FEEL: Forwarding Data Energy Efficiently with Load Balancing in Wireless Body Area Networks

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Abstract—In this paper, we propose a reliable, energy efficient and high throughput routing protocol for Wireless Body Area Networks (WBANs). In Forwarding Data Energy Efficiently with Load Balancing in Wireless Body Area Networks (FEEL), a forwarder node is incorporated which reduces the transmission distance between sender and receiver to save energy of other nodes. Nodes consume energy in an efficient manner resulting in longer stability period. Nodes measuring electrocardiography (ECG) and glucose level send their data directly to the sink in order to have minimum delay. Simulation results show that FEEL protocol achieves improved stability period and throughput. As a result it helps in continuous monitoring of patients in WBANs.

Keywords: Wireless Body Area Networks (WBANs), Forwarder node, Energy efficiency, Throughput, Threshold

I. INTRODUCTION

NOW a days, health care systems are facing challenges due to increase in the elderly population and limited financial resources. The total health care expenditure in Pakistan was Rs. 3.791 billion in 2007-08 [1] and expected to increase in the coming years. This appeals scientists and researchers to find the best and economical solutions for health care. Remote monitoring of patients’ vital signs presents a solution to the increasing cost of health care. Therefore, monitoring of human body and surrounding environment is important, especially for patients, athletes and soldiers. A WBAN consists of miniaturized, low power and intelligent nodes deployed on, in or around the human body for monitoring and diagnosis. It is one of the solutions to the increasing cost of health care. We use the term sensors, nodes and sensor nodes interchangeably in this paper. These sensors collect data from the body and transmit via single-hop or multi-hop mechanism to the sink. The sink further sends the collected data to the medical server. The medical specialist at a remote place can access the patients’ data and issue an advice. WBAN provides long term health monitoring without affecting the routine activities. It can also handle recovery from surgical procedure and emergency situations [2].

In WBANs, non-invasive nodes can be used to monitor the physiological parameters of the human body. These nodes send the data to the nearest device e.g. cell phone, laptop, etc. Therefore, it provides flexibility in terms of data gathering. Furthermore, nodes give accurate data and are cost effective. There are a number of applications of WBANs including real time health monitoring of patients. They are also used to monitor the soldiers in the field. The sensors deployed on the body measure different physiological parameters and send data to the concerned authorities. Interactive gaming is an emerging application of WABNs. The players can physically move their limbs and the sensors deployed on the body send data to the gaming device. It provides enhanced entertainment. The sensors used in WBANs have limited energy. It is difficult to replace or recharge the batteries very often. Therefore, it is necessary to use minimum energy in order to increase the network lifetime. It also increases the throughput by sending more packets to the sink.

There are different routing protocols used to enhance the network lifetime. We propose a high throughput and reliable routing protocol for WBANs having increased stability period. We deploy eight nodes at different positions on the human body. Two cases are considered for the placement of sink on the human body. In the first case, sink is placed on the chest while in the second case, sink is placed on the wrist. Two sensors measuring ECG and glucose level communicate directly to the sink. They possess critical data which is sent to the sink immediately without any delay. The other six nodes communicate to the sink via forwarder node. All nodes are homogeneous and have same specifications. This scheme uses energy efficiently and increases the stability period and throughput of the network.

The rest of the paper is organized as follows. Section II consists of related work, while section III discusses the motivation. Radio model is shown in section IV and FEEL protocol is presented in section V. Energy consumption analysis and simulation results are discussed in section VI and VII respectively. Finally, section VIII gives the conclusion along with future work.

II. RELATED WORK

A number of routing protocols are available in WBANs. They can be categorized into single-hop and multi-hop communication protocols. In single-hop communication protocols, nodes send their data directly to the sink. On the other hand, nodes in multi-hop communication protocols use intermediate nodes to route their data to the sink.

A. Ehyaie et al. [3] propose an upper bound on the number of relay nodes, sensors and their distance from sink. The relay nodes are distributed on the human body as a network. The sensors communicate to the relay nodes which further
route data to the sink. J. Elias et al. [4] give Energy-Aware WBAN Design (EAWD) model. It gives the position and optimum number of relay nodes in WBANs. Relay nodes are responsible for data collection from sensors and routing it towards the sink. They propose integer linear programming for relay nodes for energy efficient routing. Authors in [5] derive a propagation and radio model for energy efficient communication in WBANs. They studied energy efficiency on a line and tree topologies using these models. They found that single-hop communication is inefficient in WBANs.

A two tier hierarchical architecture for WBANs is presented in [6]. Authors present an interference free routing protocol. Nodes send their data to cluster head (CH). This scheme monitors multiple patients and routes their data to the base station (BS). S. H. Seo et al. [7] present an adaptive routing protocol. The priority and vicinity of nodes is taken into account for the selection of parent node for mobile human body. T. Watteyne et al. [8] formulate a self organization protocol for BANs. Nodes are grouped into clusters which send their data through CH to reduce energy consumption and increase the network lifetime. The protocol shows that clustering based approach is suitable for WBANs. In [9], authors suggest a WBAN protocol for monitoring the patients at home. The home server collects the data from nodes deployed on the human body and routes it to the medical server via internet. In [10], C. Wang et al. propose a distributed WBASN for medical supervision. The system contains three layers: sensor network, mobile computing network, and remote monitoring network. It collects and stores vital signs such as ECG, blood oxygen, body temperature, etc.

M. Quwaider et al. [11] present a routing protocol for WBANs, which counts for changes in the network. It uses store and forward mechanism to increase the probability of successful packet transmission. The location based packet routing is developed in this protocol.

DARE [12] uses multi-hop scheme to monitor the patients in a ward of the hospital. Sensors attached to the patients send data to the body relay. The body relay aggregates the received data and routes it to the sink. S. Akram et al. [13] give THE-FAME to measure the fatigue in the soccer players. They employ a composite parameter for fatigue measurement which consists of a threshold parameter for lactic acid and distance covered. The implanted sensor sends the data to the nearest sink deployed at the boundary of the field. Similarly, N. Javaid et al. [14] present a routing protocol for fatigue measurement of a soldier. Three sensors are attached to the body to measure temperature, heartbeat and glucose level in the blood. Different scenarios are considered for the movement of soldier.

Authors in [15] form virtual groups between doctors and nurses for efficient patient monitoring. Virtual groups are formed and modified according to the requirements of patients and doctors. They propose a new metric called Quality of Health Monitoring.

III. Motivation

WBANs monitor human health with limited energy resources. Different routing schemes are used to route data towards sink, which further sends data to the medical server or other monitoring station. Mobility-supporting Adaptive Threshold-based Thermal-aware Energy-efficient Multi-hop Protocol (M-ATTEMPT) [16] uses multi-hop communication for normal data delivery to sink. Nodes communicate directly to the sink for routing critical data. However, they deplete their energy quickly resulting in shorter stability period and lack of critical data from some nodes. Stable Increased-throughput Multi-hop Protocol for Link Efficiency in Wireless Body Area Networks (SIMPLE) [17] uses a cost function for forwarder node selection and uses energy efficiently to prolong the stability period. However, load is not distributed uniformly on all the nodes. The placement of sink is also an important parameter as it affects the throughput greatly. In addition, the human comfort level must also be taken into account when deciding the position of sink.

In order to improve the stability period and network throughput, we propose FEEL for WBANs. Our contribution includes:

- Efficient criterion for forwarder selection.
- The sink is placed at two different locations on the human body.
- FEEL for WBANs consumes energy efficiently resulting in longer stability period. Nodes stay alive for more time resulting in long time monitoring of vital parameters of the human body.
- Increased stability period results in high throughput.

IV. Radio Model

There are different radio models in the literature. We use first order radio model given in [18]. The equations for first order radio model are given below:

\[ E_{TX}(k, d) = E_{TXelec}(k) + \varepsilon_{amp}(k, d) \]  
\[ E_{TX}(k, d) = E_{TXelec}(k) + \varepsilon_{amp}(k, d)^2 \]  
\[ E_{RX}(k, d) = E_{RXelec}(k) = E_{RXelec}(k) \]

Where \( E_{TX} \) is the energy consumed in transmission process and \( E_{RX} \) is the energy consumed by the receiver. \( E_{TXelec} \) and \( E_{RXelec} \) are the energies required to run the electronic circuit of transmitter and receiver respectively. \( \varepsilon_{amp} \) is the energy required by the amplifier circuit, \( k \) is the packet size whereas \( d \) is the distance between transmitter and receiver. In WBANs, the communication medium is human body which contributes attenuation to the radio signals. Therefore a path loss coefficient parameter \( n \) is included in the radio model.

Equation for the transmitter energy consumption is:

\[ E_{TX}(k, d) = E_{TXelec}(k) + \varepsilon_{amp}(k, d)^n \]

The energy parameters depend upon the hardware of the system. We consider two transceivers, Nordic nRF 2401A and Chipcon CC2420, which are used frequently in WBAN technology. The energy parameters for these transceivers are shown in Table I.
TABLE I
ENERGY PARAMETERS OF TRANSCEIVERS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>nRF 2401A</th>
<th>CC2420</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC current (TX)</td>
<td>10.5</td>
<td>17.4</td>
<td>mA</td>
</tr>
<tr>
<td>DC current (RX)</td>
<td>18</td>
<td>19.7</td>
<td>mA</td>
</tr>
<tr>
<td>Min. supply voltage</td>
<td>1.9</td>
<td>2.1</td>
<td>V</td>
</tr>
<tr>
<td>$E_{TX,elec}$</td>
<td>16.7</td>
<td>96.9</td>
<td>nJ/bit</td>
</tr>
<tr>
<td>$E_{RX,elec}$</td>
<td>36.1</td>
<td>172.8</td>
<td>nJ/bit</td>
</tr>
<tr>
<td>$E_{amp}$</td>
<td>1.97</td>
<td>271</td>
<td>nJ/bit/mV</td>
</tr>
</tbody>
</table>

V. FEEL: PROPOSED PROTOCOL

In this section, we discuss a novel routing protocol for WBANs. Uniform energy consumption of nodes is important for long term health monitoring in WBANs. We propose FEEL, a new routing protocol with improved stability period and throughput. The following subsections give detail of the proposed protocol.

A. Deployment of Nodes

In FEEL, we deploy eight homogeneous nodes on the human body. Node 8 is ECG and node 7 is glucose level sensor. These two nodes send their data directly to the sink. We use two different topologies for the placement of sink on the human body. In the first case, sink is placed on the chest while in the second case it is placed on the wrist. Fig. 1 shows the placement of nodes and sinks on the human body. It also shows the distances of nodes from sinks.

B. Start-up Phase

In the initial phase, sink broadcasts a HELLO message containing following three types of information:
- Location of sink.
- Location of neighbours.
- Information about possible routes to the sink.

The nodes receive this HELLO packet and update their routing table. They also send information about their IDs and residual energy status to the sink. Fig. 2 shows the contents of HELLO message.

C. Selection of Forwarder Node

In this section, we present the selection criteria of forwarder node. In order to save energy and balance the energy consumption of the network, FEEL selects a new forwarder in
each round. As sink knows the residual energy of all nodes, it broadcasts the ID of the node having maximum residual energy to make it the forwarder node.

\[ \text{Forwarder node} = \text{Node}_{\text{max}(R.E)} \quad (5) \]

Where \( R.E \) is the residual energy of a node. Residual energy is calculated by subtracting the consumed energy from initial energy.

\[ \text{Energy}_{\text{residual}} = \text{Energy}_{\text{initial}} - \text{Energy}_{\text{consumed}} \quad (6) \]

The node having maximum residual energy is selected as a forwarder node. All the neighboring nodes send their data to the forwarder node. The forwarder node aggregates the received data and routes it to the sink. In the next round, again a new forwarder node is selected based upon the residual energy. In this way, forwarder node rotates uniformly and all the nodes get a chance to become a forwarder. Therefore, energy is consumed more uniformly as compared to SIMPLE and M-ATTEMPT resulting in increased stability period and throughput.

\section*{D. Scheduling Phase}

In this phase, forwarder node assigns Time Division Multiple Access (TDMA) based time slots to its children nodes. All nodes send their data to the forwarder node in their allocated time slots. Proper scheduling of nodes minimizes their energy consumption.

\section*{E. Data Transmission Phase}

All other nodes except ECG and glucose level measuring nodes send their data to the forwarder. The forwarder node aggregates the received data and routes it to the sink. Nodes measuring ECG and glucose level communicate directly to the sink as they have critical data. If a node possesses energy less than a threshold (\( \gamma \)), it communicates directly to the sink. In addition, it does not further take part in the selection of forwarder. This is done to save the data aggregation energy of nodes. If a node has shorter distance to the sink than forwarder node, it routes its data directly to the sink.

\section*{VI. Energy Consumption Analysis}

In this section, we develop equations for single-hop and multi-hop communications. Energy consumed for single-hop communication is:

\[ E_{SH} = E_{TX} \quad (7) \]

\( E_{TX} \) is the transmission energy as given by:

\[ E_{TX} = k \times (E_{\text{elect}} + \varepsilon_{\text{amp}}) \times d^2 \quad (8) \]

Where, \( E_{\text{elect}} \) is the energy consumed by electronic circuit. Now, energy consumed during multi-hop communication is given by:

\[ E_{MH} = k[m \times (E_{TX}) + (m - 1) \times (E_{RX} + E_{da})] \quad (9) \]

Here, \( E_{RX} \) is the reception energy and \( m \) is the number of nodes.

\section*{VII. Simulation Results and Analysis}

In order to verify the performance of FEEL protocol, simulations are performed in MATLAB. We study the performance of the proposed protocol in comparison with SIMPLE and M-ATTEMPT. The initial energy of all nodes is same i.e. 0.5 J. In simulation, we ignore the sensing energy consumed by the nodes. Simulations are performed five times and average results are plotted. Table II shows the values of different parameters used in simulation. We evaluate different performance metrics of the proposed protocol. Introduction to some of the metrics is given below.

\subsection*{A. Network Lifetime}

It is the total time till the death of last node. It represents time for which the network operates. In WBANs, a protocol is required to offer maximum network lifetime.

\subsection*{B. Stability Period}

It is the time before the death of the first node. It is an important parameter in WBANs.

\subsection*{C. Throughput}

Throughput is the number of packets successfully received at sink.

\subsection*{D. Residual Energy}

It is the difference of initial energy and consumed energy.

\subsection*{E. Path Loss}

It is the difference between transmitted power and received power. It is represented in decibel (dB).

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|}
\hline
Parameter                  & Value      & Units  \\
\hline
\( E_{RX_{\text{elect}}} \) & 36.1       & nJ/bit \\
\( E_{TX_{\text{elect}}} \) & 16.7       & nJ/bit \\
\varepsilon_{\text{amp}}   & 1.97       & nJ/bit/m^2  \\
\( E_{da} \)              & 5          & nJ/bit  \\
\( d \)                   & 0.1        & m      \\
\( \gamma \)              & 0.1        & J      \\
Packet size (k)           & 4000       & bits   \\
Frequency (f)             & 2.4        & GHz    \\
Initial energy (E_o)      & 0.5        & J      \\
\hline
\end{tabular}
\caption{Simulation Parameters}
\end{table}
B. Throughput

It shows the number of packets successfully received at sink. WBANs require maximum data reception at the sink with minimum packets dropped. We use Random Uniformed Model [19] for packet drop calculation. The status of communication link can be good or bad depending upon the probability. We suppose the probability of link status to be good is 0.7. FEEL protocol achieves higher throughput than M-ATTEMPT and SIMPLE as shown in figs. 5 and 6. Throughput depends upon the number of nodes which are alive. More nodes send more packets so throughput increases. As the stability period of M-ATTEMPT and SIMPLE is less, so less number of nodes send packets resulting in less throughput. Whereas, the FEEL protocol has longer stability period, so more nodes send packets resulting in increased throughput. Throughput of the FEEL protocol is even higher in second case due to increased stability period.

C. Residual Energy

The residual energy of the network is shown in figs. 7 and 8. The FEEL protocol uses multi-hop communication for data transmission to the sink. All nodes except 7 and 8, transmit their data to the forwarder node which routs it to the sink. The forwarder node is selected at the start of each round. The selection of new forwarder in each round saves energy. In FEEL protocol a new forwarder node is selected in each round, removing the burden of data transmission from a single node. In M-ATTEMPT and SIMPLE, nodes die early due to heavy traffic load and non-uniform load distribution.

D. Path Loss

Path loss shows the difference in the transmitted and received power represented in decibels (dBs). The posture of human body affects the signal. As a result path loss shows different behaviour during the movement of human body. There are different models used to estimate the path loss. It is a function of distance and frequency as expressed in [20] and
shown below:

\[ PL(f, d) = PL_o + 10n \log_{10}\left(\frac{d}{d_o}\right) + X\sigma \] (10)

Where, \( PL_o \) is path loss at reference distance \( d_o \) and \( n \) is path loss exponent. The distance between transmitter and receiver is \( d \), \( X \) is a gaussian random variable and \( \sigma \) is the standard deviation.

Path loss at reference distance \( d_o \) is given by:

\[ PL_o = 10 \log_{10}\left(\frac{4\pi d_o}{\lambda}\right)^2 \] (11)

Where, \( \lambda \) is the wavelength of electromagnetic waves.

Figs. 9 and 10 show the path loss in each round. In simulation, we use a fixed frequency of 2.4 GHz from ISM band. We use path loss coefficient of 3.8 and standard deviation of 4.1. FEEL has lower path loss as shown in the figs. 9 and 10. In the proposed protocol, path loss decreases after 4000 rounds. It is due to the fact that some nodes die after 4000 rounds. So less number of nodes have lower path loss. FEEL protocol has lower path loss than M-ATTEMPT.

The improvement (%) provided by the FEEL protocol to M-ATTEMPT and SIMPLE is shown in tables III and IV.

VIII. CONCLUSION

We propose FEEL, a new routing protocol for efficient utilization of energy in WBANs. Nodes send their data to the forwarder node which routs it to the sink. Forwarder node is selected on the basis of residual energy. The node having maximum residual energy is selected as a forwarder node. Two nodes measuring ECG and glucose level send their data directly to the sink as their data is critical. These two nodes do not deplete their energy quickly and stay alive for longer time. Simulations show that FEEL protocol achieves longer stability period and throughput. In future, we intend to implement Expected Transmission Count (ETX) link metrics as discussed in [21,22].

REFERENCES

(Accessed on 20-NOV-2013)
Improvement in Percentage for case 1

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Improvement (%) in M-ATTEMPT</th>
<th>Improvement (%) in SIMPLE</th>
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</thead>
<tbody>
<tr>
<td>Stability period</td>
<td>0.005</td>
<td>0.0083</td>
</tr>
<tr>
<td>Network lifetime</td>
<td>93</td>
<td>20</td>
</tr>
<tr>
<td>Throughput</td>
<td>1.08</td>
<td>0.0098</td>
</tr>
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<td>Average residual energy</td>
<td>17</td>
<td>-0.278</td>
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</table>

Improvement in Percentage for case 2

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Improvement (%) in M-ATTEMPT</th>
<th>Improvement (%) in SIMPLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stability period</td>
<td>162</td>
<td>27</td>
</tr>
<tr>
<td>Network lifetime</td>
<td>-0.005</td>
<td>-0.0083</td>
</tr>
<tr>
<td>Throughput</td>
<td>93</td>
<td>20</td>
</tr>
<tr>
<td>Average residual energy</td>
<td>1.08</td>
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<tr>
<td>Average path loss</td>
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