Energy-Balanced Location-Aided Routing Protocol for E-Health Systems

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Abstract

E-Health is one of the most promising applications of wireless sensor networks. This paper describes a prototype for e-Health systems. Based on the system, we propose the energy-balanced location-aided routing protocol. The location and energy information of the neighbor Coordinators is collected and stored in the neighbor discovery procedure. And then the Coordinator selects the most suitable neighbor to forward the data. The simulation results show that the proposed protocol has better performance than the three other routing protocols.

1. Introduction

Recently, e-Health systems have gained the attention of various researchers. Wireless body area network (WBAN) is one of the most suitable technologies for building unobtrusive, scalable, and robust e-Health systems. In WBANs, sensors continuously monitor human's physiological activities and actions, such as health status and motion pattern.

Since the wireless sensor nodes are energy constrained, it is necessary to find an energy-efficient routing protocol to deliver the data. The authors of [2] give a survey of energy-efficient routing protocols which can be applied in e-Health systems. However, most of the protocols are designed for the general wireless sensor networks. Actually, there are few existing routing protocols for WBANs specially.

In this paper, we present architecture for the e-Health systems. Based on it, we propose the Energy-Balanced Location-Aided (EBLA) routing protocol. After the neighbor discovery, the local Coordinator calculates which neighbor is most suitable to forward the data packet according to the location and energy information. In the simulation, the performance of EBLA is compared with three other routing protocols: PAOLSR [3], EOLSR [4], and MMPR [5] in terms of latency, energy consumption, and throughput. The simulation results show that the EBLA has the better performance than the three other routing protocols.

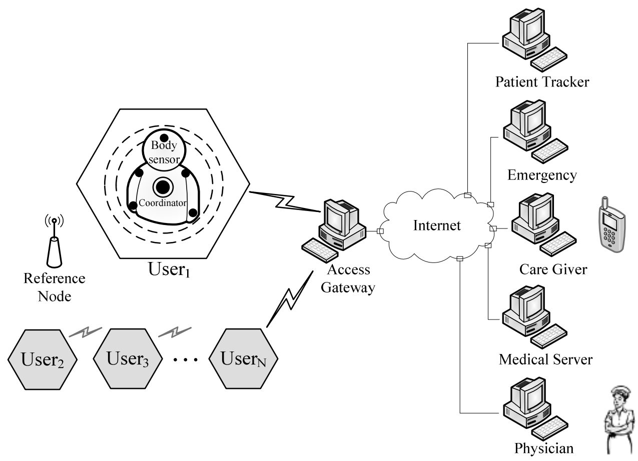
The remainder of this paper is organized as follows. In section 2, we describe the architecture of e-Health systems. Section 3 introduces the energy-balanced location-aided routing protocol. Section 4 presents the performance evaluation of our protocol. Finally, section 5 concludes this paper.

2. Architecture of E-Health systems

The architecture of the e-Health systems is illustrated in Fig. 1. It is composed of the WBANs and a broader telemedicine system. It services hundreds or thousands of individual users. Each user wears a number of body sensor nodes that are placed on or in the human body, each capable of sampling, processing, and communicating [1].

For each WBAN, the Coordinator, which has more energy and computing ability, organizes the whole network on one human. It collects data from the sensor nodes, and then delivers data to the Access Gateway (AG) through other Coordinators using multiple hop routing. AG may be plugged into either a hospital server or a wired or wireless network appliance.

Since the users' location information is also essential in the e-Health system, localization scheme is used. There are some Reference Nodes (RNs) around. They are GPS equipped or preprogramming nodes with their locations. The Coordinators can get their own locations from the signal of RNs and the localization algorithm.



(Figure 1) Architecture of the e-Health systems

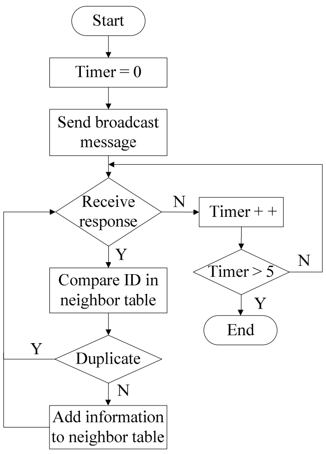
The AG also transmits the data to the medical server through Internet. The physicians can analyze the patients' information and provide medical services. If the patient needs an ambulance in an emergency, the system can send the instruction to the nearest ambulance on the way.

3. Energy-balanced Location-aided Routing Protocol

Routing protocols for e-Health systems can be divided in intra-body communication and extra-body communication ones. The first controls the information handling between the body sensor nodes and Coordinator. The latter ensures communication from Coordinator to the AG. In this paper, we just consider the extra-body routing since the intra-body WBAN is star structure in this system.

After the association procedure, the Coordinators perform the neighbor discovery procedure, whose flow chart is shown in Fig. 2. Firstly, the local Coordinator establishes a neighbor table to store the information of the neighbor Coordinators. And then it sets a timer to 0. After that, the Coordinator sends a broadcast message to find the neighbors. The Coordinator which receives this message sends a response message containing its information including ID (e.g., address), location, and residual energy. Before the timer increase to 5, if the Coordinator receives the response from the neighbor Coordinators, it examines it is a duplicate. If its ID is unique, the responding Coordinator will be added to the neighbor table.

The neighbor discovery procedure is repeated every period of time to update the neighbor table. The update interval depends on the rate of mobility in the network and range of Coordinators' radios. If there's no neighbor (user moves out of the communication range), the Coordinator automatically begin buffering data locally. When the user returns, the route link is reestablished. The Coordinator automatically uploads stored sensor and event data.



(Figure 2) Flow chart of neighbor discovery

After the neighbor discovery procedure, the Coordinators have the information of reachable Coordinators. Each Coordinator collects the data packets from its sensor nodes. The destination of these data packets is the AG. Location information of the AG is stored in every Coordinator after the system setting. When the AG is in the transmission range of the Coordinator, it transmits the data to the AG directly. Otherwise, it sends the data to one of its neighbor Coordinators. The mechanism of the neighbor selection impacts on the packet delay and energy consumption of the whole network.

Firstly, the distance from a neighbor Coordinator to AG is considered. Less distance can reduce the average packet delay. Secondly, to balance the energy consumption and prolong the network lifetime, the residual energy of the Coordinator is also took into account. We tend to choose the one which has more residual energy. A parameter *k* is defined to indicate which Coordinator neighbor is most suitable to forward the data packet, which can be calculated by

$$k = a\frac{D_N}{D_S} + b\frac{E_T}{E_R} \qquad (1)$$

where D_N is the distance between the neighbor Coordinator and AG. D_S is the distance from Coordinator itself to AG. E_T is the data packet transmission energy. E_R denotes the residual energy of the neighbor Coordinator. There are two weighting parameters *a,* and *b*, which are between 0 and 1. They can be adjusted according to the application scenario.

The pseudocode of energy-balanced location-aided forwarding is shown in Fig. 3. Suppose the address of AG is *g.a*. The location of AG is *g.l*. Each Coordinator has a neighbor table (N), each of whose entries contains the information of a neighbor Coordinator: address (*a*), location (*l*), and residual energy (*e*). We denote the own address and location of a Coordinator by *self.a* and *self.l*. *k* is calculated by (1). The initial k_{best} is set to 1. If there is one neighbor Coordinator which has smaller *k*, k_{best} is substituted by this value. After one loop, n_{best} represents the neighbor Coordinator which has the smallest *k*. This neighbor Coordinator is the most suitable one to forward the data packet. After transmitting data to neighbor Coordinator, next step forwarding begins. This forwarding repeats until the data packet reaches AG.

```
n_best = self.a
  k_best = 1.0
  for each (a,l,e) in N
    do k = k (l,e)
    if (a = g.a) or (k < k_best)
      then n_best = a
        k_best = k
        if a = g.a
          then break
        end if
    end if
  end for
  if n_best = self.a
    then return forwarding failure
    else forward p to n_best
      return forwarding success
  end if
```

(Figure 3) Pseudocode of energy-balanced location-aided forwarding

4. Performance Evaluation

To evaluate the performance of the proposed protocol, we did a series of simulations using Network Simulator (NS-2). 100 sensor nodes and 10 Coordinators were deployed in a 10m×10m field. The basic parameters used in the simulation are tabulated in Table 1. The application traffic was a constant distribution with the fixed data rate of 2kbps. All nodes generated their first data frame randomly in one cycle. The data frame had the fixed payload length. The sensor node energy consumptions of the transmission, reception, idle, and sleep were set to 36.5mW, 41.4mW, 41.4mW, and 42μW, respectively. Coordinators and nodes move at a speed distributed uniformly between 0 and 1m/s, which approximates to the walk speed. The parameters *a*, and *b* were set to 1/2. All simulations were run independently and their results averaged fewer than 1000 seeds. The simulation held on for 1000 seconds.

We compared EBLA with PAOLSR [3], EOLSR [4], and MMPR [5] in terms of the energy consumption, latency, and throughput. Firstly, the energy consumption denotes the average amount of energy consumed by the Coordinators and sensor nodes. Secondly, the latency is defined as the average time taken for a data packet from the sensor to AG. Thirdly, the throughput is a measure of the average amount of data transmitted from the sensor nodes in a unit period of time (second).

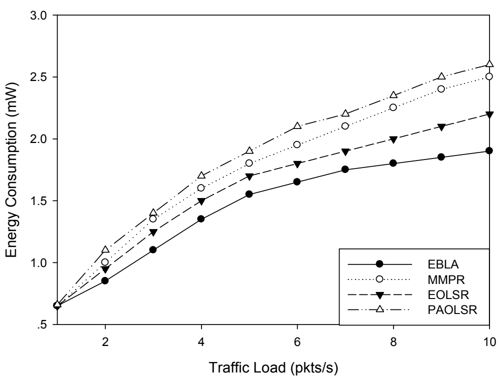
< Table 1 > Basic simulation parameters

Parameter	Default Value
radio propagation range of body sensor node	2m
radio propagation range of Coordinator	25m
frequency band	2400-2483.5MHz
channel rate	250kbps
simulation start time	1sec
simulation end time	1000sec
payload size	10byte
MAC header	27byte
maximum packet size	127byte

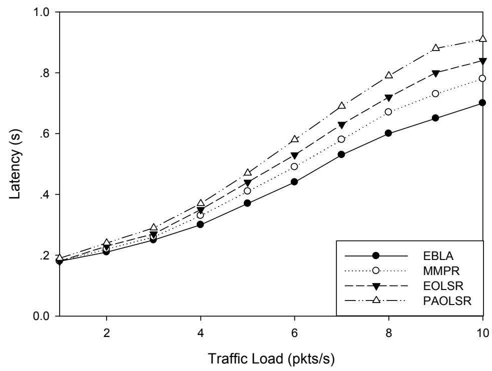
The simulation results of the energy consumption varying with the traffic load are shown in Fig. 4. EBLA consumes less energy since it reduces the number of hops by choosing neighbor nearest to the AG and balances energy consumption of each Coordinator. Fig. 5 illustrates the latency varying with the traffic load. It can be seen that the latency of EBLA is considerably reduced as it selects a proper forwarding node. The throughput varying with the traffic load is presented in Fig. 6, from which we can see that EBLA has higher throughput since the average delay is reduced.

5. Conclusion

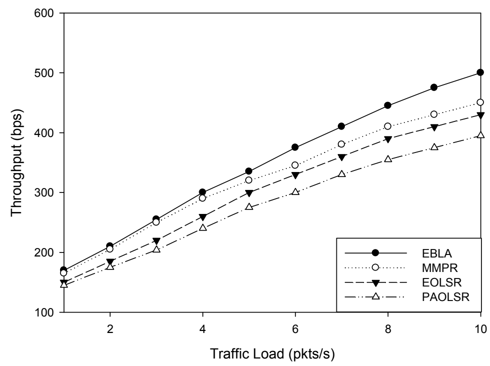
In this paper we describe the architecture of an ambulatory e-Health system including WBANs and a broader telemedicine system. A WBAN consists of multiple sensor nodes. They can collect the vital signs of the user. The information is delivered to the AG through Coordinators. The AG transmits the information to the Internet, where the broad telemedicine system can get it. Based on this system, we propose an energy-balanced location-aided routing protocol. The Coordinators get the location and residual energy information of their neighbors in the neighbor discovery procedure. Using the energy-balanced location-aided forwarding, the Coordinator selects the most suitable Coordinator to forward the data. According to the simulation results, EBLA has the better performance than the three other routing protocols.



(Figure 4) Energy consumption varying with the traffic load



(Figure 5) Latency varying with the traffic load



(Figure 6) Throughput varying with the traffic load

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