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Sustainable and Robust Rechargeable Wireless Sensor Network Using Markov Decision Process Based Switching Algorithm

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ABSTRACT:

Wireless Sensor Networks (WSNs) consist of a group of sensor nodes which are capable of sensing data (from the environment), such as, temperature, light, humidity, vehicular movement, noise levels, the presence of certain kinds of objects, wind direction and speed.

Sensor nodes may have limited energy or energy harvesting capability. In these sensors, energy efficiency is an important issue that affects the operation of WSN. To prolong network lifetime, energy harvesting sensor nodes are preferably used over limited battery-powered nodes depending on the availability of energy sources. Rechargeable sensor nodes scavenge energy from surrounding sources, such as, solar, wind, vibrations, and passive human movements.

In a tree-based wireless sensor network (WSN), a tree structure rooted at sink node is usually created for efficient data collection. Recently, the use of solar harvesting technologies for rechargeable sensor nodes is evolving. Moreover, in a tree-based rechargeable WSN, the nodes that belong to different routes will have different energy dissipation due to unequal harvested-energy and utilized-energy.

The proposed Markov decision process approach finds the optimal switching policy for sensor nodes, which switch from one parent to another based on energy levels to preserve sustainability. A detailed theoretical analysis has been performed along with simulation results to show the efficacy of the proposed approach.

Introduction

Wireless sensor networks have found their way in wide variety of applications ranging from surveillance and tracking to home automation and smart spaces for elderly assistance. A major hurdle in their wide adoption is the limited lifetime of their energy source, which cannot be replaced easily due to their location and often infeasibility to access the sensor nodes. The need for miniaturized size of sensor nodes does not allow to use larger batteries, which is essential to ensure long lifetime and high transmission rate. In addition, the slow progress of the battery technology (in contrast to computing as well as communication technologies), leads to the conclusion that a solely battery driven node architecture is not a promising solution at least in near future.

Moreover, frequent replacement of the batteries may not be a viable option under many circumstances. A promising solution to deal with energy supply problem is to employ sensor nodes with energy harvesting capability, which can be based on solar, wind, vibration, pressure to name a few. In this paper we have selected solar powered sensor node architecture, as solar cells are one of the most viable options for energy harvesting purpose. However, improving the performance of energy harvesting based sensor nodes, demands amelioration both at communication protocols level as well as energy harvesting techniques. The goal is to increase the system availability, in contrast to the objective of system lifetime maximization in case of battery powered nodes. In addition, the existing modeling approaches used in case of battery powered nodes are not suitable for energy harvesting nodes since they do not account for the uncertainty of the energy source.

In this paper, a solar powered sensor node architecture is considered, where the battery charging process takes into account the environmental conditions while the application performance demands are incorporated in the form of data transmission constraints. To achieve an efficient trade-off between energy efficiency and data transmission rate, an optimal strategy needs to be developed. Traditionally, a wireless sensor network (WSN) is composed of a large number of sensor nodes powered by no rechargeable batteries with limited energy storage capacities. As a result, a WSN can only function for a limited amount of time. The idea of energy harvesting was proposed to address the problem of finite lifetime in a WSN by enabling the sensor nodes to replenish energy from ambient sources, such as solar, wind, and vibrations [3], [4]. The design considerations of an energy harvesting WSN are different from a non rechargeable-battery-powered WSN in many ways.

First, with a potentially infinite amount of energy available to the sensor nodes, an energy harvesting WSN can remain functional for a long period. Hence, energy conservation is not the prime design issue. Second, the energy management strategy for an energy harvesting WSN needs to take into account the energy replenishment process. For example, an overly conservative energy expenditure may limit the transmitted data by failing to take the full advantage of the energy harvesting process. On the other hand, an overly aggressive use of energy may result in an energy outage, which prevents some sensor nodes from functioning properly. Third, the energy availability constraint, which requires the energy consumption to be less than the energy stored in the battery, must be met at all time. This constraint complicates the design of an energy management policy since the current energy consumption decision would affect the outcome in the future. We propose Markov decision process based solution approach, which provides and optimal policy that satisfies the minimum data transmission rate constraint for different battery states. The strategy aims to maximize the ability of the sensor node to detect and transmit an event of interest, while aiming to preserve the battery energy level. It exploits the current battery state and Wireless Sensor Networks (WSNs) consist of a group of sensor nodes which are capable of sensing data, such as, temperature, light, humidity, vehicular movement, noise levels, the presence of certain kinds of objects, wind direction and speed energy harvested by a sensor node depends on the availability of energy sources and also varies according to weather conditions including seasonal changes. Once a rechargeable sensor node exhausts its energy, it may join the network again after the next recharge schedule. Solar-powered Rechargeable Wireless Sensor Network (RWSN) is considered to design a sustainable data sensing paradigm. Network is an important issue to improve the overall lifetime of the network. In a typical non-rechargeable tree structured WSN, sensor nodes forward sensed data to a central sink using a data collection tree.

In this work, a Markov Decision Process (MDP) based load balancing technique has been designed with varying the energy levels of sensor nodes while choosing the operation of sensor nodes adaptively according to residual energy. Using the proposed algorithm, a node chooses the operations (sensing, transmitting and receiving) adaptively to sustain till the next recharge schedule (cycle) in the network. Energy consumptions have been estimated using real-time network traffic with various sensor operations.

A prediction algorithm has been adopted to analyze the amount of harvested energy in a rechargeable WSN. Provided as inputs to the MDP algorithm. The proposed algorithm selects the optimal policy and takes energy balancing (switching) decision based on the residual energy of each node. An energy-balanced network is generated when the energy consumption of sensors adaptively changes based on harvesting energy sources and network traffic loads. To the best of our knowledge, this is the first work which proposes a MDP algorithm to improve lifetime for a sustainable rechargeable WSN.

Existing System

In a tree-based wireless sensor network (WSN), a tree structure rooted at sink node is usually created for efficient data collection. Recently, the use of solar harvesting technologies for rechargeable sensor nodes is evolving. Moreover, in a tree-based rechargeable WSN, the nodes that belong to different routes will have different energy dissipation due to unequal harvested-energy and utilized-energy. Network sustainability and energy efficiency are important issues in a treebased rechargeable sensor network.

Limitations on Existing System

- Energy dissipation due to unequal harvested-energy and utilized-energy.
- Energy efficiency should be increased.
- Network sustainability.

Problem statement

For balancing the data collection tree so that all nodes have uniform load in terms of data forwarding. Limited battery powered sensor nodes are considered. In a tree based rechargeable WSN, the nodes that belong to different routes will have different energy dissipation due to unequal harvested-energy and utilized-energy.

Proposed System

Markov Decision Process based algorithm has been proposed in a rechargeable sensor network. The proposed algorithm maximizes the sustainable time of data collection trees in terms of data collection rounds. A switching decision is taken on the basis of residual energy of the node to balance the tree. From the simulation results, it has been observed that the network is connected for more number of data collection rounds in comparison to an existing randomized switching approach.

Further, it has been observed that the node sustainability time is improved significantly using the proposed method. Energy utilization has been studied by varying various weather conditions. Network connection statistics have been studied in the presence and absence of harvesting energy.

Advantages

- The network is connected for more number of data collection rounds in comparison to an existing randomized switching approach.
- The node sustainability time is improved significantly.
- Energy utilization has been studied by varying various weather conditions.

IMPLEMENTATION

Overall Descriptions of wireless networks

This section provides a description of the general factors that affect the product and its requirements. It also helps in an easier way to understand the specific requirements based on the functionality requirements, performance requirement and supportability. This section also deals with user characteristics, constraints on using the product and dependencies of the product on other applications.

Product Perspective

Network Simulator (NS2) is a discrete event driven simulator developed at UC Berkeley. It is part of the VINT project. The goal of NS2 is to support networking research and education. It is suitable for designing new protocols, comparing different protocols and traffic evaluations. NS2 is developed as a collaborative environment. It is distributed freely and open source. A large amount of institutes and people in development and research use, maintain and develop NS2. This increases the confidence in it. Versions are available for FreeBSD, Linux, Solaris, Windows and Mac OS X.

Product Functions

To find the optimal shortest path through which the Wireless charging nodes move to the sensor node in the network.

User Characteristics

This product has been specifically designed to meet the requirements of all kinds of users. As the interface is GUI based, a non-technical user can easily work with this system. User is required to know the basics of the working software in order to use it to its full efficiency.

Constraints

It’s difficult to construct renewable energy cycle where the remaining energy level in a sensor node’s battery exhibits some periodicity over a time cycle. Moreover, wireless power transfer is immune to the neighbouring environment and does not require a line of sight between the power charging and receiving nodes.

Assumptions and Dependencies

The optimization of communication for distributed systems makes several assumptions: Network performance is high and stable. Network topology can change.

Supportability of Wireless Sensor Networks

These are constraints within which the system must work. These requirements pertain to their information needed to produce the correct system and are detailed separately. The program must be self-contained so that it can easily be moved from one computer to another. It is assumed that ns-2.35 will be available on the computer on which the program resides. The system shall achieve high capacity, scalability, and availability, maintainability at all the times.

- Capacity is the ability to hold the data.
- Scalability is the ability of computer application to continue to function well when it is changed in size or volume in order to meet user needs. The system shall be scalable to support additional clients.
- Availability is the degree to which a system is in a specified operable and committable state at the start of the machine when the machine is called at random time.
- The system should be optimized for supportability, or ease of maintain as far as possible. This may be achieved through the use documentation of coding standards, naming conventions, class libraries and abstraction.

Design Constraints in Wireless Sensor Networks

The designers must be design the system in system in such a way that any user can be able to communicate effectively with the system. The MANET applications have some constraints. User should be aware of these constraints, these are as explained below:

1. This product in the first release and will be used a virtualized simulation environment.

2. A NAM must be installed in the system to use the GUI Application. The application is supported in Linux (ubutun 12) or above

MODULE IMPLEMENTATION

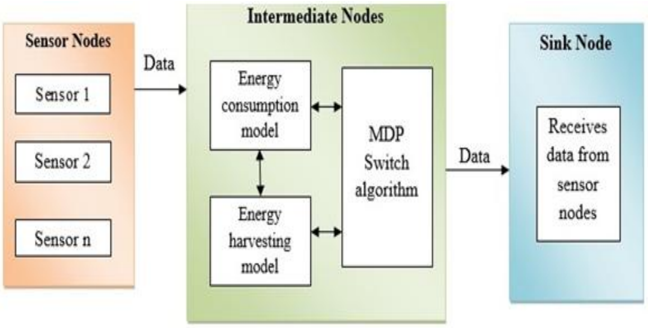


Fig 4.2- Modules Implementation

Three Main modules are:

- Energy Consumption Model
- Energy Harvesting Model
- MDP model

Energy Consumption Model:

- Using energy consumption model find nodes energy consumption by level wise
- Find Energy consumptions by a sensor node in sensing, receiving and transmitting data over a distance
- Energy consumption includes energy consumption per bit by the transmitter, energy dissipation in the transmit, energy consumption per bit by the receiver and energy consumption for sensing a bit.
- Also find Energy Consumption of a Node in a Sensor Tree, Energy Consumption of Leaf Level, Energy Consumption at Level k

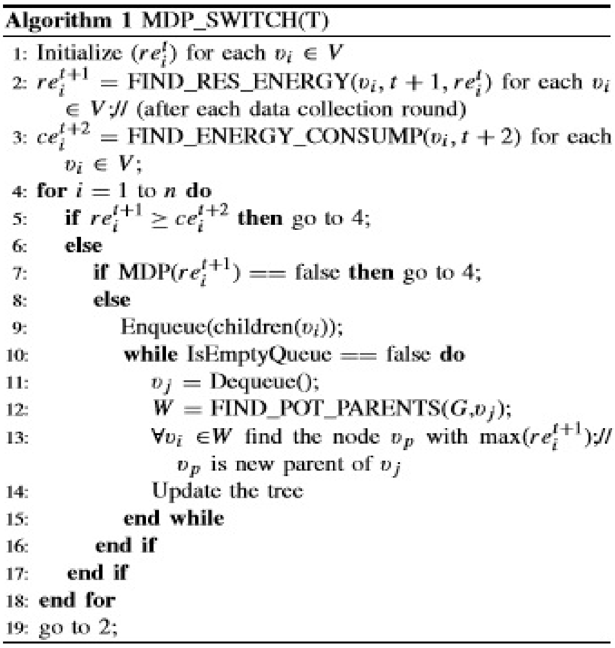
Energy Harvesting Model:

- The energy harvesting model is used for predicting the harvested energy using solar sensors. Energy prediction is required for making decisions for the future time slots in the proposed switching method. i.e The future energy available to the system can be predicted by using past history.

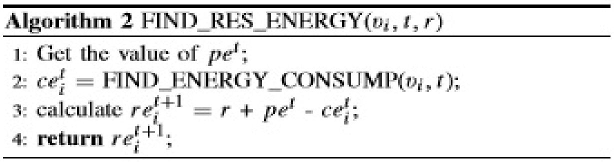
MDP Model:

- Using Energy consumption model find nodes energy consumption by level-wise
- If Energy is not available Select potential parent for switching using MDP algorithm
- By using MDP algorithm, find the residual energy of a node and energy consumption of a node, Select the potential parent for a node which is selected for Switching and switches the children to respective potential parents.

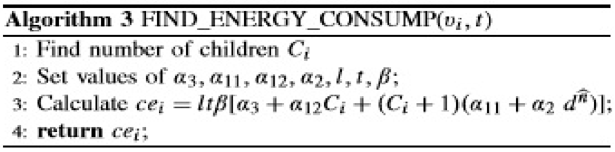
ALGORITHMS



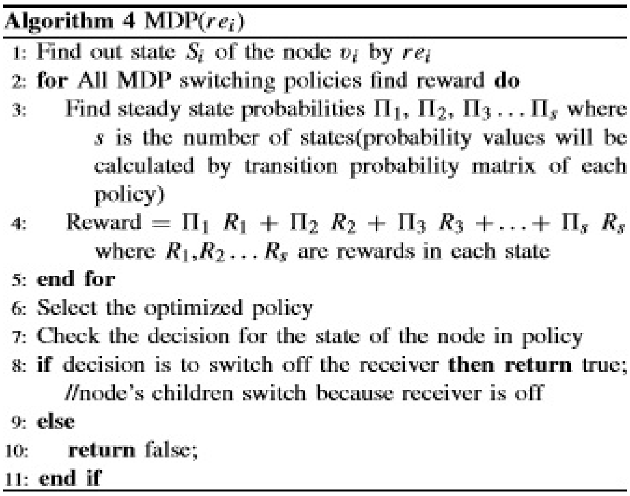
```
Algorithm 1 MDP_SWITCH(T)
1: Initialize ($re_i^t$) for each $v_i \in V$
2: $re_i^{t+1}$ = FIND_RES_ENERGY($v_i, t+1, re_i^t$) for each $v_i$
       $\in V$;// (after each data collection round)
3: $ce_i^{t+2}$ = FIND_ENERGY_CONSUMP($v_i, t+2$) for each
       $v_i \in V$;
4: for $i = 1$ to $n$ do
5:     if $re_i^{t+1} \geq ce_i^{t+2}$ then go to 4;
6:     else
7:         if MDP($re_i^{t+1}$) == false then go to 4;
8:         else
9:             Enqueue(children($v_i$));
10:            while IsEmptyQueue == false do
11:                $v_j$ = Dequeue();
12:                $W$ = FIND_POT_PARENTS($G$,$v_j$);
13:                $\forall v_i \in W$ find the node $v_p$ with max($re_i^{t+1}$);//
                       $v_p$ is new parent of $v_j$
14:                Update the tree
15:            end while
16:        end if
17:    end if
18: end for
19: go to 2;
```



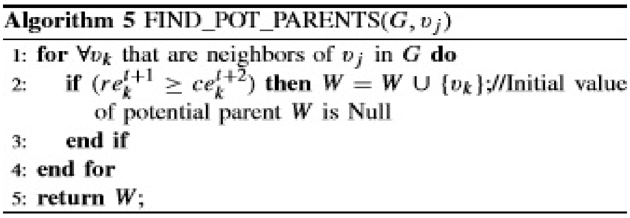
```
Algorithm 2 FIND_RES_ENERGY($v_i, t, r$)
Get the value of $pe^t$;
$ce_i^t$ = FIND_ENERGY_CONSUMP($v_i, t$);
calculate $re_i^{t+1} = r + pe^t - ce_i^t$;
return $re_i^{t+1}$;
```



```
Algorithm 3 FIND_ENERGY_CONSUMP($v_i, t$)
Find number of children $C_i$
Set values of $\alpha_3, \alpha_{11}, \alpha_{12}, \alpha_2, l, t, \beta$;
Calculate $ce_i = lt\beta[\alpha_3 + \alpha_{12}C_i + (C_i + 1)(\alpha_{11} + \alpha_2\ d^{\hat{n}})]$;
return $ce_i$;
```



```
Algorithm 4 MDP($re_i$)
Find out state $S_i$ of the node $v_i$ by $re_i$
for All MDP switching policies find reward do
    Find steady state probabilities $\Pi_1, \Pi_2, \Pi_3 \ldots \Pi_s$ where
        $s$ is the number of states(probability values will be
        calculated by transition probability matrix of each
        policy)
    Reward $= \Pi_1\ R_1 + \Pi_2\ R_2 + \Pi_3\ R_3 + \ldots + \Pi_s\ R_s$
        where $R_1$,$R_2 \ldots R_s$ are rewards in each state
end for
Select the optimized policy
Check the decision for the state of the node in policy
if decision is to switch off the receiver then return true;
    //node's children switch because receiver is off
else
    return false;
end if
```



```
Algorithm 5 FIND_POT_PARENTS($G, v_j$)
for $\forall v_k$ that are neighbors of $v_j$ in $G$ do
    if ($re_k^{t+1} \geq ce_k^{t+2}$) then $W = W \cup \{v_k\}$;//Initial value
        of potential parent $W$ is Null
    end if
end for
return $W$;
```

Algorithm 6

For the sixth algorithm, we use iterative filtering. Iterative filtering is done in this project in a two step method

1) Generating hash value
2) Attacking.

We first generate hash value for the nodes. We also introduce extra unwanted packets into the structure, this is termed as attacing

We will now do iterative filtering only if, the following criterias are met

1) No. of packets= threshold no.
2) Bandwidth= threshold value
3) Hashvalue remains same

based on these three conditions, if the node shows same charaterstics, then it is termed normal, else that node is blocked, as it is now a malicious node

ALGORITHM

Do iterative filtering
{
If(no. of packets== threshold && bandwidth==threshold && hash value is same)
}

```
Do( introduce extra packets into the system)
{
If( node parameters remain same)
{
Normal operation;
}
Else
{
Block the node, and declare it to be malicious
}
}
```

RESULTS AND ANALYSIS

In result phase of the project the system performance is estimated using various factors to check whether the predefined intensions are fulfilled or not. This chapter includes the results details of the project, providing description of the various complexity phases of the project and explaining them using a graph. The project's result phase is a stage in which evaluation of system is done to account for performance also whether the goals specified in the start of the project is accomplished or not. This stage aims at obtaining appropriate data which can be checked and plotted for validating the performance.

The project's outcome aspects are covered in this chapter, giving details of the different complexity levels of the project and explaining them with the assist of a graph. The phase of execution requires the following steps of executing the code comprising multiple parameters, to obtain the time of execution for dissimilar components of the project and data deploying by means of a graph to realize the performance.

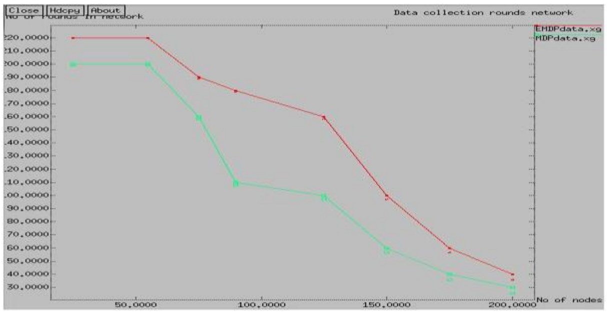


FIGURE 1: NUMBER OF DATA COLLECTION ROUNDS

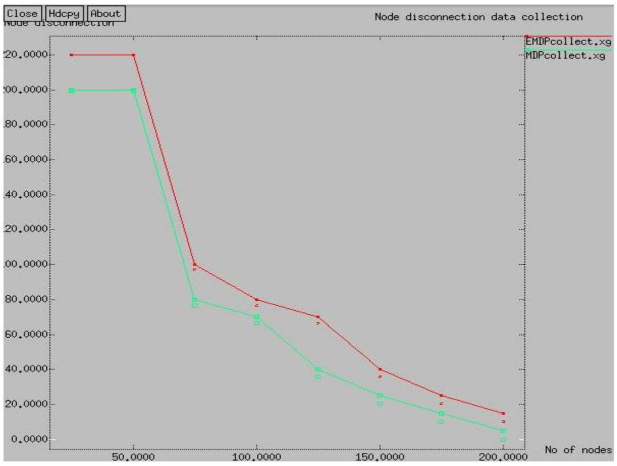


FIGURE 2: NODE DISCONNECTION DATA COLLECTION ROUND

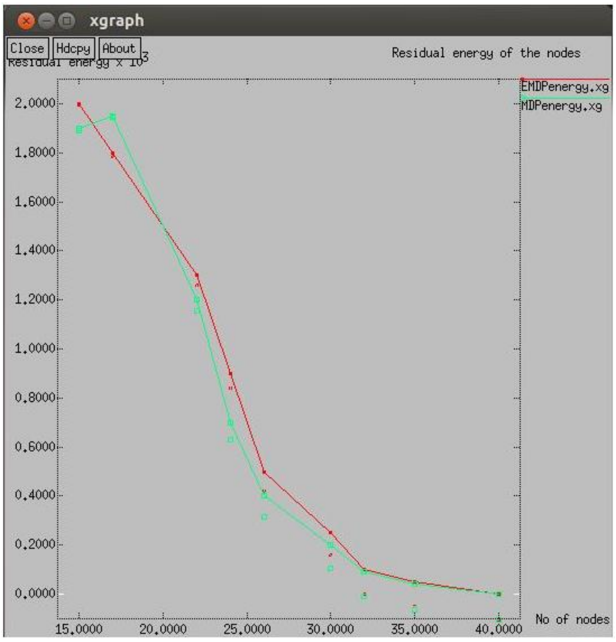


FIGURE 3: RESIDUAL ENERGY OF NODES

The green lines represent existing systems and the red lines represent the proposed system

CONCLUSION AND FUTURE WORK

A Markov Decision Process based algorithm has been proposed in a rechargeable sensor network. The proposed algorithm maximizes the sustainable time of data collection trees in terms of data collection rounds.

Further, a switching decision is taken on the basis of residual energy of the node to balance the tree. From the simulation results, it has been observed that the network is connected for more number of data collection rounds in comparison to an existing randomized switching approach. Further, it has been observed that the node sustainability time is improved significantly using the proposed method. Energy utilization has been studied by varying various weather conditions. Network connection statistics have been studied in the presence and absence of harvesting energy. As a future research challenge, MDP-based switching can also be applied in other types of network architectures, such as, clustered network and wireless sensor actor network. Further, the authors would like to investigate the performance of the protocol in a real-field sensor network.

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