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Modeling mobility and psychological stress based human postural changes in wireless body area networks

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ABSTRACT

Mobility models play a vital role on the performance accuracy of simulations in Wireless Body Area Networks (WBANs). In this article, we propose a mobility model for the movement of nodes according to the posture patterns formed either because of psychological stress or any kind of mobility. During routine activities, body exhibits different postures like, standing, sitting, laying, etc. We form a mathematical model for the movement of nodes according to the posture pattern. In walking and running postures, the nodes placed on the limbs move in a defined trajectory repeatedly. In these postures, the nodes placed on trunk of the body are minimally mobile. On the other hand, in sitting and laying positions, the movement of limbs is nondeterministic. However, we can locate an area in which the node's presence is most probable. Postures change from one state to another depending upon probabilities. During movement, the distance between nodes and sink is changed. As energy consumption, delay, and path loss depend on distance, so they also change due to mobility. We implement the proposed mobility model in multi-hop and forwarder based routing techniques. In multi-hop routing technique, nodes send data to the sink using neighboring nodes. Whereas, in forwarders based scheme, two forwarders are selected in each round to transmit, alongwith their own data, the received data of neighboring nodes. Simulation results show that forwarder based routing schemes has increased stability period, network lifetime and throughput.

1. Introduction

Wireless Body Area Network (WBAN) consists of nodes attached on or implanted in the human body to monitor different vital signs like heart rate, glucose level, blood oxygen level, etc. These miniaturized and intelligent nodes monitor different physiological parameters and send the sensed attributes to the sink (gateway node) which may be placed on-body or off-body. (Hereinafter we use the term sensor, node and sensor node interchangeably.) The sink aggregates the received real-time data and routes it to the personal devices (such as, smart phone, laptop, etc.) which further send it to the medical center for inspection and diagnosis. WBAN offers economical and reliable solution to the increasing cost of healthcare. There are different advantages introduced by WBANs which include flexibility, effectiveness and cost-effectiveness. Flexibility allows the sensors to transmit the data to nearby devices such as laptop, PDA, etc. It is easy to process the received signals from nodes to obtain reliable and accurate physiological estimation. Furthermore, with the increase in demand, more sensors are being produced at relatively low costs, especially in gaming and medical environments.

As WBAN consists of tiny sensor nodes, they have limited energy resource. It is necessary to utilize the nodes' energy efficiently for long term health monitoring. Routing protocols having increased stability period and network lifetime perform health monitoring for extended period of time. There are different challenges in the design of WBANs including limited energy, interoperability, privacy, interference, constrained deployment, constant monitoring and cost. Limited energy of nodes in WBAN urges the researchers to develop energy efficient and cost effective techniques for reliable health monitoring. There are different routing protocols developed

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for energy efficient data transmission. Tsouri, Prieto, and Argade (2012) propose global routing protocol for balanced energy consumption in WBANs. They give a link cost function which is used to route data from nodes to sink. A link having minimum link cost is selected to route the data. The proposed protocol increases network lifetime due to balanced energy consumption of nodes. Different techniques at MAC layer have also been developed for reliable and collision-free data transfer in WBANs. A hybrid MAC protocol; PMAC for WBANs is described in Ullah, Imran, and Alnuem (2014). In PMAC, there are two contention access periods for handling the emergency data. The sensed data of critical patients need immediate attention. PMAC has also a contention free period to transmit the large amount of data packets. The applications of WBANs include the monitoring of armed personnels, patients, athletes, elderly people and newly born babies.

Mobility models play a vital role on the accuracy of simulations for WBANs. Several mobility models are proposed in literature for ad hoc and sensor networks. However, they are not suitable for WBANs due to their different movement pattern. In general, the movement of nodes can be classified into two categories as single and group mobility. In the former case, there is no correlation between the movement of different nodes. In this scenario, nodes move regardless the mobility pattern of other nodes in the network. In the latter approach, however, nodes move in a group having a particular relationship between them. In this case, nodes move relative to a reference which decides the movement pattern of other nodes.

In WBANs, the movement of nodes is correlated with the sink. As the sink is also placed on the human body (normally on chest), therefore, the positions of nodes can be determined relative to it. Let us consider an example that a human is walking with nodes placed on his/her body and sink is on chest. During walking, the arms and legs move in forward and backward directions repeatedly. Therefore, the nodes placed on limbs of the body also move in forward and backward directions and we locate their positions. As trunk is minimally mobile, so nodes placed on trunk of body show little variation in their position relative to sink. On the other hand, in laying position, it is difficult to predict the next position of nodes accurately. However, we can locate an area in which the node's presence is most probable. Similarly, we can visualize the movement of nodes placed on human body in different postures.

In this research work, we present a mobility model for the movement of human body in WBANs. During routine activities, body exhibits different postures such as sitting, laying, walking, etc. We model these postures and discuss their movement pattern in detail. There is different transition probability from one posture to another. Furthermore, we present two newly developed routing protocols for WBANs. In multi-hop routing technique, nodes use intermediate nodes to send data to the sink. On the other hand, in forwarders based routing scheme, two forwarders are selected in each round to transmit data to the sink. We implement the proposed mobility model in these routing protocols and find that multi-hop routing scheme has lower network lifetime than forwarders based routing technique.

Rest of the paper is ordered as follows: section II states the related work and section III contains the proposed mobility model. The impact of mobility in WBANs is discussed in section IV while section V gives the energy consumption analysis. In sections VI and VII, multi-hop and forwarders based routing protocols are presented, respectively. The detailed analysis of simulation results is provided in section VIII and finally section IX gives the conclusion.

2. Related work

Authors in Hamid, Alam, Islam, Hong, and Lee (2010) present a scheme for fair data collection in WSNs. Nodes in WSN collect data and route it to sink which may be located at a longer distance. The nodes near the sink consume more energy as they receive and forward the data of nodes located farther away. Authors in this paper, develop a tree-based scheme and calculate delay, throughput and energy consumption. They observed that non-uniform energy distribution can maximize the network lifetime in WSNs. In Monowar, Alam, Rahman, Hong, and Lee (2010), authors develop LET-MAC; an energy-efficient and throughput maximized MAC protocol. It increases throughput by maximizing the channel utilization. LET-MAC reduces energy consumption during low traffic and minimizes delay during high traffic.

Xu, Fang, Zhu, and Cui (2013) use differential evolution for maximizing the network lifetime in WSNs. They employ a common method to generate test data set and present a scheme to solve disjoint set covers problems. Point-coverage application is used to evaluate the efficiency of the proposed algorithm. In Luo, Yu, and Wang (2012), authors study the effect of nodes' energy distribution on network performance in WSNs. They observe that when nodes are more heterogeneous, the network enjoys improved performance in terms of network lifetime and average path length for data transmission. Furthermore, the network uses clustering approach effectively in heterogeneous environment.

Authors in Havedanloo and Karimi (2013) present a performance metric evaluation for WSNs. In this scheme, sensors are distributed into clusters uniformly and non-uniformly. The network is provided with multiple fusion centers which are used for decision making. The presented scheme improves the reliability, average delay, energy consumption and throughput. Different characteristics of bridge health monitoring using WSNs are discussed in Zhou and Yi (2013). Authors also discuss network topology, power management, and time-synchronization in WSNs based systems. They find that important challenges in health monitoring systems are design criterion, data management, optimal sensor placement, etc.

In Zhao, Weng, Lu, and Liu (2014), authors present a collection tree based dynamic routing scheme in WSNs. The proposed scheme is evaluated in three aspects: time for generating the topology, link quality, and stability of the network. It offers increased reliability and robustness of WSNs. When some nodes in WSNs are failed (or go out of range), the problems of coverage and connectivity are raised. After the failure of intermediate nodes, the neighboring nodes may not be connected with the rest of the network. This connectivity problem generates the coverage issue as the monitored parameters cannot be delivered to the destination. Khan, Hasbullah, Nazir, and Khan (2014) address these coverage and connectivity issues in WSNs. In their proposed algorithm, when a node is failed, the neighboring nodes move to its location, one by one, for certain time period. After specific time span, these moving nodes come back to their original positions. It results in better coverage and connectivity in WSNs.

A distributed optimal power and rate control technique for WSNs is discussed in Tang, Bai, Li, and Xin (2014). In order to reduce the energy consumption of nodes, the transmission power is adjusted before data transmission. Authors use dual decomposition technique to divide the network utility maximization problem into two subproblems. Conjugate gradient method is used to solve the optimization problem. Results show that this scheme significantly improves the network throughput. Authors in Han, Jiang, Qian, Rodrigues, and Cheng (2014) compare different routing protocols of heterogeneous WSNs. They find that cluster-based routing protocols reduce energy consumption of nodes and enhance network performance. Furthermore, hierarchical clustering prolongs network lifetime by saving the energy of nodes located farther away from sink.

A priority-guaranteed MAC protocol for WBANs is presented in Zhang and Dolmans (2011). In this protocol, control and data channels are separated for collision-free routing. Priority-specific