On Energy Efficient Routing for Wireless Sensor Networks

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Abstract

The design of energy-efficient protocols for Wireless Sensor Networks (WSNs) is a crucial problem as energy is a stringent resource in these networks. In this paper, we propose an energy-aware routing protocol using a new approach. To be more specific, we present a protocol called High Power Short Distance protocol (HPSD). HPSD is a node-based protocol that selects the route to the base station (BS) based on the closest node that has the highest battery power relative to its surrounding neighbors. Thus, the energy load can be distributed among all sensor nodes instead of using certain path each time. As such, HPSD can increase the life time of the network. We simulate the performance of HPSD and compare it to other routing protocols for WSNs. Our results show that albeit being simple, HPSD proved to be a very efficient routing protocol in terms of increasing the life time of the network. Moreover, simulation results show that HPSD can efficiently adapt routes to the nodes available power.

1. Introduction

A Wireless Sensor Network (WSN) is composed of a large number of low cost and low power sensor nodes capable of sensing, local processing, and wireless communications to collaboratively achieve complex information gathering and dissemination tasks [1]. Each sensor can communicate with its neighbor sensor nodes or with external Base Station (BS). Figure 1 show a typical configuration of a WSN where the lines show an example of a route between a pair of sensor nodes. A sensor node comprises four basic units: a sensing unit, a processing unit, a transceiver unit, and a power unit [2]. The lifetime of a sensor node is mainly determined by the power supply from the finite battery source. So, a basic requirement for sensor nodes is to be able to survive with a small finite source of energy [2]. The longer the lifetime of a sensor node, the more stable and useful is the network. In fact, WSNs are very powerful and versatile networks with wide and varied applications [1] and can be created and used in situations where traditional wired networks may fail [2].

An important challenge in the design of WSNs is that the two resources of communication bandwidth and energy are significantly more limited than in a wired network environment. Ending this limitation may either cause the network to malfunction or to be completely disabled to perform its tasks.

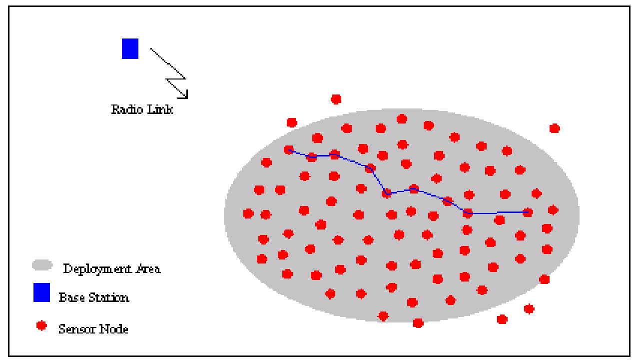

Fig. 1: A Typical WSN Network

Thus, innovative techniques to eliminate energy inefficiencies that shorten the lifetime of the network and efficient use of the limited bandwidth are highly required. For example, at the network layer, it is highly desirable to find methods for energy-efficient route discovery and relaying of data from the sensor nodes to the BS so that the lifetime of the network is maximized [5].

Many researchers addressed the issue of prolonging network lifetime with many energy efficient sensor network routing protocols [2][5][8]. A detailed survey of these protocols can be found in [2]. Examples include LEACH [5], VGA [9], PEGASIS [7], and Directed Diffusion [6].

In this paper we examine the relationship between the power usage and the system parameters of WSNs and then develop a new routing protocol of WSNs called *High Power Short Distance* (HPSD). The main aim of developing this protocol is to increase the node life time by distributing energy load among sensor nodes. This protocol forwards data packets from source nodes to BS using two phases: Initializing phase and Forwarding phase as described in Section 3. Although HPSD share some similarities with some other routing protocols, it also distinguished itself in many aspects. First, HPSD minimizes energy required per routing task, where nodes can adjust their transmission power by knowing the location of their neighbors. Hence, traditional hop count metric can be replaced by a power metric that depends on distance between nodes. Second, HPSD is loop-free

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protocol. This can be achieved by tagging each packet with the unique ID of the participating node. Third, HPSD maximizes the number of routing tasks that a network can perform by finding paths with energy abundant nodes. Fourth, HPSD minimizes the communication overhead since the exchange of control messages between neighbor nodes is event-triggered and not periodic. Fifth, HPSD avoids memorizing past traffic (e.g., queue size) or routing tables. Unlike others, HPSD is flexible in selecting routes based on the power status of the neighbor nodes which changes dynamically during the network lifetime. Finally, HPSD uses localized algorithms to make routing decisions where each node makes a decision to which neighbor to forward the message based on the location of itself, its neighboring nodes, and destination. The rest of the paper elaborates on system model, description and operation of HPSD, communication overhead analysis and performance evaluation results of HPSD.

2. System Model

In this section, we briefly describe the system model and assumptions. We assume homogeneous and flat sensor network that is composed of hundreds to thousands of sensor nodes in control of one or more Base Stations (BSs). In flat networks, each node plays the same role and sensor nodes collaborate to perform the sensing task. We assume random node deployment, where sensor nodes are scattered randomly, and thus creating an ad hoc routing infrastructure. We assume that inter-sensor communication is normally within short transmission ranges due to energy and bandwidth limitations. Therefore, it is most likely that a route in our model will consist of multiple wireless hops. The BS is placed outside the network environment with no restrictions on power, memory, and computational capabilities. We assume a simple energy model as in [7]. In this model, receiving a message is not a low-cost operation; and thus the protocol should try to minimize not only the transmit distance but also the number of transmitting and receiving operations for each message by relying more on the computational and aggregation process. We assume that nodes' power reserves fall into three levels, namely, High, Medium, and low. Also, we assume that each node has two identifiers called Power Identifier (PI) which indicates the power level of the node battery and the second called the Distance Identifier (DI) which represents the distance between the node and the base station (BS). These two parameters (PI, DI) will be used in making routing decisions as described in the next Section.

3. HPSD Protocol Operation

This Section describes the operation of HPSD. The protocol operates in two phases: Initialization phase and Forwarding phase as described below.

3.1 Initialization Phase

Initially, the base station will send a broadcast message for all sensor nodes in the network in order to determine the location of each node with respect to itself. This can be done by calculating the time needed for each message to reach sensor nodes. Then, this time will be stored at each node and reported back to the BS using special control messages. When the BS receives these control messages from all sensor nodes, it can determine the distance identifier (DI) of each node using the following simple equation: $DI=S\times T$, where DI is the distance between the node and the BS, S is the speed of the wave in air (3×10^{8} m/s), T is the time elapsed of a message to reach from the base station to a node. The BS can inform each sensor node with its distance identifier and this identifier is constant because we assume a fixed topology. In addition, all the nodes will be given the power identifier at its maximum value (High). This value decreases when the node got engaged in a communication process by an amount determined by the source node and based on the simple power model we assumed earlier.

3.2 Forwarding Phase

When an event occurs (e.g. detecting an object), the source node sends the data to the BS using the shortest path since all the nodes have the same power identifier (PI). Successive transmissions will change nodes' power levels that will be reported by exchanging special control messages on power level change (e.g., from High level to Medium level). After that, the source node will use the rule of selecting the neighbor with the highest power level (PI) and with the shortest distance (DI) to the BS. In order to prevent loops, each participating node will tag each packet of data passed through it by its ID to indicate that it is a visited node. Then, visited nodes will be avoided in future routing decisions to balance energy consumption. Figure 2 shows a high level description for HPSD. As the figure shows, the algorithm tries to optimize the routing task by selecting nodes with high power using the function *getNextNode()* which also calculates shortest distance to BS, and then combines both to find t he best route to BS using *Find_Best_Packet_Route()* function. To illustrate, Figure 3 shows an example of WSN that consists of 10 randomly-deployed sensor nodes. The BS is fixed and located in the upper left corner. Initially, node 7 selects the next neighbor node (node 6) that has the shortest distance to BS (least DI), because all nodes initially have the same power level (PI). Hence, the path will be 6, 8, 9, and BS. If, later on, node 6 changes its PI from high to medium due to participation in some routing tasks, and let node 3 has a new data to be sent to the BS, then this source node has three possible neighbors to use (6, 4, and 2). Note that node 6 participated in previous routing tasks and its PI is medium. Therefore, the source node will select either node 4 or node 2 because they have the highest PI.

4. Communication Overhead Analysis

In this section, we analyze the communication overhead of HPSD. We are interested in analyzing the expected life time of a link in terms of the total packets transmitted (both data and control packets). We assume that the network contains (see Figure 4) M source nodes and L intermediate nodes. Only source nodes initiate the transmission of a packet to the BS. Let each source node be at the same hop distance from the BS.

```
Algorithm Find-Best-High-Power-Short-Distance-Route(n, BS)

Node  getNextNode(Node  sender)
{
  /* Classify the nodes according to their power  status*/
  Array high;
  Array medium;
  Array low;
  Array final;

  foreach (Node  n  in  sender.Nieghbors)
  {// Loop beginning
    if(n.power_level = high)
    high.add(n);
    if(n.power_level = medium)
    medium.add(n);
    if(n.power_level = low)
    low.add(n);

  }// Loop end

  if(high.count > 0) final = high;
  elseif(high.count = 0 && medium.count > 0)
    final = medium;
  elseif(high.count = 0 && medium.count = 0 && low.count > 0) final
   = low;
  if(final = null) return null;

  Node  least = fnal[0];
  // Get the closest node to destination
  foreach(Node  nin  in  final)
  {
    if(nin.base_distance < least.base_distance)
    least = nin;
  }
  return least;
}

Node  Find_Best_Packet_Route(Node  source)
{
  Array  route;
  Node  next = source;
  while(!(next = null || next.is_base_station = true))
  {
    next = getNextNode(next);
    route.Add(next);
  }
}
```

Fig. 2 : HPSD: High level description of the routing algorithm

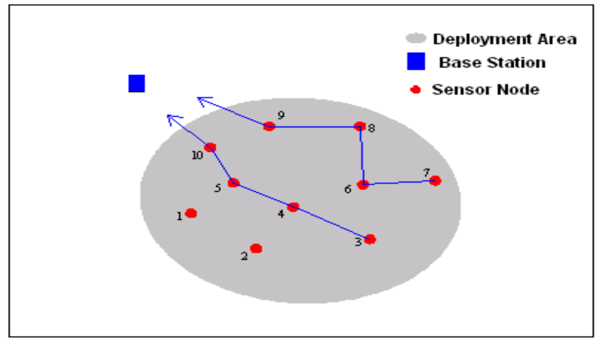

Fig. 3: An Example of HPSD Operation

Also, let each node in the network has an average number of neighbor nodes Δ, and the average distance to any of these neighbor nodes is equal *d*. Each sensor node has total stored energy E_i. Each E_i is independent random variable distributed uniformly between 0 and E_{max}. Assume that data and control packets have the distinct but same length and consume same amount of energy for transmission, namely, T and t, respectively. A path will die once an intermediate node residing on it changes its energy level. Assume that the total number of data packets transmitted by the source node during the life time of the network is equal to K, then the total energy consumed for the data packets will be ($E_d = K \times T$), the total number of control packets transmitted by an intermediate node will be ($C = \Delta \times K$), and the energy wasted for these packets will be ($W_i = C \times t$). So, we can now express the total stored energy in a sensor node E_i as:

$$E_i = E_d + W_i \quad (1)$$

Now, consider the random variable X_i, defined by:

$$X_i = \frac{E_i}{E_{max}} \quad (2)$$

According to the eq. (1), each X_i is an independent random variable uniformly distributed between 0 and 1. Working in terms of X_i will help hide away the scale and keep things as simple as possible.

First we will express the life time of a path. The packet life time of path i is given by:

$$X_{pi} = \min(X_1, X_2, \ldots, X_n) \quad (3)$$

Where *n* represents the number of intermediate nodes in path *i*. The link will live until all the paths will die. The packet life time of link can be expressed as:

$$X = \sum_i X_{pi} \quad (4)$$

Our goal is to compute the mean of X. The mean of X is the sum of means of all X_{pi}'s.

$$E(X) = \sum_i E(X_{pi}) \quad (5)$$

The probability distribution function (PDF) of X_{pi} from eq. (3) can be expressed as:

$$f(X_{pi}) = \sum \left[f_{X_i}(X_{pi}) \prod_{i \neq j} (1 - F_{X_j}(X_{pi})) \right] \quad (6)$$

$$F_n(x) = \int_{-\infty}^{x} f_n(y)\, dy$$

Where $F_n(x)$ is the cumulative distribution function (CDF) for the PDF $f_n(x)$. After calculating the PDF for the packet life time of a path, the mean of a path packet life time can be expressed as:

$$E(X_{pi}) = \frac{1}{n+1} \quad (7)$$

So the mean of packet life time of the link from eq (5) is:

$$E(X) = N \times \frac{1}{n+1} \quad (8)$$

Where N is the number of multiple paths.

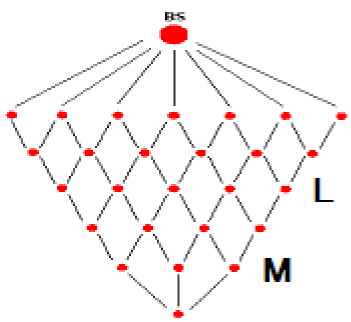

Fig.4: A simple scenario of WSN network.

5. Performance Evaluation

In order to evaluate the performance of HPSD protocol, several simulation experiments with various random topologies were run. A simple simulator was used in this paper using the Visual Studio/C# language. We simulate a flat sensor network with a base station located in the upper left corner of the network (see Figure 5). It is assumed that the network has passed its initial state and all nodes know their neighbors and their IDs. The simulation experiments were conducted for 1000, 10,000, and 100,000 packets. The source is chosen randomly on click. All nodes start with the same initial power level. For each simulation, we tested scenarios for power-aware and not power-aware routing schemes. A network size of $50 \times 50\ m^2$ was assumed. Other parameters we assumed are: number of nodes is 50 nodes and they are selected randomly, transmission range is 15 m, Packet size is 2048 bit, battery power (node's power) is 0.2 J.

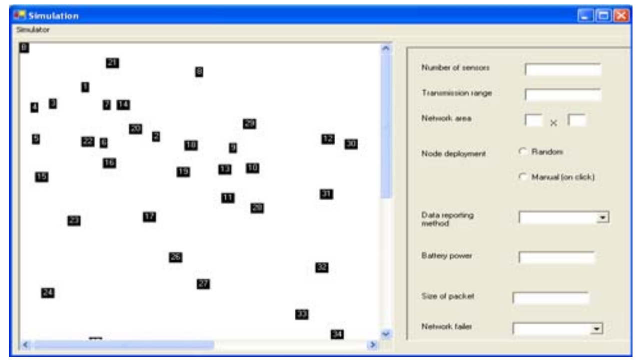

Fig.5: Simulated WSN with Node Distribution.

We noticed that our protocol (HPSD) last the 30 minutes without any dead nodes and its total power decreased from 10 J to 9.261 J as shown in Figure 6, which represents the network life time.

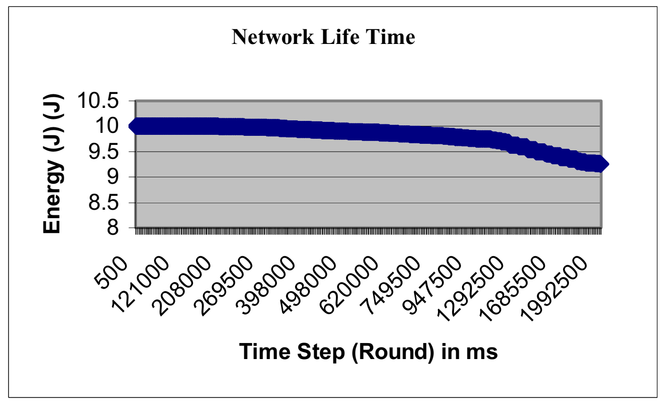

Fig.6: Network Life Time

Figure 7 displays the power delivery ratio (PDR) for our protocol during the 30 minutes for the source node number 10. The PDR is the ratio of the transmitted data packets to the sum of the data packets and control packets in the network:

$$PDR = \frac{\text{Data Packets (bits)}}{\text{Data Packets (bits)} + \text{Cntrol Packets (bits)}} \quad (12)$$

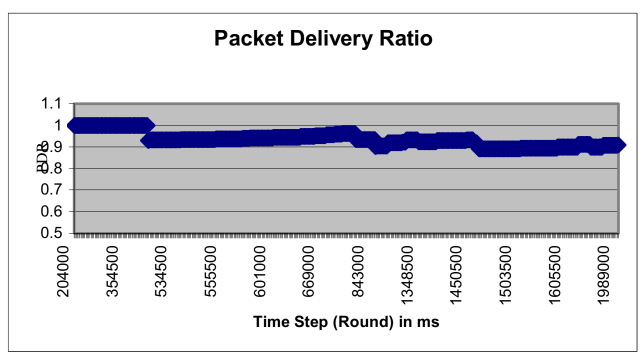

Fig.7: Packet Delivery Ratio

We note that at the beginning of the simulation the PDR is 1 because the sensor nodes do not send control packets until their power level change to acknowledge the neighbor nodes. Figure 8 shows the average route length which represents the distance that the packets take until they reach the BS. We choose also sensor node number 10 to measure the average route length.

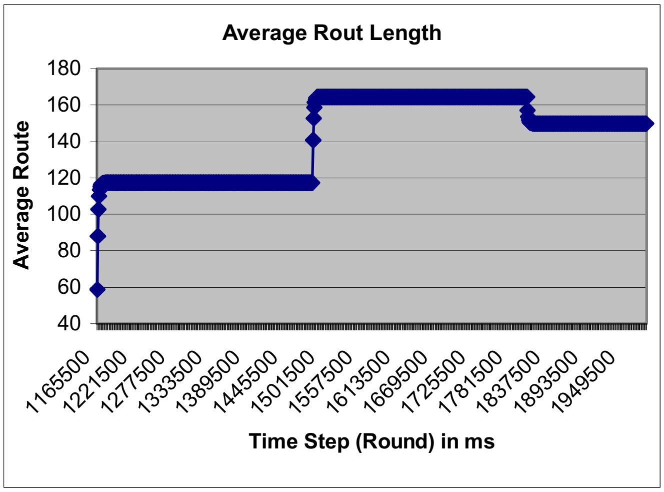

Fig. 8: Average Route Length

We have also compared our routing protocol with other protocols such as Leach, Pegasis and Direct Diffusion using different number of nodes each time for 10 minutes. We have used the same parameters for simulating all routing protocols. Table 1 shows the network life time for the various routing protocols for different number of nodes. We notice that the HPSD routing protocol has a maximum network life time (i.e. 9.6458J) when the number of sensor nodes is 50. Also we observe that the same results are obtained when we use a different number of nodes as shown in Table.1.

Network Size (no of nodes)	LEACH (J)	PEGASIS (J)	Direct Diffusion (J)	HPSD (J)
50	6.3340	3.2006	5.8124	9.6458
100	4.4520	6.8335	6.3738	19.7559
200	13.4374	29.6690	5.3710	39.6072
300	4.2051	29.2790	8.3489	59.7265

Table 1: Network Life Time of Various Protocols.

6. Conclusion

Energy efficiency is a major design consideration for routing protocols in wireless sensor networks. This is due to the fact that sensors are normally equipped with limited energy sources. In this paper, we presented a new energy-efficient routing protocol for WSNs, called High Power Short Distance protocol (HPSD). HPSD is able to select for each hop the closest node that has the highest residual energy compared to other neighboring nodes. We have studied the performance of HPSD through simulation. The results show that HPSD can increase the lifetime of the network many folds when compared to other conventional routing protocols. Furthermore, HPSD can easily adapt the selection of routes based on the available energy in the network.

7. References

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