Poster: Behavior-Aware Probabilistic Routing For Wireless Body Area Sensor Networks

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***Abstract*—Wireless Body Area Networks (WBANs) can provide continuous and remote monitoring of patients' physiological history, facilitate automatic sports training, and promote interactive games. However, existing single-hop wireless communication scheme faces two major challenges: the impermeability of human body to radio waves at frequencies commonly used in WBANs, and the highly dynamic network topology resulted from human movements. In this paper, (i) a prototype of multi-hop WBAN is built to characterize the network connectivity during human movements, (ii) a probabilistic routing algorithm is proposed, and (iii) the evaluation on our prototype system shows that the proposed scheme outperforms existing routings in terms of average delivery ratio, number of hops, and end-to-end delay.**

I. Introduction

Wearable sensors are deployed on/in human bodies to monitor human's physiological signals or to detect human's movements. The collected information is communicated back to a gateway device (connects to the Internet), which identifies the situations and may trigger some necessary responses (i.e., calling for an ambulance). These sensors and the gateway are networked together through the wireless channel to form a *Wireless Body Area Network* (WBAN). This supporting technique can help in patient diagnostics, sport-training, and interactive games [1], [2].

The major challenge of WBAN is to ensure that the communications between sensors and the gateway are reliable. Besides the usual obstacles in wireless communication, it needs to contend with the high attenuation through the human body at frequencies commonly used for WBANs (433 MHz, 2.4GHz, etc.). Furthermore, the movements of human body lead to highly dynamic network topology, which will affect wireless communication significantly. The experiments in [1] show that human movements give rise to frequent network partitioning, which confirms that single-hop WBAN [3], [4] fails to provide prompt and reliable connections. In addition, higher power RF means more energy consumption and makes battery generate more heat, which may hurt skin. Therefore, multi-hop routing [5], [6] is necessary to cover the entire body.

Motivation: We develop a prototype of multi-hop WBAN with on-body motion sensors, as shown in Fig. I. We connect a Razor Inertial Measurement Unit (IMU) sensor [7] to IRIS mote with extra power supply. Sensor nodes communicate using IEEE 802.15.4 and record the inertial data. The frequency of link measurement is set to 10Hz. We characterize the time-varying network topology by asking the tester to wear these sensors and walk or run in a corridor. The direct link states are recorded on-the-fly, while multi-hop route states are processed off-line. We discover that the number of multi-hop paths is about three times more than the number of single-hop links as shown in Fig. I. This observation necessitates the design of multi-hop routing schemes in WBANs.

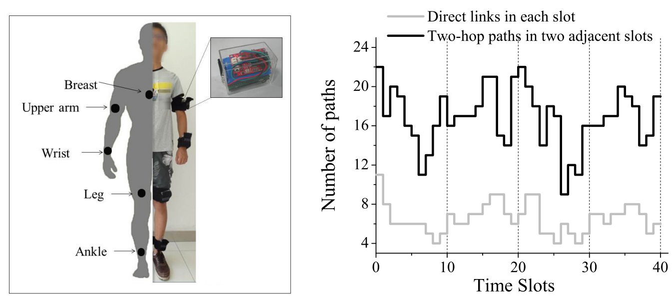


Fig. 1. Left: our prototype of multi-hop Wireless Body Area Network. Right: the number of links in each slot and that of two-hop paths in adjacent slots during walking.

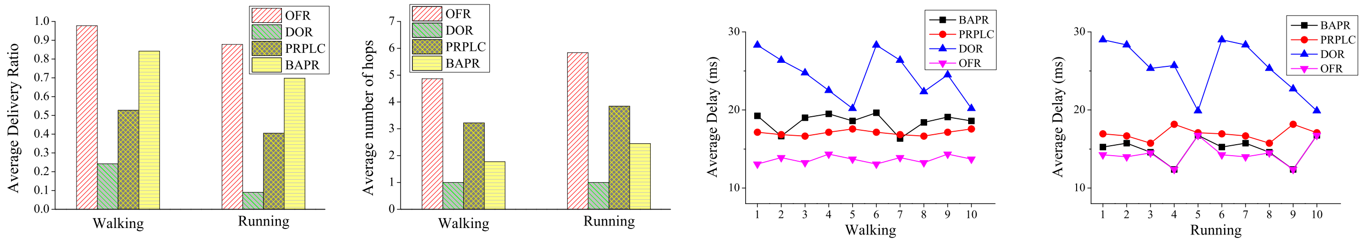
Contribution: Motivated by this observation, we propose a behavior-aware probabilistic routing, exploiting instantaneous inertial information detected by accelerometer sensors. Then, we evaluate the proposed scheme on our prototype system. The experiment results show that our scheme outperforms conventional WBAN routing protocols in terms of average delivery ratio, the number of hops, and end-to-end delay.

II. Routing in WBANs

We present three existing routing protocols in WBANs, followed by our scheme BAPR, which incorporates low-cost inertial motion information into the routing decision.

A. Existing Routings

On-body Flooding Routing (OFR): a node forwards the packet to all its neighbors. The time when the first arrived copy at the destination node indicates the minimum end-to-end delay. It ensures high delivery ratio but is not energy-efficient.
DTN Opportunistic Routing (DOR): a node delivers packet to other nodes through direct links, otherwise the packet will be stored in the buffer and wait until the link is available. There may be large delay for the nodes far away from the gateway. It is energy-efficient and simple to implement.



(a) (b) (c) (d)

Fig. 2. Experiment results of average delivery ratio, number of hops, and end-to-end delay for both walking and running scenarios.

Probabilistic Routing with Postural Link Cost (PRPLC) [6]: defines a Link Likelihood Factor (LLF) $P_{i,j}^t$, indicating the probability for link $L_{i,j}$ to be available during time slot t.

$$\begin{array}{ll} P_{i,j}^t = P_{i,j}^{t-1} + (1 - P_{i,j}^{t-1}) \cdot \omega_{i,j}^t & \text{if } L_{i,j} \text{ is connected} \\ P_{i,j}^t = P_{i,j}^{t-1} \cdot \omega_{i,j}^t & \text{if } L_{i,j} \text{ is disconnected} \end{array} \tag{1}$$

where $\omega_{i,j}^t$ is a tuning factor over a time window T_{window}.

B. Behavior-Aware Probabilistic Routing (BAPR)

The PRPLC proposed in [6] fails to take into account the current trends of the postural movement. Inertial sensors can provide acceleration and orientation information, and they can help to detect a breaking point of human behavior for burst changes on the link state.

First, we quantify the dynamic degree of a node's local topology, using the normalized entropy:

$$\bar{E}_i = \frac{E_i}{|N(i)| \cdot e^{-1}}, \quad E_i = \sum_{i,j \in N(i)} -p(i,j) \log p(i,j) \tag{2}$$

where $p(i,j)$ is the probability that a direct link is found between i and j, $N(i)$ denotes the set of node i's neighbors and $|N(i)| * e^{-1}$ is the maximum entropy.

To model the effect of postural movement, we define:

$$PM_{i,j}^t = \hat{Acc}_i^t \cdot \hat{V}_{i,j}^t \tag{3}$$

where $\hat{Acc}_i^t$ is the average inertial values collected by acceleration sensors, and $\hat{V}_{i,j}^t$ is the orientation vector.

Then, we define the connection probability based on the probability of PRPLC in Equ.(1) as follows:

$$CP_{i,j}^t = P_{i,j}^t \cdot (1 - \bar{E}) + PM_{i,j}^t \cdot \bar{E} \tag{4}$$

In the routing process, sensor node i computes $CP_{i,j}^t$ for $j \in N(i)$. Then, it chooses the node with the highest connection probability as the next hop.

III. Evaluation

We compare the performance of the routing protocols under both walking and running scenarios. The frequency of packet transmission of source nodes is set to be 10 packets/second.

Average delivery ratio is the average ratio of successfully received packets over the total generated packets. In Fig. 2(a), our scheme BAPR achieves much higher delivery ratio than PRPLC and is comparable with OFR. This improvement is benefited by the extra inertial information. However, the delivery ratio experiences some decreases for the running case.

Average number of hops: DOR uses direct link to transmit packets back to the gateway, thus needs on average one hop (Fig. 2(b)). But it suffers bad delivery ratio. For OFR, the packets are forwarded back and forth among the nodes. And thus, they form long paths towards the gateway. Because of the movement of human body, the link quality is bad. Our scheme and PRPLC need a small number of hops, since they both estimate the link connection before transmission. With the inertial information and the orientation information, our scheme can estimate the link connection more accurately.

Average end-to-end delay is the average duration for the first received packet from the source node to the destination node. In the running case (Fig. 2(d)), our scheme experiences comparable end-to-end delay with PRPLC, but is higher for the walking case (Fig. 2(c)). The reason is that we calculate the end-to-end delay only for the successfully received packets. Most packets are dropped by PRPLC due to the bad link quality which was bound to increase the end-to-end delay. Comparing the walking and running cases, we can see that our scheme possesses obviously strength for dynamic topology.

Acknowledgements

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