International Journal of Signal Processing, Image Processing and Pattern Recognition
Vol.9, No.1 (2016), pp.231-238
http://dx.doi.org/10.14257/ijsip.2016.9.1.22

Routing Design and Simulation of Body Area Network Based on Node Energy Consumption Control Strategy

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Abstract

According to the requirements of structure and communications of Body Area Network, a study is made on the node energy control strategy of Body Area Network. On the basis of dynamic routing protocol DSR, energy saving self-adaptive route E-DSR of Body Area Network has been designed, and the simulation analysis has also been made. The results show that effectively utilizing the node energy can improve the communication efficiency and lifecycle of Body Area Network by adopting E-DSR route.

***Keywords**: Body Area Network, topological structure, node energy consumption, routing design, simulation*

1. Introduction

For Body Area Network (BAN) of topological structure, the sensor nodes can forward the data to the central node through the transmission of multiple intermediate nodes (Figure 1). As BAN deployed on the human body, the miniaturization of components limits the node power capacity. Moreover, the residual energy of each node is not the same as the difference of the each node's business and energy consumption of data collection. If the using of node energy is not controlled properly, some nodes will die due to excessive energy consumption, and the result will affect the communication efficiency and life cycle of BAN [1][2].

The commonly used BAN routing protocol (such as DSR, Dynamic Source Routing Protocol[3]), with the shortest path as a basis for route selection, but does not take into account the remaining energy of nodes in the path. This will result in that in the process of communication, where the node density is relatively high, some nodes may be reused. Consequently, because of too fast energy consumption these nodes will die, and thus the original route will fail. To restore the communication, other nodes will again initiate route discovery process, resulting in the increase of packages communicated in the network, congestion or conflicts in the network, and the reduction of efficiency of network communication [4][5].

To make full using of BAN node energy and improve the communication efficiency, the energy factor is used as an indicator of route selection to design a self-adaptation energy saving E-DSR based on the node energy consumption control strategy in this paper. E-DSR will consider the node energy consumption and delay comprehensively, choose a path with larger amounts of residual energy as far as possible, and protect the nodes with less energy to extend the effective working time of the network

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ISSN: 2005-4254 IJSIP

2. Node Energy Control Strategy

In order to ensure the effective communication and energy conservation requirements of BAN, it is necessary to re-establish the routing, to transmit data through the nodes with more residual energy when there is any node with too low energy in BAN and should not continue to serve as an intermediate node.

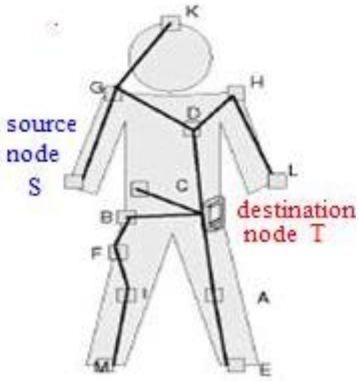

Figure 1. BAN Tree Topology Diagram

As shown in Figure 1, let S be the source node, T is the destination node, and there exists multiple paths when *S* transmits data to *T*. Considering the factor of node energy consumption, there will four kinds of routing selection strategies show in as following.

(1) The path with minimum number of hops [6] (with the least energy consumption)

If an intermediate node, after the routing request of source node is received, is judged not to be the destination node, and there is no routing in the route cache to the destination node, the routing request will be forwarded immediately to the neighboring node. According to this routing discovery process, a path with the minimum number of node hops, which also consumes the least energy in data transfer, will be obtained. However, if there is an intermediate node with less energy in the path, a lot of forwarding traffic load will quickly deplete the energy of the node, which will cause the node to die too early and thus shorten the lifetime of the network.

(2) The path with the higher node residual energy [7]

If an intermediate node, after the routing request of source node is received, is judged not to be the destination node, and there is no routing in the route cache to the destination node, a time delay will happen inversely proportional to the energy left in the current node (The more energy left, the shorter the time delay will be), and then the routing request will be forwarded to the adjacent node. With this method, the routing request will first reach the destination node along the path with more energy left in the nodes. The path with more node energy left may not be the path with the smallest number of hops, but the energy consumption of each node in the path is taken into consideration, which prevents the nodes with less energy left from dying too early.

The key point is to look for a path with more node energy left, and to determine an appropriate delay time. If the delay time is too long, the cost will be too much; if the delay time is too short, it may not be able to find a path with more node energy left. In this regard, the study is made in the literature [8] and the delay time *d(i)* can be calculated by equation (1).

$$d(i)=(D^2+E^2)/2\times D-\sqrt{(D^2+E^2)/2\times D-(e_i-E)^2} \tag{1}$$

In the equation, e_i is the residual energy of node *i*, *E* is the initial energy value, *D* is the maximum delay value.

(3) The path with the minimum energy cost

With respect to the life cycle of the node, the less energy left in a node, the higher cost for forwarding data will be, that is, the cost for a node to transmit data and the energy left in the node are inversely proportional. Let e_i be the energy left in node *i*, cost function be $1/e_i$, and then C_p, the energy cost of path *p* from the source node *S* to the destination node *T* is equal to the sum of all the node cost functions in path p, as in formula (2).

$$C_p = \sum_{S \to T} \frac{1}{e_i} \qquad (2)$$

Among all the possible paths from the source node *S* to the destination node *T*, if there is a $P_{\min}$ setting up the formula (3), $P_{\min}$ will be the path with the least cost of energy.

$$C_{p\min} = \min\{C_P \mid p \in A\} \qquad (3)$$

In the equation, *A* is the set of all the possible paths from the source node *S* to the destination node *T*.

(4) The path with the minimum fluctuations

If the same energy cost will be paid for two paths, the uniformity of energy left in nodes in the paths shall be taken into consideration. Define the path energy fluctuation value $S_p^{\ 2}$, as shown in equation (4).

$$S_p^{\ 2} = \frac{1}{n} \sum_{S \to T} \left(\frac{1}{n} \sum_{S \to T} e_i - e_i\right)^2 \qquad (4)$$

In the formula, *n* represents the number of nodes in the path *p*.

The larger the value of $S_p^{\ 2}$, the greater the energy fluctuations of the nodes in the path *p* will be. The great energy fluctuations means that the gap of remaining energy of each node in the path p is large, and in the path there must be nodes with less energy left. In order to avoid the nodes with less energy being used excessively, in case of the same path cost, we should choose the path with smaller energy fluctuations.

3. Routing Design

According to the node energy consumption control strategy elaborated above, we will design a self-adaption energy-efficient routing E-DSR based on the node energy consumption control strategies and on the basis of the dynamic routing protocol DSR.

(1) Routing discovery

The E-DSR routing discovery process involves two sets of routing information. Namely, the routing request *RREQ* <*source node ID, destination node ID, routing records, routing request ID*>, routing reply *RREP* <*source node ID, destination node ID, routing the data package passes through, routing the routing request passes through*>. The discovery procedures of the E-DSR routing are as follows.

Step 1: when the source node *S* sends data to the destination node T, first check whether there is a route to node *D* in the route cache of node S. If there is, end the route discovery process, and shift into the routing process; If there is not, forward *RREQ*, to initiate the route discovery process, and implement Step 2;

Step 2: When the intermediate node receives the *RREQ*, check whether the *RREQ* is a duplicate routing request. If so, discard the *RREQ*, and do not perform any other operations; if not, proceed to Step 3;

Step 3: Check whether this node ID is present in the route record of the *RREQ*, if it is, discard the *RREQ*, without performing any other operations; If it is not, go to Step 4;

Step 4: Check the destination node ID of *RREQ*, and if this node is the destination node, it sends a routing reply *RREP* to the source node S, and copy the routing information into the RREP. Then reversely forward *RREP*, and implement Step 7; If the node is not the destination node, perform Step 5;

Step 5: Check whether there is a route to the destination node in the route cache of this node. If there is, add the route to the routing record in *RREQ* and copy this routing record into *RREP*, and then reversely forward *RREP*, and implement Step 7. If there is not, go to Step 6;

Step 6: Add the remaining energy e_i value of the node ID to the routing record of *RREQ*, and calculate the delay time *d(i)* according to equation (1). After a delay of *d(i)*, forward the *RREQ* to the neighboring node, and implement Step 2;

Step 7: After the source node S receives the *RREP*, store the data packages in the *RREP* through the routing information into the route cache. All the nodes receiving the *RRE*P will update the node route cache according to the routing information in *RREQ*.

(2) Routing selection

If there is only one path *p* from the source node *S* to the destination node *T*, then the node *S* will transmit data directly along the path p, without considering the energy consumption of nodes in the path *p*, in order to reduce delay. If there is more than one path from *S* to *T* in the route cache, then choose $P_{\min}$, the path at the least energy cost. If there are several paths at the same energy cost, and all at the least energy cost, calculate the value of path energy fluctuations S_p^2, to choose the path with the smallest value of energy fluctuations.

(3) Routing maintenance

When an error occurs in the data transmission of a node, the node will return an routing error message *REER <first segment node ID of the failure link, end node ID of the failure link, the source node ID, route that REER passes through>* to the source node. The nodes receiving *REER* delete the route containing this link from their own route cache. When the source node receives the *REER*, it will initiate another route discovery process.

4. Simulated Analysis

In this paper, the simulation tool OPNET is used to build the simulation model[9], and simulation analysis is made on the BANs adopting the DSR and E-DSR protocols, respectively.

The simulation area is arranged in a 2m×2m indoor environment. The total number of nodes is 15, of which one is the central node. Operating frequency is 2.4GHz, modulation system is BPSK, network data flow is CBR flow, data transfer rate is 256kbps, and the simulation time is 60 minutes. The initial total energy of nodes is 100J, the energy consumed for sending and receiving 1bit data once is 5mJ, and 4mJ is consumed per second in the idle state.

(1) Node model

The node model is composed of wireless transceiver, MAC layer, routing layer and application layer. For the MAC layer of E-DSR network nodes, the energy model is added, as shown in Figure 2.

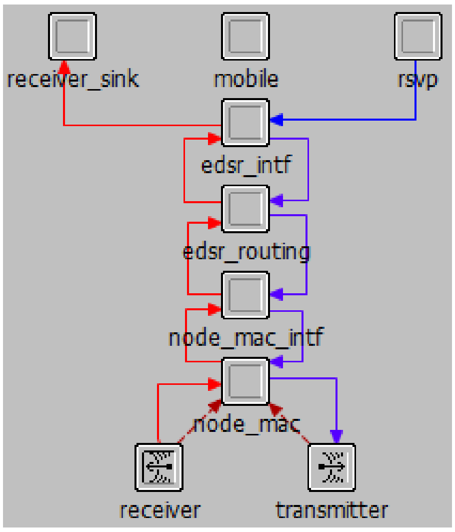

Figure 2. Node Model Diagram

(2) Process model

The MAC process is obtained by improving the self-owned 802.11 protocol of OPNET, shown in Figure 3. The process model of edsr_routing includes the ENERGY state, the function of which is to receive the energy information coming from the MAC, as shown in Figure 4, but the process dsr_routing does not include an ENERGY state. Energy consumption is calculated according to the literature [10].

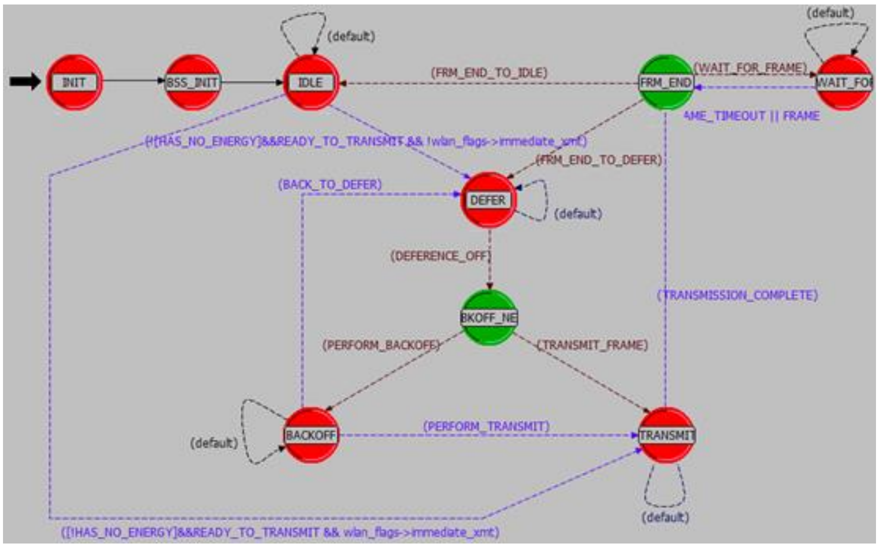

Figure. 3 MAC Process Model

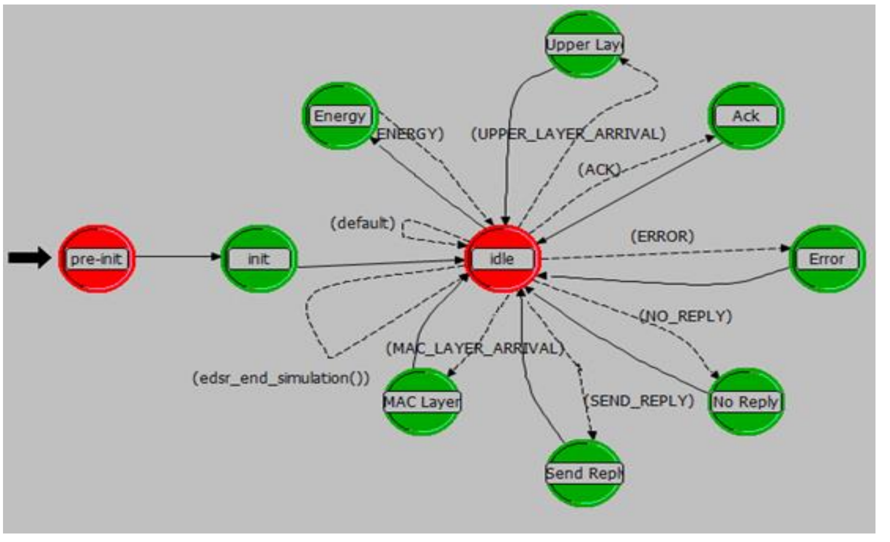

Figure 4. E-DSR_routing Process Model

(3) Analysis of simulation results

End-to-end time delay: as shown in Figure 5, the end-to-end time delay of E-DSR is longer than that of DSR. This is because E-DSR is energy optimal. The path selected is not necessarily the shortest path, so the delay will increase. However, the delay gap between E-DSR and DSR is small, only 0.03 seconds.

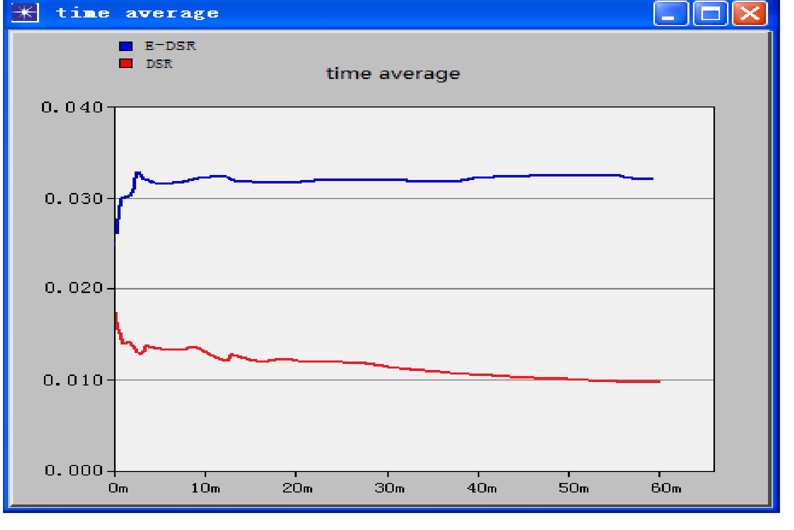

Figure 5. Comparison of End-to-End Delay

Network lifecycle: the network lifecycle is defined in many ways. Here, the network lifecycle refers to: the duration from the start of operation to the first node death, after the network initialization is complete. As shown in Figure 6, the time of the first node death of E-DSR is later than that of DSR, and the network lifecycle of E-DSR is longer. Moreover, in the same period of operation, the number of dead nodes in E-DSR is obviously smaller.

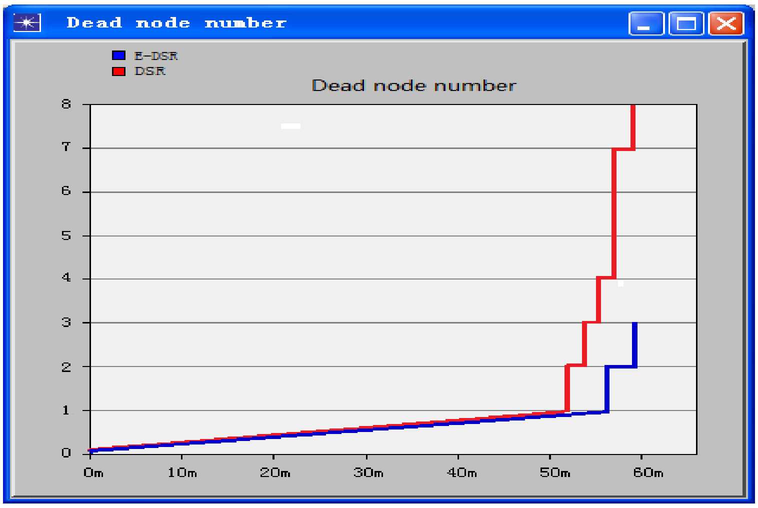

Figure 6. Comparison of Time of Node Death

Simulation analyses show that routing protocol E-DSR has the idea of routing protocol DSR and the features of BAN. Also, the routing mechanism of DSR has been optimized in routing protocol E-DSR. For BAN applications, routing protocol E-DSR has improved energy consumption and network lifecycle. Though the delay is increased in some sense, the difference is not significant, so it can meet the requirements of BAN

5. Conclusion

For the BAN with a tree topological structure, data may be transmitted from the source node to the destination node through multiple paths. If the factor of node energy consumption is taken into consideration, there may be four kinds of route selection strategies, namely, path with minimum hops, path with more remaining node energy, path at the minimum energy cost and path of the minimum energy fluctuations. Comprehensively considering these four strategies, we have designed a self-adaptive energy-efficient routing protocol E-DSR, and used the simulation tool OPNET to make the simulation analysis. The simulation results show that E-DSR protocol is improved to some extent in energy consumption and network lifecycle compared with DSR protocol.

Acknowledgement

National Science Fund Project of Guizhou Province: Stage Research Results of Research on Environment and Safety Monitoring of Wireless Sensor Network System ([2011] No.J2204 Contract of Technology Gallery in Guizhou Province).

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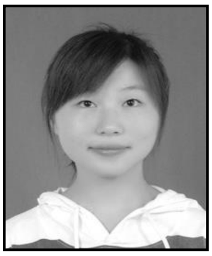

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