilities to provide real-time observations. WSNs are interesting compliments to mobile robots [1]. In the reverse, the realistic applications of wireless sensor networks can be extended by mobile robots in gathering information from the sensor nodes and thus acting as a gateway between the sensor nodes and the end user as they typically forward data from WSN on to a server. An important and exciting technology WSNs have great potential for improving many application area. In fact, it is much difficult to separate any application area from using WSN.

WSNs are spatially distributed autonomous sensors to monitor physical or environmental conditions and to cooperatively pass their data through the network to a main location. Each node has multiple sensory capabilities such as temperature, blood pressure, light, humidity, etc. The robots are equipped with wireless sensor nodes to facilitate data and audio/video transfer. These wireless mobile robots can navigate freely in obstructed environment and are very easy to track their locations once they wander out of the operators’ sights by the use of sensor networks. The sensor networks are highly desirable for search and rescue robots operating in unstructured environment.

One of the main characteristics of sensor is its ability to withstand harsh environmental conditions [2]. However, the sensors have battery energy which cannot be replaced or supplemented. Thus the focus on energy efficient use of sensors has drawn attention. One major approach for efficient energy consumption is sleep scheduling which allows some of the deployed nodes to sleep and conserve energy. Activating a small subset of nodes rather than all the nodes will not only save energy, but will also reduce the network’s traffic, thus avoiding collision of packets and decreasing the delay of transmitted data. Even after sleep scheduling, to periodically check the network activity, the nodes operate in a low-duty cycle. A most important issue is the arrangement of sensors without affecting the normal operation of the whole network. Sleep scheduling mechanism must be accompanied by both coverage and connectivity.

Our starting point is a 3-tier architecture for sensor deployed robotic networks which facilitates our proposed sleep scheduling for localization and other purposes. The paper is organized as follows. Section 2 gives a brief overview of sensory deployment in mobile robots. And sleep scheduling as related work. Section 3 introduces our 3-tier hybrid architecture. Section 4 discusses our proposed sleep scheduling scheme. Section 5 presents performance evaluations comparing our scheme with the previously proposed sleep scheduling algorithms. Finally, section 6 concludes the paper and presents some future work.
**RELATED WORK**

A sleep/wake scheduling scheme to minimize end-to-end delay is presented in [3]. Transmission delay problem is mainly focused. The sensors are in prominent positions where they can be easily communicated. The mechanism imposes more wake up time to save power in sensors waiting for transmission. But the sensor operation would take so long which in turn caused hot spot issue and thus the network lifetime is shortened.

A probability-based prediction and sleep scheduling protocol to improve energy efficiency of proactive wake-up is presented [4] and [5]. Based on probability and kinematics, a target prediction method is proposed. The nodes to awaken are selected by the protocol and the energy efficiency is enhanced by reducing the node active time with limited tracking performance loss. It is fully based on the prediction results. Since optimization methods are used, the protocol does not define any performance constraint when reducing the energy consumed. The protocol cannot be configured towards its goal of best energy-performance tradeoff without performance constraints. Also since many physics problems are involved, optimization is difficult.

A geographic-distance based connected-k neighborhood sleep scheduling algorithm is proposed in [6] and [7]. The length of paths given by geographic routing in duty-cycled mobile WSNs is minimized. The connected-k neighborhood requirement and geographic routing requirement are integrated to change the state of sensor nodes. Neighbor nodes that are closer to the sink can only be accessed after sleep scheduling which imposes the complex of network connectivity.

A TDMA based sleep scheduling is proposed in [8], [9] and [10]. The wake-up time is divided into frames. Sensor nodes are assigned certain number of time slots per frame to reduce the frequency of state transitions. Transmission between the sensor nodes occur in those slots. Each frame needs tight synchronization which made the algorithm complex one. Thus the sensors have limited flexibility and also energy consumption is high during the state transitions.

A sleep scheduling algorithm based on Q-learning with linear function approximation is proposed in [11]. The algorithm is formulated as a partially-observable Markov decision process with continuous state-action spaces. A best policy to minimize the long-run is devised through incremental updates. The algorithm shows large oscillations when involving high-dimensional state spaces. It involves conflicts of making more number of sensors sleep and more intruder detection at the same time. Also the sensors did not collaborate in the absence of a central controller.

A collaborative location-based sleep scheduling scheme for dynamically allocating the sleep/wake state of sensor based on the location of mobile user is presented in [12]. The algorithm sends a flag to the base station based on the current location of mobile user. The sensor nodes goes to sleep/wake state according to the flag it receives in each epoch. A sensor node is sleep scheduled based on the EC-KCKN scheme. Before a node goes into sleep state, the epoch ensures that the node has at least k-connected neighbors.

**3-TIER HYBRID NETWORK ARCHITECTURE FOR WSN DEPLOYMENT**

**Design Framework**

In WSN deployment, each scenario has its own specific requirements. Each mobile robot is equipped with numerous sensors. The sensors are placed in the disaster environments by the mobile robots for their control and target tracking. A 3-tier hybrid network architecture is designed which is capable of distributed sensing, processing and storage.

The network is organized into four groups:

**Wireless Robotic Network (WRN) level**

Sensor nodes which are embedded in mobile robots handle critical event monitoring tasks. Only sensing tasks are executed by this level and no complex routing is done...

**Figure 1**: 3-Tier Hybrid Network Architecture

![3-Tier Hybrid Network Architecture](image)

**Figure 2**: Robotic Node Behavior

During state 1, the robotic sensor node continuously monitors the environment for any victims. If the sensed data shows the presence of any victim, an event is triggered off and it goes to state 2 indicating the event to the coordinator node. It alerts the coordinator by sending a wakeup message and waits for acknowledgement for a certain time slot. It re-transmits the...
message if no acknowledgement is received before the timer ends.

**Beacon Network (BN) level**

Sensor nodes which are capable of routing multimedia contents provide both environmental sensing like heat sensing, smoke sensing, etc and taking audio/video pictures. This tier plays a fundamental role for computing robot’s current position and path and identification of victims in their field of view. It transmits the sensed data and routes the packet towards the sink. The BN tier facilitates multi-flow on-demand simple or multimedia data transfer.

**Coordinator (C) level**

Coordinators are the intelligent mobile nodes aggregate sensed data and are responsible for interaction between BN tier and WRN tier. It aggregates sensed data and supervises WRN and BN node behaviors. It then analyzes the received messages to select either sink or beacon node. It waits for a message from the robotic node in state 1. It moves to state 2 when a message is received. The received message is analyzed and the coordinator adds its own behavior information to the appropriate successor. It then waits in state 3 for receiving acknowledgement message from the node in WRN tier. If the acknowledgement is not received, it sends the message to beacon node and waits for acknowledgement in state 4. It moves to operate in state 2 if no acknowledgement is received. It uses selective transmission technique for limiting retransmissions in states 3 and 4.

**Sink (S) level**

Sink which is the base station has complete knowledge of the network.

**Interaction between the tiers of the network**

In our proposed design, the applications in sink interact with other nodes through the HTTP. The corresponding application sends a HTTP request message regarding location and movement of a mobile robot or sensing the environment to the underlying platform gateway.

At the platform side it is converted into a corresponding operation request message. This request message is forwarded to the mobile robot through the robot gateway. Then the microserver, which is embedded in the robotic framework itself triggers a network read operation to the robotic node. After sensing, the required data is aggregated and the robotic node sends back the results to the microserver. This result message is converted into robot message by the robot gateway from where it gets hopped through the beacons or coordinators. The platform gateway in sink converts the received message into an XML document as specified by the web service.
The energy of sensors drains quickly if all the sensors are switched ON indefinitely. Since the sensors cover the presence of mobile robots with short transfer delays, vast coverage area monitored by the sensors is not required. In our algorithm, all nodes will be sleep schedules based on shifts. Only after receiving a wakeup message the sleep state is disturbed. With our any delay, the sensors will start doing their sensing tasks.

Basic Information
After the sensors are placed in appropriate places by the mobile robots, the network will create virtual circles in the sensing environment. To achieve this, three tables are stored in each sensor;

Own Data Table (ODT)
The table stores information about the sensors.

<table>
<thead>
<tr>
<th>Sensor_ID</th>
<th>Ext_Time</th>
<th>Layer</th>
<th>Status</th>
</tr>
</thead>
</table>

The field Sensor_ID gives the ID value of the sensor. Ext_Time decides whether to extend wake up time which is initially NULL. Layer value specifies the layer where the sensor resides, which is also initially NULL. The status field gives whether the sensor is in sleep or wake up status.

Volatile Data Table (VDT)
It records variable information.

<table>
<thead>
<tr>
<th>Energy</th>
<th>Status</th>
<th>Packet_ID</th>
</tr>
</thead>
</table>

Energy field specifies the remaining battery power of the sensor. Value of status specifies one of five current status of the sensor, transmit, receive, wake_up, sleep and low_power. Packet_ID stores ID of the packet received or transmitted.

Neighbor Data Table (NDT)
This table contains neighbor information.

<table>
<thead>
<tr>
<th>Neighbor_ID</th>
<th>Neighbor_Layer</th>
<th>RSSI</th>
</tr>
</thead>
</table>

Neighbor_ID gives the Sensor_ID of the neighboring sensor. Neighbor_Layer have information about the layer in which neighbor sensor is in. RSSI indicates value of the received signal strength. Each message packet sent/received contains three additional information,

- Sensor_ID – ID of the sensor that sends the message packet
- Sender_Layer – Layer in which the sensor resides.
- Power_Level – the power level used by the sensor.

After defining all the tables, the relationship of communication distance between sensors must be defined for creating routes. Whenever a message is received by a sensor node, it first checks for the information in ODT. The receiver’s layer can be calculated as,

\[ L_R = L_S + P_S \]

\[ L_R \] specifies the receiver’s layer, \( L_S \) is the sender’s layer and \( P_S \) is the power level. Consider \( D_L \) as the distance between each layer and \( D_C \) is sensor’s maximum transmit distance, to ensure that alternate circles,

\[ D_C = D_L \times 3 \]

![Virtual Layery View of the Sensing Environment](image)

Figure 6: Virtual Layery View of the Sensing Environment

Layer Assignment
Initially sink broadcasts a message packet with power level 1. After receiving the message, the sensors will update their ODT and NDT. Those sensors will be assigned layer zero. Then a second broadcast message with 2 power level is sent by the sink. The sensor in layer 2 forwards the sink’s message to its neighbor with power level 2. The process is repeated until all the sensors are updated.

Algorithm for assigning layers to sensors:
Step 1: Broadcast MSG_PKT
Step 2: MSG_PKT received by sensor
Step 3: If Sensor_Layer is NULL, then

\[ L_R = L_S + P_S \]

Update NDT and goto Step 7.
Step 4: If Sensor_Layer is not NULL, and the Sender_Layer is greater than Sensor_Layer, goto Step 7.
Step 5: If Sensor_Layer is greater than Sender_Layer, and if the neighbor layer is not equal to zero, update its NDT and goto Step 7.
Step 6: If Neighbor_Layer is Zero, broadcast MSG_PKT by 2 power level.
Step 7: If Layer_Distance is greater than the network area then all layers are assigned. If not, then goto Step 2.
The Sleeping Mechanism

When all the sensors are updated, the network falls into the operational phase and initiates sleep scheduling based on shifts. In our sleep scheduling algorithm, both the sleep time and wake-up time are equal. When sensors in one layer are in sleep state, the sensors in neighbor layer are in wake-up state. The sensors are in sleep for half-a-time and wake-up in another half to sustain the entire network operation. When the sleep scheduling begins, initially the sensors in odd layers will be put to wake up based on the ODT. If any new data is sent or any event is triggered, the sensors send the data to the nearest neighbor with the help of the information in the NDT. The data is then forwarded to sensors in odd/even layers. The sensors will remain in the same state until its shift is completed. When the sensors in odd layers are in wake-up, the sensors in even layers will be in sleep and vice versa.

Packet Transmission

In the normal transmission, sensed data reaches the sink by multihop transfer. If the Ext_Time field is NULL, data transmission requires considerably small amount of time and the MSG_PKT will be forwarded to the sink in the same odd layers based on the NDT. If a sensor’s wake-up time is to be extended, a value is set in the Ext_Time and the sensor is not forced to sleep if its shift is completed. The operating time of sensors is increased and reserves its wake-up time in sensing the required data. In either cases the shifts of all sensors won’t change except the one whose Ext_Time has a value associated. Once the needed information is sensed, the sensor will fall in the current shift where all other sensors in the same layer are in.

EXPERIMENTAL RESULTS

Simulations were conducted using the NS-2 Simulator to evaluate the proposed sleep scheduling. The range of the network chosen is 200 sq.m. the total number of sensors deployed is 100. Initial power given to sensors is 4.8W, the power needed to transmit data is 60mW, power to receive data is 30mW, power in idle mode is 30mW and finally power in sleep state is 0.003mW. Transmission range of a sensor node is kept as 50m and transmission time is 2.45ms. the shift time is taken as 30s.
Figure 10 shows the comparison of number of alive sensors when run in a span of 300 times. By observing the power consumption of sensors, in probability-based prediction, the needs of the network to send a message is not considered which leads to more idle time and thus more energy is consumed. In geographic distance-based and TDMA scheduling, sensors close to centre area needs more wake-up time to communicate, thus increasing the energy consumed. Our proposed scheme balances the energy consumed and shifts around the whole network increasing its lifetime.

Figure 11 shows comparison of alive sensors near sink. We placed 40 sensors near the sink. Those sensors imposes heavier burden in reducing the hot spot issue. Our scheduling mechanism reduces the hot spot issue by balancing the sleep time of each sensor much near the sink with their workload.

Figure 12 Shows comparison of average delay per packet. We can observe that TDMA has the worst packet delay. This is because the sensor’s sleeping time is not considered in the case of sensors at much long distances from the sink. Whereas in the probability-based scheduling duty cycle arrangements are more complex in the deeper network topology. It is also basically more difficult to fix the duty cycle along the deepest route. The geographic distance-based model and our algorithm results are much closer since both the schemes take the situation of delay in deepest route. Our scheme also reduces the transmission path disruption which may happen in sensors due to different duty cycle.

Figure 13 shows the packet loss ratio comparison. By observing the results, there is a high packet loss ratio for the probability-based scheduling and collaborative location-based scheduling schemes, since the transmission path of the duty cycle is not considered. Packet loss rate is reduced in our scheme.

CONCLUSION AND FUTURE WORK
We proposed an energy efficient sleep scheduling mechanism for the sensors that are deployed in rescue robots for target tracking and environmental sensing. The design of 3-tier hybrid network architecture for supporting the sleeping scheme is proposed. The shift-based sleep scheduling is proposed which divides the network into different odd and even layers. If the sensor in odd layers are in sleep, then the even layer sensors will be in wakeup state and vice versa. The simulation results shows that our scheme can reduce the energy usage of the sensors thus increasing the network lifetime, reducing the packet delay and loss and increase the performance of the network. As a future work, we need to reduce the energy consumption when assigning layers to sensors.

REFERENCES


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