Energy Efficient Routing Protocol with Real-Time Packets Delivery in Wireless Sensor and Actor Networks

Ka. Selvaradjou, V. Rajesh

Abstract: Wireless Sensor and Actor Networks (WSANs) are heterogeneous form of Wireless Sensor Networks(WSNs) with nodes of differing capabilities. Sensor nodes are small and static devices with limited power, computation, and communication capabilities that are largely used in environmental monitoring applications. The actor nodes are relatively resource rich nodes that can move and perform appropriate actions. The combination of these types of nodes brings closed loop operation in the monitoring applications. There are three specific challenges in WSAN: (i) delivery of the event detection report to the actor within a specified deadline, (ii) energy constrains of the sensor nodes and (iii) the reliable delivery of the sensed report. In this paper we propose a real-time, energy aware, routing protocol. Our protocol works in three phases: (i) route establishment, (ii) route maintenance and (iii) route deletion. During the establishment of routes between sensors and actors, the RREQ control packet is embedded with the information such as route, remaining power level, average traffic and current time, At the destination, the route with the maximum remaining power is chosen for transmission. In the maintenance phase, if any intermediate link fails, then RREQ process takes place. The route deletion phase is entered, if the remaining power of a route is below a threshold, thus removing the route entry the routing table. While sending a packet, the node calculates the current remaining power of the route using the previously received packets from that route. If the current remaining power is below a threshold, then the route is not chosen for transmission, the node tries with other route or starts new route establishment process. In our protocol, the intermediate nodes forward the packet based on the deadline associated with them, thus making it suitable for real time nature of WSAN. The performance of the proposed protocols is evaluated through extensive simulations and compared with that of Ad hoc On Demand Distance Vector (AODV) and Greedy Rumor Forwarding Routing (GRFR) protocols in terms of packet delivery ratio, deadline miss ratio, and lifetime of the network.

Index Terms—Wireless Sensor Networks, energy efficiency, routing protocol.

I. INTRODUCTION

The recent advances of embedded technology have turned systems such as sensors, actuators and various mobile devices. Wireless Sensor Network (WSN) [1], which is formed by a group of sensors and a sink, has become extremely popular in recent years with its capability of monitoring the environments. However, sensors are passive devices for collecting data only and not interactive to the environments. Wireless sensor-Actuator Network (WSAN) [2], which includes both actuators and sensors, then becomes an extension to WSN.

Actuators are mobile devices that can make decisions and perform appropriate actions in response to the sensor measurements. Actuators are resource rich devices equipped with more energy, stronger computation power, longer transmission range, and mobility enabled.

Sensors and actuators collaborate together to monitor and react to the surrounding physical world. Sensors perform the sensing and report the sensed data to the actuators, while the actuators then carry out appropriate actions in response to the sensor measurements. The actions performed by actuators include the coordination of one or more other actuators to react on the event area. This coordination is known as Actuator to Actuator Coordination (AAC) [3]. There are two different architecture of AAC, viz. (i) Fully automated and (ii) Semi automated. Sensors detecting a phenomenon transmit their readings to the actor nodes, which process all the incoming data and initiate appropriate actions. Figure 1 illustrates the fully automated architecture. On the other hand, the sensors detecting a phenomenon route their data to the sink, which may in turn issue action commands to the actors as shown in Figure 2.

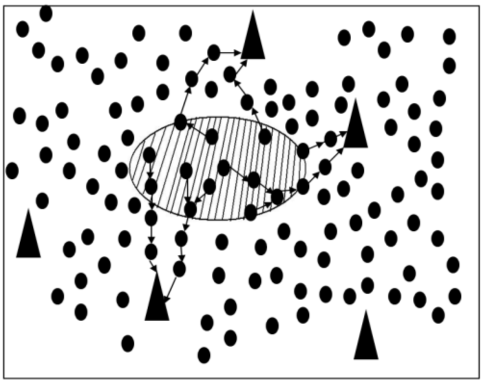

Fig 1: The Fully Automated Architecture

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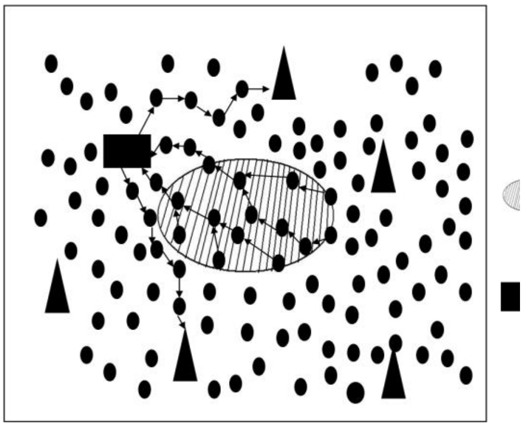

Fig. 2: The Semi Automated Architecture

In WSAN, nodes are deployed in the region of interest, where it is impractical or infeasible for humans to interact with or monitor them, thus unattended. In this case, how to maximize the network lifetime with constrained resource becomes complex and crucial. Besides, in some scenarios such as fire suppression, the communication traffic is typically delay-sensitive. Therefore, supporting a real-time communication is critical in the applications of WSAN. We in this paper, propose a new routing protocol for WSANs that take into account the scarce energy resources on sensor nodes and the real-time demands of the events. Rest of the paper is organized as follows: Section 2 discusses the study on the related work. In section 3 working of the proposed power aware and real time protocol is explained. Section 4 presents the preliminary results of the protocol through simulation and Section 5 summarizes the contributions of the work.

II. RELATED WORKS

The existing routing protocols for the Mobile Ad Hoc Networks (MANET) [4] are not suitable for WSANs, because of its heterogeneity. In Genetic Algorithm based routing algorithm for MANET (GAMAN) [5] the paths are maintained through fault tolerant techniques. This technique fails when the nodes move or fail. In SPEED [6] the issue of real-time communication in sensor networks is considered. However, the energy constraints of the nodes and reliability of the reported event are not addressed. Ad Hoc on Demand Delay constrained Distance Vector Protocol (AOD^{2}V) [7] is enhancement of the Ad Hoc on Demand Vector Protocol (AODV) [8] protocol which includes the Earliest Deadline First (EDF) [9] technique. These results in the delivery of packets within the delay bound. In Greedy Rumor Forwarding Routing (GRFR) [10] for WSANs is an extension of Rumor Routing Protocol [11]. GRFR uses the geographical information of the destination node to forward the packet. That is, whenever a packet is to be forwarded, the next hop is chosen based on its relative distance towards destination. GRFR delivers the packet within its deadline and in less number of hops, but fails to extend the lifetime of the network.

III. OUR WORK

We in this section describe our proposed routing protocol for WSANs called Power Aware and Real-Time Routing Protocol (PRTRP).

PRTRP is a source initiated distributed routing protocol where each node keeps its own routing table. Therefore, it fits the requirements of mobile sensor/actor networks where the system is unattended and routing decisions are done based on local information. In addition, it is an on-demand routing protocol that creates path whenever requested. In WSAN, most of the time sensors do not move and only actors are mobile and the routing is done within clusters with relatively less number of nodes. Thus, PRTRP becomes a good candidate to be employed as an underlying protocol.

A. Overview

Similar to AODV, our protocol works in three phases, viz. (i) Route establishment, (ii) Route Maintenance, and (iii) Route repair. During route establishment phase of PRTRP, a source node sends a route request (RREQ) packet similar to AODV with additional parameters such as residual battery power, current traffic, deadline of the packet, and the time of packet generation. The forwarding nodes of PRREQ packet, alters the additional information fields in the packet in such a way that they include their own information also. This updating of the fields in PRREQ happens will the destination is reached. Then, the destination node chooses the best route among the routes received. The route is then updated into the routing table. After the route establishment, the intermediate nodes monitor the deadline associated with the data packets and accordingly give preference to the packets with earliest deadline.

B. Control Packets

We modified AODV in order to implement power awareness and real time delivery on top of it. However, we needed to make some changes to the used control packets RREQ and route reply (RREP). The new packets are called PRREQ and PRREP respectively. Four additional fields are included in the RREQ packet of AODV. Figure 3 shows the structure of the PRREQ packet.

The Source address indicates the address of the node which transmits the data. The Source Sequence Number indicates the sequence number used at the source node. Destination address represents the address of the target node to which the packet is intended to. Destination sequence is the last sequence number received in the past by the source for any route towards the destination. Then, the broadcast id is for identifying the PRREQ packet from the same source uniquely. Hop count is for denoting the number of intermediate hops in the route. Deadline is assigned by the source node to notify how earlier the packet has to reach its destination. The Minimum Remaining Battery field denotes the minimum remaining battery of the entire path. The final field, generation time indicates the time of generation of the packet at the source.

Source Address
Source Sequence Number
Destination Address
Destination Sequence Number
Broadcast ID
Hop Count
Minimum Remaining Power
Average Traffic Load
Generation Time
Deadline

Fig. 3. PRREQ structure.

The basic RREP Packet is adopted as PRREP packet. Here, no additional fields are included. The structure of the packet is as shown in Figure 4.

Destination Address
Source Address
Source Sequence Number
Hop Count
Lifetime

Fig. 4. PRREP structure.

When a node moves or failure happens, a route error (PRRER) packet will be sent back to the source. This packet informs the source to seek for alternate route as the current one no more exists.

We added three more fields to the routing table of AODV, the figure 5 shows the structure of the updated routing table. The remaining battery power, average traffic, and generation time are the newly added fields to the routing table. The minimum remaining power represents the minimum available energy in a node in the route under consideration. Average traffic denotes the traffic flow of the route which is inferred from the queue sizes of the intermediate nodes. The generation time is the time at which the route request (PRREQ) is generated and this field is used for calculating the current minimum energy of a node in the route.

Destination Address
Destination Sequence Number
Hop Count
Next Hop
Lifetime
Minimum Remaining Power
Average Traffic
Generation Time

Fig. 5. PRTRP Routing table structure.

C. Routing Mechanism

In this section, we explain the working of our PRTRP algorithm by utilizing the updated control packets. There are three main steps as follows:

1. Connection Establishment:

Creation of PRREQ packet at the source: Insert the deadline of the packet, Source sequence number, etc., Broadcasting of PRREQ packet: If the packet is not seen, at the one hop node from the source, after receiving the PRREQ packet, the remaining battery of the PRREQ packet is set to the remaining battery value of the node. The traffic load parameter of the PRREQ packet is assigned with the value of the number of packets in the input queue of the node. At the intermediate node, if the remaining battery power in PRREQ packet is less than its own remaining battery then the node forwards the packet. Otherwise, the remaining battery of the node is assigned to the remaining battery field of the PRREQ packet. The forwarding node updates the traffic load field by calculated using the following formula:

ATL= (TL(i) + PRREQ(TL))/2

Here, the average traffic load (ATL), TL(i) refers to the traffic load of the i^{th} node in the route, and PRREQ(TL) denotes the traffic load value present in the PRREQ packet. Then, ATL value is assigned to the traffic load value in the PRREQ packet and the packet is forwarded. In addition, the nodes update the remaining battery.

After receiving the PRREQ packets via several paths, the destination node selects a best route based on,

i) The route with the highest of Minimum remaining battery power.

ii) If more than one route meets this constraint, then the route with minimum number of hops is selected.

iii) The selection of routes are further resolved with respect to ATL.

iv) Ties, if any, are broken by selecting a route arbitrarily.

The steps are described in Algorithm 1.

```
//OldPRREQ is the received Route Request packet
//newPRREQ is the to be forwarded Route Request packet
//S is the source node
//S1 is the one hop node from the Source node
//Si is the intermediate node i (forwarder)
if(CurrentNode=S)
{
  Set GenerationTime and Deadline of the PRREQ packet;
  Broadcast PRREQ packet;
}
else if(CurrentNode=S1)
{
  receive(OldPRREQ);
  copy(OldPRREQ,newPRREQ);
  Set
newPRREQ.MinimumRemainingPower=S1.RemainingPower;
  Set
newPRREQ.AverageTrafficLoad=S1.InputQueuePacketsCount
;
  forward(newPRREQ);
}
else if(CurrentNode=Si)
{
  receive(OldPRREQ);
  copy(OldPRREQ,newPRREQ);
  if(OldPRREQ.RemainingPower<Si.RemainingPower)
  {
newPRREQ.RemainingPower=OldPRREQ.RemainingPower;
  }
  else
  {
    newPRREQ.RemainingPower=Si.RemainingPower;
  }

newPRREQ.AverageTrafficLoad=(OldPRREQ.AverageTraffic
Load+Si.TrafficLoad)/2;
  forward(newPRREQ);
}
```

Algorithm 1. Route Establishment

2. Data Transmission:

During the data transmission, the node checks its routing table for the route's existence. If the route is not available, then the PRREQ process takes place. If the route is available, then the node calculates the expected minimum remaining battery of the route using the following relation.

$$E_p = \text{MinEnergy}(R) - \text{Traffic load} * \text{Cost} * (\text{Current time} - \text{generation time})$$

where, E_p is the calculated minimum remaining energy of the route. MinEnergy(R) is the remaining energy of the route R in the routing table. Traffic load is the traffic load entry (number of packets awaiting in queue) of the route in the routing table. Cost is the transmission cost in terms of energy per packet. Current time is the time of the node currently. Generation time is the generation time of the route. If the value of E_p is less than a threshold value then the route is not considered for transmission. In this case, a new route establishment phase is initiated.

IV. PERFORMANCE EVALUATION

We implemented our proposed protocol in NS-2.33 simulator. The simulation consisted of 30 sensor nodes and 5 actor nodes randomly deployed in a terrain dimension of 600m X 600m. The simulation parameters are shown in Table. 1.

We evaluated the performance of the protocol for the following metrics: packet delivery ratio and deadline miss ratio. The Figure 6 shows the PDR performance of PRTRP and AODV protocols. It is observed that PRTRP shows about 20% improvement in PDR performance when compared with AODV. The decrease in PDR at higher mobility is due to the frequent disconnection of the routing path. Figure 7 shows the Deadline Miss Ratio (DMR) performance. Under moderately higher traffic, the DMR performance is poor in both the protocols. However, PRTRP has a performance improvement of 5 to 10% over the AODV.

We define the lifetime of the network as the time since the beginning of the simulation to the time until a node drains energy below a threshold. Accordingly, the simulation results shown in Figure. 8 reveals tat the PRTRP fairs better than AODV irrespective of the node density. Figure. 9 shows the throughput performance of the PRTRP compared with that of AODV.

Table. 1. Simulation Parameters.

Parameter	**Value**
Channel	**Channel/WirelessChannel**
Propagation	**Propagation/TwoRayGround**
Network Interface	**Phy/WirelessPhy**
MAC	**Mac/802_11**
Radio Range	**Phy/WirelessPhy set RXThresh_ 2.13643e-07 Phy/WirelessPhy set CSThresh_ 2.13643e-07**
Interface Queue Size	**50**
Terrain Dimension	**100mX100m**
Simulation Time	**100 Seconds**
Packet Size	**500 Bytes**
Number of Nodes	**20, 40, 60, 80, 100**
Actor Mobility	**0 m/s to 5 m/s**
Energy Model	**Reception -rxPower 0.3\ Transmission-txPower 0.5**

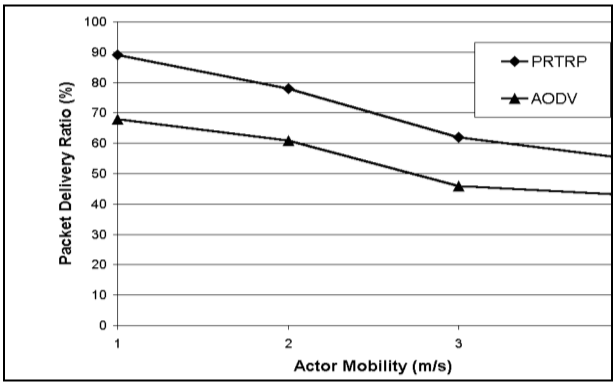

Fig. 6. Packet Delivery Ratio.

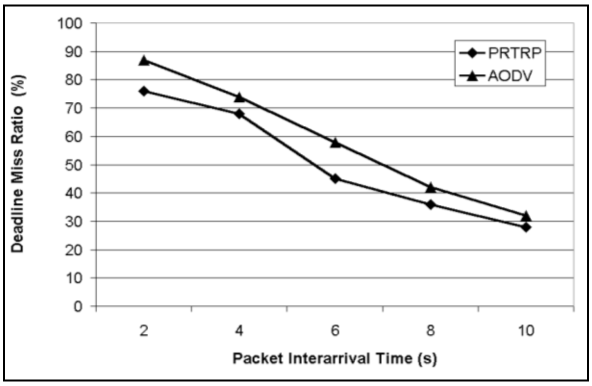

Fig. 7. Deadline Miss Ratio.

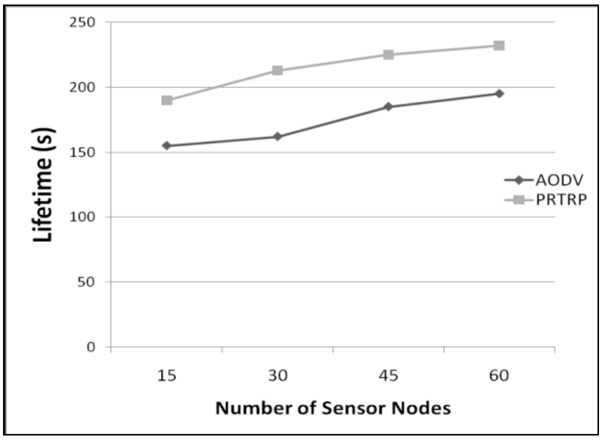

Fig. 8. Lifetime performance.

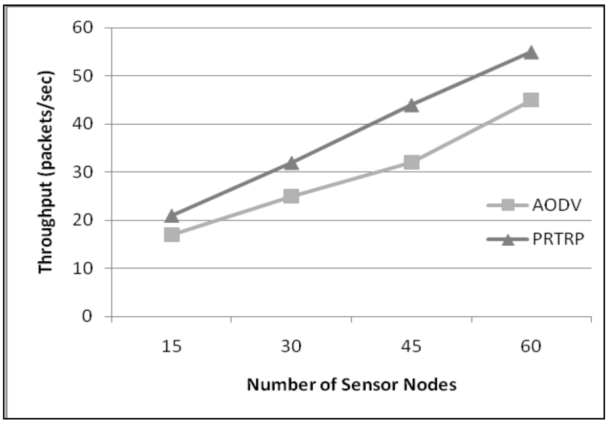

Fig. 9.Throughput performance.

SUMMARY

Real-time reporting of events and appropriate actions are important in WSANs. The sensor nodes pose several challenges due to the energy constraints. It is essential to design energy conserving protocols for WSANs without compromising on the real-time guarantees for the data delivery. We in this work, proposed a routing protocol for WSANs that take into consideration the available energy on a selected path for choosing a better route for the prolonged lifetime of the network. The protocol also gives preferences for the packets based on their deadline parameters so as to meet the real-time responses of the actor nodes. We evaluated the protocol's performance using network simulation and the results are presented in this paper.

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