Abstract—Wireless Body Area Sensor Networks (WBASNs) consist of on-body or in-body sensors placed on human body for health monitoring. Energy conservation of these sensors, while guaranteeing a required level of performance, is a challenging task. Energy efficient routing schemes are designed for the longevity of network lifetime. In this paper, we propose a routing protocol for measuring fatigue of a soldier. Three sensors are attached to soldier’s body that monitor specific parameters. Our proposed protocol is an event driven protocol and takes three scenarios for measuring the fatigue of a soldier. We evaluate our proposed work in terms of network lifetime, throughput, remaining energy of sensors and fatigue of a soldier.

I. INTRODUCTION

Wireless Sensor Networks (WSNs) seek the attention of researchers due to their effectiveness in multiple applications. A particular subclass of WSNs known as WBASN consists of multiple sensors attached with the human body to provide us real time feedback like temperature, heartbeat, pulse rate and ECG monitoring. Through WBASN a patient is monitored, and in case of critical situation an immediate action is made possible. Sensors collect data from the body of a patient and send it to physician. The primary application of WBASN is continuous healthcare monitoring.

In WBASNs, monitoring of environment is a challenging task due to limited number and sensitive placement of sensors. Misplacement of sensors cause degradation in the quality of captured data. So, placement of tiny and light powered sensors is an important factor. To prolong the lifetime of sensors, route selection is of key importance. Thus, Authors in [1], [2] and [3] proposed energy efficient routing protocols. A common method for maximizing the sensors lifetime is minimization of communication between sensors. For energy consumption minimization [4], special attention must be given to enhance the communication system.

Fatigue, physical or mental, is a subjective feeling of tiredness. Sometimes, it is correlated with lethargy. Physical fatigue is the inability of muscles to maintain optimal physical performance. Medically, fatigue is considered as a symptom rather than a sign because it is reported by a patient in a subjective manner. Normally, fatigue is caused by loaded work, depression, boredom, mental stress, lack of sleep, etc [5]. Different routing protocols have been proposed for various data demands in WBASNs. If sensors sense and gather data constantly and transmit it periodically then this type of communication is called clock driven communication. In event driven communication, transmission is triggered by a particular event. Query driven communication deals with the transmission occurrence in response to a query.

Various techniques are proposed for improving the efficiency of direct communication. In this paper, we present a new routing scheme for measuring the fatigue of a soldier. Our routing protocol takes three scenarios into account: (1) walking (2) slow running and (3) fast running. We use an event driven approach i.e. transmission is triggered by a particular event.

II. RELATED WORK AND MOTIVATION

Authors in [6] proposed Energy-Balanced Rate Assignment and Routing protocol (EBRAR) for body area networks. In EBRAR, routes are selected on the basis of residual energy of nodes. Moreover, intelligent data transmission and uniform distribution facilitate network lifetime enhancement.

In [7], authors proposed an opportunistic routing scheme for WBASNs. Quality of link between nodes in WBASN is effected by the body movement. Therefore, proposed opportunistic routing protocol maximizes the lifetime of sensors during body movements.

N. Javaid et al. [8] proposed a routing protocol for heterogeneous WBASNs. Data is transmitted directly for on-demand data and multi-hop communication is used for normal data delivery in the proposed protocol.

Authors in [9] introduced 3 types of nodes with different energies, i.e. normal, advanced and super nodes. Energy of super nodes is more than normal nodes and advanced nodes. CHs are selected on the basis of their energies.

In Q-LEACH [10], the network is divided into four quadrants. Each quadrant possesses specific number of nodes, and is further divided into sectors. Each sector selects its own CH and hence load on CH reduces.

HEER [11] is a cluster based reactive routing protocol which uses residual energy of nodes and average energy of the network for the selection of CH. Furthermore, introduction of hard and soft threshold helps to conserve energy of the sensors.

A. Ahmad et al. proposed DDR (Density controlled Divide-and-Rule) scheme for energy efficient routing in wireless sensor networks [12]. In DDR, static clustering technique is used.
Nodes are distributed uniformly in the network and randomly in the clusters. In DDR, network is divided into segments. Each segment is designed such that distance between CH and nodes, and between CH and base station is reduced. After every round new CH is selected in each segment with the ability of fixed number of CH in each round. CH is selected such that its distance from central reference point is minimum. In every segment mutihop communication strategy is adopted.

Authors in [13] present a system in which multiple sensors are attached with the body to monitor various body parameters such as, heart activities. It is a radio based wireless network technology.

Authors in [14] conducted a comprehensive survey on different architectures used in WBASNs for ubiquitous healthcare monitoring. Various standards and devices used in these architectures, and finally the influence of path loss in WBANs are also provided.

According to our knowledge, existing routing protocols in WBASNs are mainly concerned with energy efficiency of nodes. Thus, we propose a routing protocol to consider specific real time mobility scenarios like walking, slow running and fast running with an additional capability to measure fatigue.

III. PROPOSED PROTOCOL

For the improvement of security, we must know the physical status of soldiers. An important factor in physical status of soldier is fatigue. If we know the state of fatigue in soldiers then we can send backup to them. In this proposed protocol, we measure the fatigue of a soldier through WBASN. Sensors collect several body parameters of a soldier, send this data to Base Station (BS) placed on body and BS sends it back to headquarter. The main problem in WBASNs is the limited energy of sensors. So, an efficient routing protocol is needed for maximizing the lifetime of sensors. In this paper, we propose a protocol for measuring the fatigue of a soldier and also a routing protocol for maximizing the lifetime of sensors.

A. Placement of sensors

We place three sensors on the body of a soldier, each of which has a specific attribute to sense. Sensors that are placed on the body are:

→ Temperature sensor
→ Blood glucose level sensor
→ Heartbeat sensor
→ BS

1) Temperature sensor: This sensor is placed on the fingertip of soldier to measure the temperature.

2) Blood Glucose level sensor: The purpose of this sensor is to check glucose level in the blood of soldier. It is positioned on fingertip. As glucose level can only be checked by taking blood samples, so we assume that sensor takes the blood samples periodically and checks glucose level in the blood.

3) Heartbeat sensor: This sensor is placed on heart of soldier to measure heartbeat.

4) BS: BS is placed on the wrist of soldier. We assume that BS do not have battery problem and is enriched with energy. All the above three sensors (temperature, blood glucose level and heartbeat) send data to BS. Fig. 1 shows the placement of nodes on soldier.

![Fig. 1. Placement of nodes on soldier’s body](image)

B. Scenarios

Following are the scenarios for measuring the fatigue of soldier:

→ Soldier is walking
→ Soldier is running slowly
→ Soldier is running very fast

1) Walking: When soldier is walking, temperature of the body increases slowly. We assume that initially body temperature of soldier is normal. When soldier starts to walk, temperature sensor starts to sense the body temperature. Initially, transmitter of sensor does not transmit data to BS because the body temperature of soldier is slowly increasing and is not in danger. Sensor remains in sleep mode for a specific period of time. Whenever body temperature crosses threshold limit, transmitter sends data to BS.

Heartbeat sensor checks the heart rate of soldier. At the beginning, heartbeat of soldier is normal. When soldier starts to walk, heartbeat slowly increases. Sensor remains in sleep mode for normal heartbeat. Heartbeat sensor is triggered whenever palpitations cross a predefined threshold level.

Blood glucose level sensor measures glucose level in the blood of soldier. Blood glucose level of a person decreases while walking. We assume that sensor takes blood samples periodically and compare the sensed value with threshold that is predefined. If the sensed value decreases from the threshold then sensor sends data to BS which is an alarm that glucose level in blood of soldier is less.

During walk, temperature and heartbeat of soldier increases and glucose level in blood decreases with time. This means that energy of soldier is being consumed. Sensors sense the values and send it to the BS that is placed on wrist of the soldier. BS checks received data and also the current energy of soldier. If state of fatigue is achieved then BS sends data to
head quarter. For fatigue state we use Harris Benedict Formula. i.e.

\[ A = (13.75 \times \text{weight}(kg)) \]  
\[ B = (5.003 \times \text{height(cm)}) \]  
\[ C = (6.775 \times \text{age(years)}) \]  
\[ BMR = 66.5 + A + B - C \]

Basal Metabolic Rate (BMR) is the amount of energy required to maintain normal metabolic rate of the body. This is the energy required for the functioning of vital body parts like heart, lungs, kidneys, liver, nervous system and skin. We take this amount of energy as minimum energy of soldier and if a soldier’s condition meets this level then this is called as ‘state of fatigue’.

2) Slow Running: If soldier is running slowly then sensors sense heartbeat, temperature and glucose level in blood. However, in this scenario the heartbeat, temperature and glucose level reach the threshold earlier than walking.

3) Fast Running: In this scenario soldier is running at very high speed. So, in this case the fatigue state comes earlier than walking and slow running.

IV. RADIO MODEL FOR TRANSMISSION

Here we discuss how much energy of sensors is consumed during transmission. In this paper, we use the energy consumption model used in [15], and is summarized in the following equations.

\[ E_{tx} = E_{TXelec} \cdot k + E_{amp} \cdot (n) \cdot k \cdot d^n \]  
\[ E_{rx} = E_{RXelec} \cdot k \]

Where, \( E_{tx} \) is the transmission energy, \( E_{rx} \), \( E_{TXelec} \) denotes the energy dissipated by radio to run the circuitry for the transmitter, \( E_{RXelec} \) represents the energy dissipated by radio to run the circuitry of the receiver, \( E_{amp} \) is the energy for transmit amplifier, \( n \) is the path loss exponent.

Its value is 3.38 for line of sight communication and for non line of sight communication its value is 5.9. \( k \) shows the number of transmitted bits. Heartbeat sensor transmits 240 bits, while blood glucose level sensor and temperature sensor transmit 2400 bits data [15].

| TABLE I | RADIO MODEL PARAMETERS | Value |
|---------|------------------------|-------|
| Initial energy \( E_0 \) | 0.3 J |
| Transmitting and receiving energy \( E_{TXelec} \) | 16.7nJ/bit |
| Transmitting and receiving energy \( E_{RXelec} \) | 36.1nJ/bit |
| Amplification energy \( E_{amp} \) | 1.97nJ/bit/m^2 |

Fig. 2 shows the transmission of data from nodes to server. Firstly, nodes sense data then they transmit it to the BS on the wrist of soldier. BS then transmit received data to server through mobile station.

V. SIMULATION AND RESULTS

We use MATLAB [16] for simulation purpose. Radio model parameters used in simulations are shown in table 1. For simulations purpose, nodes are distributed as shown in Fig. 1. BS is placed on the wrist of soldier. All the three nodes send data to BS directly if threshold value is satisfied. We take 5 simulations to find average for each scenario and plot average results with 90% confidence interval. In simulations we assume that walking speed of soldier is 3.0 miles per hour, slow running scenario speed is 5.0 miles per hour and fast running the speed of soldier is 7.0 miles per hour. Our goals in conducting simulations are,

→ Measuring the fatigue of the soldier while walking, running slowly and running very fast.

→ Extension of node lifetime.

Fig. 3 shows graph of alive nodes verses rounds. Round means network operation time in which nodes send data to BS. We assume that duration of a round is one second. In Fig. 3, we can see that in walking scenario the lifetime of nodes is more than slow running and fast running scenarios. If soldier is walking, his/her activity is less and nodes do not send data more often. From activity we mean heartbeat, body temperature and glucose level of blood. Fig. 3 shows that sensor lifetime of walking scenario is more than slow running and fast running scenarios because, when a soldier is running the heartbeat and temperature increases and glucose level decreases quickly. So in fast running scenario, nodes send data to BS after very short interval of time which decreases the lifetime of nodes. Similarly in slow running scenario nodes send data to BS when nodes detect change in heartbeat, temperature and glucose level in blood which is comparatively less then fast running scenario. It results in better network lifetime for slow running scenario as compared with fast running scenario.
Because, throughput is related with the heartbeat of soldier and heartbeat has a direct relation with the body temperature. So, in first scenario when a soldier is walking, his/her heartbeat is normal and throughput is less. Now, when the soldier is running fast, his/her temperature raises because of increased heartbeat and number of packets sent to BS increases.

In measuring the fatigue of soldier we set a threshold by using the Harris Benedict Formula. The threshold 1500 (joules) is set in our simulations. Fig. 5 shows the fatigue of soldier. We see that when soldier is walking, his state of fatigue comes later compared with slow and fast running scenarios because the activity of soldier’s body is less and the energy is not consumed at faster rate. In fast running scenario the heartbeat and temperature increases at a faster rate which decreases the glucose level continuously. Therefore, soldier reaches his fatigue level much earlier.

Fig. 6 shows the remaining energy of nodes in the network. In network every node has 0.3 joules energy. So total energy of nodes in the network is 0.9 joules. In fast running scenario, the activities of soldier are much greater than the walking scenario, and sensors are busy in getting the data from soldier’s body and drain off their energy more quickly than the walking scenario. It can be seen that in slow running scenario the energy consumption is a bit less than fast running scenario.

Table 2 shows analytical comparison of the nodes in three scenarios. From table we can see lifetime of the nodes in walking scenario is more than the slow and fast running scenarios.

| Protocol       | First node dead (round) | Last node dead (round) | Throughput  |
|----------------|-------------------------|------------------------|-------------|
| Walking        | 8116                    | 17010                  | $2.22 \times 10^4$ |
| Slow running   | 7114                    | 8854                   | $2.27 \times 10^4$ |
| Fast running   | 7015                    | 8617                   | $2.28 \times 10^4$ |
In simulations, we assume total energy of soldier to be 2500 joules. Soldier reaches the state of fatigue when his/her energy lowers to 1500 joules. Table 3 shows the round in which soldier reaches to state of fatigue in all three scenarios.

| Protocol       | Fatigue (round) |
|----------------|-----------------|
| Walking        | 10182           |
| Slow running   | 6454            |
| Fast running   | 3811            |

### VI. Conclusion and Future Work

Energy saving of sensor node is a challenging task for researchers nowadays. In this paper, we proposed an event driven routing protocol for WBASNs. Specifically, Three sensors are attached with soldier’s body to monitor his/her heartbeat, body temperature and glucose level in blood. An additional measure is fatigue of the soldier. Our proposed protocol takes three scenarios for measuring the fatigue of soldier i.e. (1) walking, (2) slow running and (3) fast running. Results show that our protocol performs better in terms of network lifetime and throughput.

As a part of our ongoing research, we are working on implementing our proposed protocol for more than one soldier. In future, we are interested to work on MAC layer energy efficient protocol like [17], [18], [19], [20], [21], etc.

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