Journal of Engineering Science and Technology
Vol. 13, No. 11 (2018) 3516 - 3531


# DATA DELIVERY MECHANISM IN WBAN CONSIDERING NETWORK PARTITIONING DUE TO POSTURAL MOBILITY

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## Abstract

Wireless Body Area Network (WBAN) represents one of the most promising approaches for improving the quality of life, which allows continuous remote patient monitoring especially in case of patients suffering from age-related chronic diseases such as heart disease. WBANs allow miniaturized, low power, intelligent and invasive/non-invasive sensor nodes to be placed strategically in or on the human body for constantly monitoring the body functions. Ultrashort wireless range and postural mobility lead to a frequent change in the topology resulting in the network partitioning. To deal with this situation, we propose a mechanism for reliable data delivery to the coordinator in the proposed scheme. To achieve this, each sensor node maintains two paths, i.e., a primary path and secondary path. The primary path uses an RF link to transmit the normal data whereas the secondary path uses BCC link and is used in case of emergency data or in case of failure of the primary path. The sensor node switches to the secondary path to inform the coordinator about the failure and to re-configure the network. Simulation results show that the performance of the proposed scheme is better in terms of the convergence period and network lifetime. The proposed scheme also reduces delays in data transmission and energy consumption.

Keywords: BCC technology, Multipath routing, PDA, RF Technology, Wireless body area network (WBAN).

## 1. Introduction

Unlike Bluetooth (IEEE 802.15.1), which is designed for applications with high Quality-of-Service (QoS) requirements [1], WBANs are designed for applications with low data-rate and low-latency requirements. Usually, WBANs employ Radio Frequency (RF) technologies for their communication, which operate in the Industrial, Scientific and Medical (ISM) radio band. Regardless of the specific wireless communication technology, when too many sensor nodes are deployed on a human body, a WBAN in a star topology is usually created so that all the on-body sensor nodes communicate with a gateway for forwarding the collected data. Although RF is the only practical mechanism to forward data in this scenario, several significant problems remained. RF signals suffer considerably from body shadowing in a highly variable way with respect to the human body [2-4]. This makes communication between on-body sensor nodes and off-body sensor nodes very unreliable. This inherent unreliability of RF communication around the human body is a critical problem for several real-life applications.

Routing issues in WBAN in the presence of network partitioning due to the short transmission range and postural mobility is explored in this article. For embedded applications, RF transceivers designed with limited energy cause short transmission range and low power to these transceivers. Based on a study by Mikami et al. [5], to combat this scarcity, these transceivers are often supplied harvested energy from the human body. Some of the low transmission range transceivers are given in Table 1. These transceivers can be charged with energy generated by common energy harvesting techniques such as piezoelectric generation from body movements.

**Table 1. Low power and short-range RF transceivers.**

| Ref. | Tx range (meter) | Tx power consumption (mW) | Rx power consumption (mW) |
|---|---|---|---|
| **[4]** | 0.2 - 1 | 1.5 - 3.5 | ~2.5 |
| **[5]** | 0 - 1 | 2 | 2 |
| **[6]** | 0.2 | 0.75 - 3.75 | 0.75 - 3.75 |
| **[7]** | 0 - 1 | 6 | 5.1 |

Postural mobility and short RF transmission range cause frequent network partitioning in WBAN, which results in a Delay Tolerant Network (DTN) [6-10]. Unpredictable RF attenuation due to blockage of the signal by clothing material or body parts aggravates network partitioning. Network partitioning necessitates the design and development of routing protocols with performance goals of low: (i) end-to-end delay, (ii) packet loss and (iii) transmission energy consumption.

To avoid communication failure in WBAN due to postural mobility, all sensor nodes in our architecture are equipped with both Radio Frequency (RF) and Body Coupled Communication (BCC) transceivers. When the RF link is failed, sensor nodes use the BCC link to forward their data to PDA through the human body. The BCC link is also used for emergency data as it is extremely power-efficient and takes less time compared to RF link. According to Fazzi et al. [11], the BCC transceiver uses baseband communication and has a small form factor. The WBAN sensor node with two transceivers in the proposed mechanism is an economically and technically feasible option for real-life applications. The remainder of this paper is organized as follows. In Section 2, the related work is presented. The details of the system model are presented in Section 3. Section 4 presents simulation results and performance analysis of the proposed scheme. Finally, the work is concluded in Section 5.

## 2. Related work

Recently too many schemes/protocols for WBANs are presented in the literature [12-15], which used on-body sensor node communication. Some of these works mainly focus on issues related to on-body MAC layer. As explained by Otto et al. [12], the system architecture is presented, which collects data from on-body sensor nodes and delivers it to the sink in a collision-free manner. A sink is designated to transmit beacons periodically to synchronize transmission slots. A scheme is presented by Jovanov et al. [13], which uses IEEE 802.15.4/ZigBee based MAC for on-body adaptation.

As stated by Braem et al. [14] and Latre et al. [15], in the presence of specific routing, MAC-routing cross-layer issues are investigated via distributed transmission coordination. An energy-efficient slotted MAC is presented by Braem et al. [14], which uses cross-layer techniques to achieve efficient distributed coordination of the separated wireless links for on-body packet routing. A protocol is designed by Latre et al. [15] for reducing delay in packet delivery over an on-body spanning tree, which uses similar tree-based cross-layer approach. To support patient mobility, protocol reconstructs and maintains spanning tree used for routing the packet in the network.

Jones and Ward [6] categorized the existing work on routing in disconnected networks as: (i) replication based [7], (ii) knowledge-based [8] and (iii) hybrid of the above two [9]. In a replication-based approach, several copies of a packet are disseminated to increase the chance to deliver a packet to destination whereas, in knowledge-based strategies, information about connectivity dynamics is used to make forwarding decisions efficient. The replication and knowledge-based strategies are combined in a hybrid approach. In all these approaches, the main principle is as follows: when any sensor node is encountered during the process of packet forwarding by a sensor node, the node in the process determines if the packet should be transferred to that node or it should be buffered. The rule to forward a packet is based on the estimate whether the encountered sensor node is more likely than the forwarding node to visit the destination. The sensor nodes need to have a certain degree of spatial and temporal locality in their mobility for the above scheme to work [16]. To capture spatiotemporal locality present in the sensor node mobility pattern within a dynamically partitioned wireless network, PROPHET [10] develops a probabilistic framework. Based on studies by Leguay et al. [9], a high-dimensional Euclidean space called MobySpace is defined, which are constructed upon sensor nodes' mobility patterns. Based on the locality of movements specific MobySpace is evaluated.

Abbasi et al. [17] proposed a Least Movement Topology Restoration (LeMoToR) approach to restoring network partitioning. It is based on a localized and distributed scheme in which, the least number of node movements and least message complexity of the network is used. To find the topology structure of the network, existing path discovery activities are exploited. To maintain intra-smallest block connectivity, local view of each node is done recursively during a recovery process. The main drawbacks of LeMoToR: (i) large amount of energy consumed by each node due to large computation overhead, (ii) the scheme is not suitable for time-critical applications because a lot of calculations are done even for the smallest block at the time of recovery, (iii) a large communication overhead occurs for path discovery activities during recovery from network portioning.

Alfadhly et al. [18] described a distributed scheme called Least Distance Movement Recovery (LDMR) approach in which, recovery from network partitioning is done by moving direct neighbours of the failed node towards this failed node and replacing it with its nearest non cut-vertices. The main limitations of LDMR: (i) consumption of a large amount of energy by each node to search the non-vertex node at the time of recovery, (ii) congestion occurs in the network due to flooding of the messages by each node to search the non-vertex node.

Akkaya et al. [19] described efficient reactive distributed approaches (RBA-DARA, RBA-PADRA) to repair failures in WSNs. Network partitioning is repaired by using formerly maintained routing information. The recovery nodes are selected based on their minimum distance either from the failed nodes or sink. The main drawbacks of these approaches: (i) stability conditions of the nodes are not considered while node connectivity issues during recovery process, (ii) approaches are not applicable to many partitions in the network, (iii) network lifetime decreases if low energy nodes are to be chosen for recovery.

As stated by Wang et al. [20], PA-DPLM protocol tackles the shadow effect, which may arise during human walking, by using posture aware approach. An energy-efficient MAC protocol is specifically designed for maximization of network lifetime. Argyriou et al. [21] explained that the new hybrid WBAN architecture is designed in two communication technologies to avoid communication failure due to body shadowing. All sensor nodes are equipped with both Radio Frequency (RF) and Body Coupled Communication (BCC) transceivers. When the RF link is a failed sensor, nodes use the BCC link to forward their data to the node that has an active RF connection. Sabti and Thiel [22], proposed a protocol to determine the best transmitter locations around the human body to achieve maximum link connectivity to the gateway located on the chest and in order to achieve good wireless communications between the nodes during human running. Sabti and Thiel [23] designed a novel energy-efficient human gesture transmission method based on time multiplexing for on-body wireless communication. The technique uses the sensed acceleration data to determine high-reliability locations to avoid energy cost for multiple transmissions and prolongs the network lifetime.

Younis et al. [24] provided a thorough analysis and comparison of network topology management techniques to tackle node failures in WSNs. The existing techniques have been classified into two broad categories based on reactive and proactive methods. Ranga et al. [25] reviewed the present network partitioning recovery techniques and provided an overall view by summarizing previous achievements. According to Ranga et al. [26], network partitioning is handled by using a localized hybrid timer based on cut-vertex node failure recovery approach called distributed prioritized connectivity restoration algorithm (DPCRA). Joshi and Younis [27] proposed a straight skeleton based distributed approach (SSBR) for reconnecting a WSN partitioned into disjoint segments. In the proposed scheme, network area is decomposed into a two-dimensional set of paths that can be used for recovery by deploying mobile nodes. Wang and Wu [28] introduced an in-advance mechanism to avoid network partitioning in the initial deployment phase. The approach is scalable to large networks as every node needs to know local information of its 1-hop neighbours only.

The proposals discussed above are applied to networks spanning across local to wide areas [29]. The main objective of our work is to develop a mechanism, which should be energy efficient to prolong network life, delay sensitive and support network partitioning due to postural mobility.

## 3. Proposed Scheme

This article proposes a heterogeneous WBAN architecture comprising two technologies, i.e., BCC and RF, and two different types of devices, i.e., sensor node and PDA. The scheme is developed keeping in mind the postural mobility and its suitability for remote patient monitoring especially in case of patients suffering from age-related chronic diseases such as heart disease, which requires continuous monitoring rather than sporadic assessments.

### 3.1. System model

The proposed scheme uses the TDMA approach. The predefined and dedicated time slots in TDMA provide a collision-free environment for data communication. In the proposed WBAN architecture, PDA and sensor nodes are strategically placed at predefined locations. We have assumed that the communication channel is error-free and sensor nodes are supposed to transmit their data only in the stable state, which may be in any posture. Sensor nodes are homogeneous in nature and perform the role of sensing of physiological signals as well as relaying the received data from other sensor nodes. The BCC technology is used only in case of emergency or in case of RF link failure due to postural mobility as it affects human tissues.

The cost overhead due to the inclusion of the secondary path is negligible as it uses BCC, which can be realized with two electrode transmitter/receiver devices capacitive coupled to the human body. A variable electric field is generated by the transmitter, and the variable potential of the body with respect to the environment is sensed by the receiver. A signal attenuation measured between these devices placed at various positions on the human body is less than 70 dB [11]. The human body channel is especially affected by interference below 1 MHz while for higher frequencies the interference level is below -75 dBm.

### 3.2. System model operation

The entire working of the proposed system is divided into the following three phases.

#### 3.2.1. Network configuration

The locations for deployment of sensor nodes and PDA are identified by the doctor or medical practitioner and sensor nodes are manually deployed at identified locations. But before their deployment, sensor nodes are first registered at PDA. Furthermore, TDMA slots for various sensor nodes and TDMA frame (containing TDMA slots for various sensor nodes) are computed using equations (i) and equation (ii) respectively. Thereafter, the sensor nodes are strategically placed at pre-defined locations. Their distance from each other and PDA is calculated, and a weighted graph is constructed. From the weighted graph, the efficient primary path, which remains fixed throughout the network lifetime is computed for all sensor nodes by applying any shortest path algorithm and is fed into their memory. Once sensor nodes get registered at the PDA and primary path is fed into their memory, they are placed at their specified locations. Now PDA constructs Beacon packet containing its own id and TDMA frame as shown in Fig. 1 and broadcast it in the network. The sensor nodes in the network receive Beacon packet and get themselves synchronized with PDA. Finally, the network enters the communication phase.

$$T_{s(i)} = \frac{N_i}{f_{c1}} + \frac{N_{oh}}{f_{c1}} + \frac{N_{ack}}{f_{c1}} + T_g \quad (1)$$

$$T_{frame} = \sum_{i=1}^{n} T_{s(i)} \quad (2)$$

| | | |
|---|---|---|
| Beacon Packet | PDA Id | TDMA Frame |

**Fig. 1. PDA broadcast Beacon Packet in the network to synchronize nodes.**

### 3.2.2. Communication phase

In standing and straight lying positions, there is no obstacle due to body segment. So, sensor nodes use RF link to send their sensed data through the specified primary path to PDA in multi-hop. They send data in the slot allocated to them in the TDMA frame using algorithm 1.

**Algorithm 1. To deliver data to PDA.**

1. If acts as a relay.
2. Deliver the received packet to successor on the path.
3. Else:
   i. Wait for its own slot.
   ii. End data to PDA through the specified path.
   iii. Start a timer & waits for ACK.
4. If ACK received within allocated slot remove the corresponding pkt from buffer else //RF link is fail.
   i. Turn on BCC transceiver.
   ii. Send warning packet to PDA using BCC link.
   iii. Go to sleep mode and wait for response from PDA.

### 3.2.3. Network partitioning

In other postures, RF link may fail due to the shadowing effect, which results in network partitioning. It can be detected by not receiving the ACK within the slot allocated to the transmitting sensor node. To deal with RF link failure, sensor node constructs a warning packet containing its own id and warning message as shown in Fig. 2. This warning packet is sent to the PDA using BCC link because the PDA may not be in the communication range of the sensor node. Thereafter, the network enters the reconfiguration mode. As the warning packet contains the id of PDA; other sensor nodes in the network simply ignore the packet and only PDA responds.

A relay sensor node in the network does not wait for its own slot and immediately delivers the received data from its predecessor to the successor on the path. The process is continued and finally, the data is delivered to the PDA. The sensor node can transmit a single packet during its allocated slot. The detailed structure of the TDMA frame is shown in Fig. 3.

| | | |
|---|---|---|
| Warning Packet | PDA Id | Warning message |

**Fig. 2. Packet delivered to PDA by node to inform about RF link failure.**

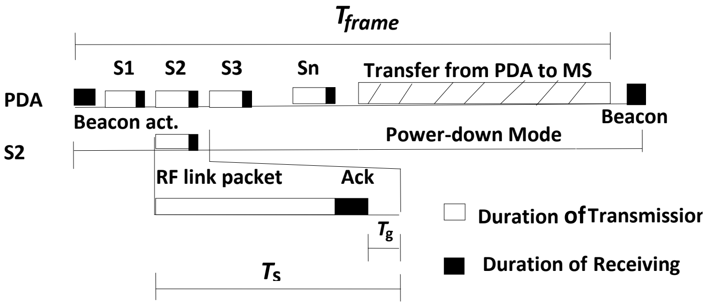


**Fig. 3. Structure of TDMA frame of the proposed scheme.**

Each $T_{frame}$ consists of Beacon (containing information about the time slots allocated to various sensor nodes in the network) followed by actual slots allocated to various sensor nodes S1, S2,......, Sn. Each slot consists of a transmission period and a receiving period. In the transmission period, sensor nodes send their sensed data to PDA and in receiving period sensor nodes wait for ACK from PDA. Sensor nodes are in active mode only in the slot allocated to them and rest of the time they remain in power down mode to save their battery energy to prolong the network life. Two consecutive slots are separated by a time gap of duration $T_g$. The duration of $T_g$ should be enough to change the mode of transmitter of current sensor node from on to off ($T_{on-off}$) and the transmitter of the next sensor node in turn from off to on ($T_{off-on}$ ) plus time taken by sensor nodes to inform the PDA about the status in case of communication failure due to shadowing effect and to get the response back from PDA. In response, PDA informs all sensor nodes to temporarily suspend their transmission till further notification. At the end of each $T_{frame}$, a fixed duration period is also reserved in which, PDA aggregates the data received from various sensor nodes and delivers it to the Monitoring Station (MS) where appropriate action is taken.

### 3.2.4. Effect of network partitioning

The network partitioning causes failure of data delivery to the PDA and causes a delay as well. In case of the normal data, it is not a big issue but for emergency data, it is not tolerable because it may be life-threatening. To avoid such delay due to partitioning, the concept of a secondary path is introduced, which is always available. Once the network partitioning is detected, the network must be re-configured, which needs several packets to be exchanged in the network. This exchange of packets consumes a lot of energy and affects average delay in data delivery apart from network life.

### 3.2.5. Network re-configuration

On receiving the warning message from a sensor node in communication phase, PDA constructs an Alarm packet containing its own id and alarm message and broadcast it in the network using BCC link (as the sensor node may be hidden from PDA due to shadowing effect). On receiving the alarm packet from PDA, the network enters reconfiguration using algorithm 2. Each sensor node in the network suspends its transmission temporarily. To get the information about the sensor nodes within its communication range each sensor node broadcast hello packet containing its own id and hello message using RF link and waits for the response. On getting the response, each sensor node measures the RSSI value of the received signal from various sensor nodes. From this value, the sensor node computes its distance using Eq. (3) [30] and maintains a list containing its id and distance of those sensor nodes for which, RSSI value is greater than or equal to some threshold value $\delta$ (the packet with RSSI value $\delta$ is ignored as being noise signal) as shown in Fig. 4.

$$d = 10^{\lfloor (P_0 - F_m - P_r - 10 \times n \times log_{10}(f) + 30 \times n - 32.44) \div 10 \times n \rfloor} \quad (3)$$

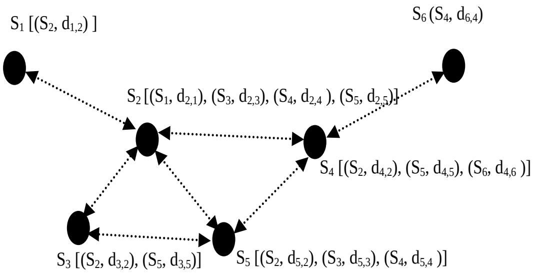


**Fig. 4. Neighbour list containing their ID and distance.**

Now each sensor node constructs route request packet containing its own id and list of neighbours' ids along with their distance from itself and sends it to PDA using BCC link through the primary path. Various packets exchanged between sensor nodes and PDA to re-configure the network are shown in Fig. 5.

PDA stores the route request packet received from the sensor nodes at its own end and constructs a weighted graph as shown in Fig. 6. It further constructs a route reply packet containing its own id, sensor nodes' id and the path to PDA for each sensor node. PDA broadcasts this packet in the network using the BCC link and computes the efficient alternate path for each sensor node.

Each sensor node in the network receives the route reply packet and extracts its own path to PDA. It stores this information into its own memory and uses it for future communication. The PDA also reconstructs the beacon packet with updated information and broadcasts it in the network. Sensor nodes in the network receive Beacon packet, get synchronized themselves and the network again enters the communication phase. Each sensor node in the network uses this path for future communication to PDA till posture remains same. The entire re-configuration process is repeated if the posture is changed.

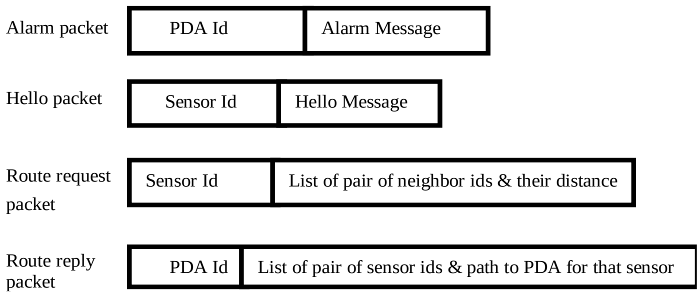


**Fig. 5. Packets exchanged between sensor nodes and PDA during network re-configuration.**

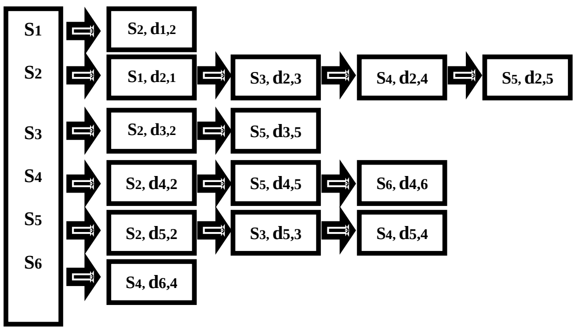


**Fig. 6. Neighbourhood graph reconstructed at PDA after RF link failure.**

**Algorithm 2. To re-configure the network.**

// on receiving alarm message from PDA:

1. Sensor nodes broadcast hello packet and wait for reply from neighbours.
2. For I =1 to n-1 // each sensor maintains neighbourhood list if RSSI value of the received signal >= δ.
   i. Compute d using Eq. (3) // distance of replying sensor node.
   ii. Neighbour_list[i].id = responder_id.
   iii. Neighbour_list[i].dist=d.
3. Construct Route_Request_packet.
4. Send it to PDA and wait for Route_Reply_packet // on receiving Route_Reply_packet from PDA.
5. For I = 1 to n:
   i. If $Id_i$ = path_list[i].id.
   ii. Extract path and store in its memory.
6. If sensor nodes received beacon packet synchronize themselves and wait for their turn.

## 4. Simulation and Performance Analysis

The system model presented in Section 3 is simulated using Matlab simulation platform. The average delay, packet delivery ratio, average energy consumption and network lifetime are the metrics used for performance analysis. Table 2 shows the simulation parameters used in simulation [31, 32].

**Table 2. Simulation parameters.**

| Parameter | Value |
|---|---|
| $P_{Tx}$ | 36.5 mW |
| $P_{Rx}$ | 41.4 mW |
| $P_{Idle}$ | 712 µW |
| **Channel rate** | 250 Kbps |
| **Symbol times** | 16 µs |
| **Superframe duration** | 122.88 ms |
| **aUnitBackoffPeriod** | 20 symbols |
| **macBeaconOrder (BO)** | 3 |
| **macSuperframeOrder (SO)** | 0 |
| **macMaxCSMABackoffs** | 5 |
| **macMinBE** | 3 |
| **macMaxBE** | 5 |
| $T_{beacon}$ | 0.36 ms |

The effect of postural stability on the average delay can be seen in Fig. 7. From this figure, it can be observed that the average delay in flooding is least among all the schemes. It is because in flooding the packet is delivered through all possible available paths. The time taken by the first arrived packet at the destination (PDA in this case) is considered a delay. The average delay to deliver the packet to the PDA by the proposed scheme is somewhere in the middle of flooding and RMPR scheme. As the postural stability increases the average delay decreases. Therefore, an average delay will be better than both the schemes if posture is stable. TDMA channel access mechanism is used so no queue maintained at intermediate sensor nodes as there is a single packet in the network. Therefore, no delay is added. But if the network is partitioned, it must be reconfigured immediately in the proposed scheme as there is a single path for normal data. The reconfiguration of the network causes a delay in data delivery. In the other two schemes, more than one path is available, so immediate reconfiguration is not required.

The delay will be least for emergency data in the proposed scheme as there is a separate path, which uses BCC technology and is always available. This path is also used in the process of reconfiguration of the network to exchange various packets. The time taken to reconfigure the network plays a major role in the computation of average delay, so, if the frequent reconfiguration is required, again the proposed scheme is better than both schemes.

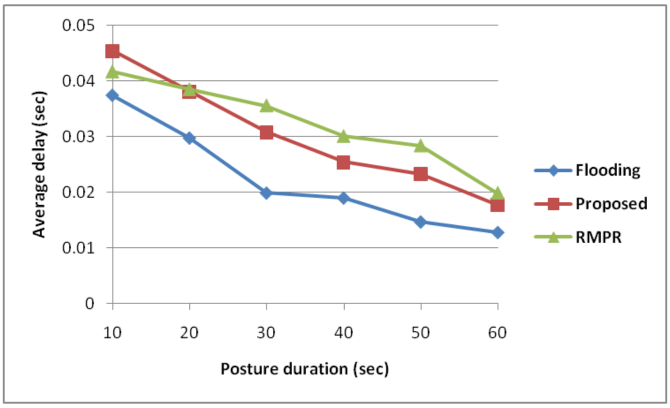


**Fig. 7. Effect of posture duration on average delay.**

Figure 8 shows the effect of postural stability on packet delivery ratio, which increases as the postural stability increases. If there is a frequent change in posture, then the packet may be lost on the path due to network partitioning. It can be seen from the figure that the packet delivery ratio of the proposed scheme is better than RMPR and is poorer than flooding. The packet delivery ratio of the proposed scheme is better than RMPR because in RMPR whenever the network is disconnected during transmission, it must be reconfigured to retransmit the current packet. But in the proposed scheme BCC link is used to retransmit the current packet along with the warning message to inform the PDA about the status.

The effect of postural mobility on average energy consumption is depicted in Fig. 9. We can observe from the figure that the average energy consumption in the proposed scheme is the least. This is because it uses the TDMA channel access mechanism. Therefore, there will be no collision and hence no retransmission is required. On the other hand, in the other two schemes data are transmitted on more than one path simultaneously causing more energy consumption. Moreover, there will be multiple packets in the network at the same time due to which, collision may occur. Hence, retransmission is required, which again consumes energy. We can also observe that as posture duration increases, the average energy consumption decreases. As the posture duration increases, the frequency of network partitions decreases hence a smaller number of reconfigurations is required. The energy consumption in the process of reconfiguration plays a major role in the computation of average energy, which is minimum in the proposed scheme as it uses BCC link, which is always available and consumes less energy as compared to RF link.

Figure 10 shows the effect of posture duration on the network life. As we can see that the network life in the proposed scheme is maximum and the network life increases as the postural stability increases. This is because if there is a frequent change in posture, the network may be disconnected frequently and due to which, network must be reconfigured again and again. The energy consumed in the proposed scheme is minimum during the network reconfiguration as it uses BCC link to exchange the packets, unlike the other two schemes, which use RF link for reconfiguration and therefore consume more energy.

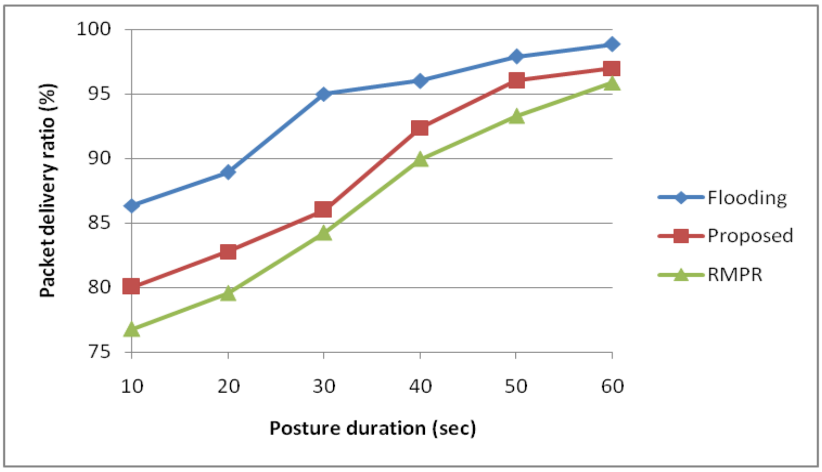


**Fig. 8. Effect of posture duration on packet delivery ratio.**

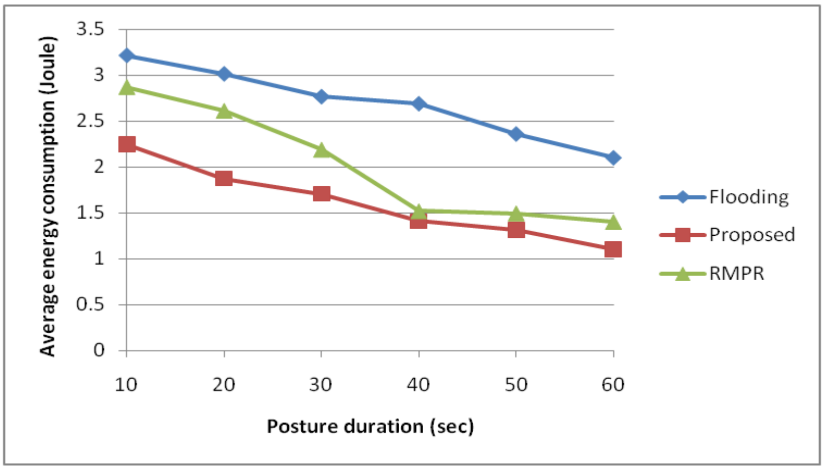


**Fig. 9. Effect of posture duration on average energy consumption.**

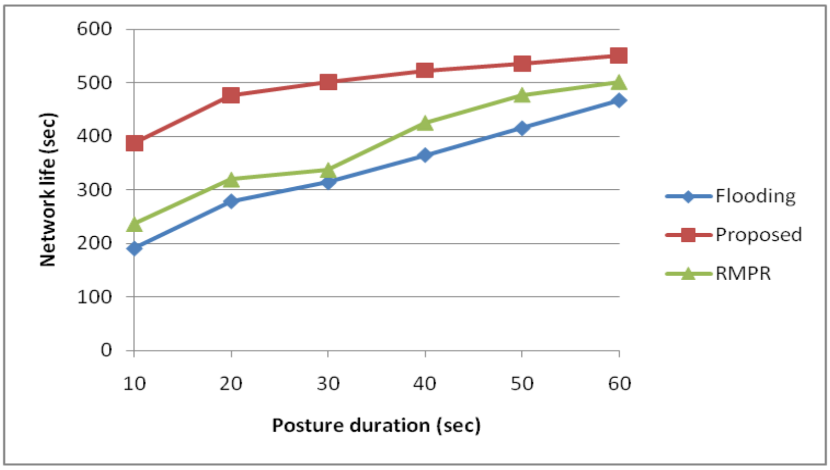


**Fig. 10. Effect of posture duration on network life.**

## 5. Conclusions

A data delivery mechanism for WBAN considering postural mobility is presented in this paper, which uses two types of links, i.e., RF link and BCC link. There is a trade-off between RF link and BCC link. RF link consumes more energy for retransmission in case of network partitioning and suffers from delay whereas BCC link affects body tissues as it uses the human body as a communication medium. Keeping this in mind, the proposed mechanism uses a hybrid of these two links for efficient working. The RF link is used for normal data whereas BCC link is used for emergency data for the quick response. BCC link is also used to exchange various packets required in the process of network reconfiguration. The proposed data delivery mechanism is best suited for hospitalized patients or aged patients where mobility is less. As stated by Baldus et al. [33] and Schenk et al. [34], the BCC link supports a high data rate, low energy consumption and highly reliable communication. As compared to RF, BCC is also more efficient in terms of per bit energy consumption and delay per bit.

The proposed scheme is also compared with flooding and RMPR schemes. The results show that the proposed mechanism is better than both schemes in terms of average energy consumption and network lifetime. The performance of the proposed scheme is better than RMPR in terms of average delay and packet delivery ratio, but poorer than flooding. But as the postural stability increases, the performance of the proposed mechanism also improves and reaches flooding.

## Nomenclatures

| | |
|---|---|
| $D$ | Distance between any two nodes |
| $F$ | Signal frequency in MHz- 2412-2483.5 MHz for Ralink 5370 |
| $F_m$ | Fade margin |
| $f_{c1}$ | Transmission rate of sensors in bits per seconds |
| $N$ | Path loss exponent, ranges from 2.7 to 4.3 |
| $N_{ack}$ | Number of ACK/NACK bits |
| $N_i$ | Number of bits sampled by $i^{th}$ sensor in one time frame |
| $N_{oh}$ | Number of overhead bits |
| $P_0$ | Signal power (dBm) at zero distance - Get this value by testing |
| $P_r$ | Signal power (dBm) at distance r - Get this value by testing |
| $T_{frame}$ | Duration of one TDMA time frame |
| $T_g$ | Time required by sensors nodes to turn on/off transceiver (in milliseconds) |
| $T_{s(i)}$ | Duration of $i^{th}$ TDMA time frame slot |

### Abbreviations

| | |
|---|---|
| BCC | Body Coupled Communication |
| DTN | Delay Tolerant Network |
| GTS | Guaranteed Time Slot |
| MAC | Medium Access Control |
| MS | Monitoring Station |
| PDA | Personal Digital Assistant |
| QoS | Quality of Service |
| RF | Radio Frequency |
| TDMA | Time Division Multiple Access |
| WBAN | Wireless Body Area Network |

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