Adaptive Routing Protocol for wireless Body Area Networks with Heterogeneous Nodes

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Abstract – Wireless Body Area networks are being widely used in medical domain and considered to be as the next generation in Wireless Sensor Network. Such networks gather variety of patient data and deliver them to doctor for further analysis. An important challenge in this regard is the design of a protocol which is considerably dynamic, lightweight and energy efficient which can satisfy the QOS requirements of different health care applications. In this paper, we proposed strong solution for an Adaptive routing Protocol using the Adaptive heuristic critic and Temporal Difference (TD) learning algorithm. It uses rewards and experiences to learn the best path from source to the destination while considering parameters like residual energy, link reliability, free queue size and minimum distance of one node to other at each node to make the routing decision .In this algorithm each node makes the decision independently in choosing the next hop until the packet reach destination.

Index Terms – Sensor Network, Machine learning, Body Area Network, TD Algorithm, Adaptive Routing Protocol.

1. INTRODUCTION

Integrating biomedical sensors within a wireless sensor network can potentially address a great number of applications. Body area networks are composed of tiny sensor nodes which are responsible for taking the vital signs from nodes and sending them to a sink node which can be further transmitted to the internet for health status monitoring, diagnosis and treatment. One of the main requirements on body area WSNs is that the data should be transferred reliably and efficiently. But dynamic nature of the network and severe resource constraints make it a challenging task to design a routing protocol that can meet this requirement. Moreover nodes in a Body Area Network (BAN) have strict energy constraints since these nodes cannot be replaced. For example consider a node which is inserted in the human body to monitor the heart rate so there needed an operation to replace that node with other node so energy constraints is much more strict than other networks. Every node differs regarding its computation power, energy level, and data rate and thus there is a need for routing protocol that considers these parameters when providing the desired Quality of Service (QOS). Most of the existing energy aware protocols consider to the sink a static optimal path in order to minimize the energy consumption. But the energy of any such path would drain quickly which being an undesirable outcome as the lifetime of the overall network would decrease very quickly as a result [1]. IEEE 802.15.6 standard supports medical or health-care applications as well as the entertainment facility. Owing to the energy variation in different devices and size variation of different traffic, the routing protocols of Wireless sensor network (WSN) cannot be directly used in WBANs. In WBANs, the nodes are usually heterogeneous having varied characteristics. For example if we consider the sensor nodes under a medical scenario then there are different kinds of data for the heart rate monitoring or the brain activity etc. If we consider WBANs in entertainment then we see that functional requirements are quite diverse like high transmission rate, or the provision for event driven data. For example, transmitting large amounts of data through tiny sensor nodes with limited resources would result in a large decrease in the life time of over- all network. Hence, it is also important to take into account the different device types along with the design goals of IEEE 802.15.6 standard when designing the routing protocols. Most of the existing protocols suffer a high communication over-head with additional computation cost. Furthermore it is a complicated task to maintain the overall network through routing tables which not only consumes more energy but it has also increases the computation cost. Hence, there is a need for lightweight, distributed and highly adaptive routing protocol which can cope up with aforementioned challenges. The physical and the Mac Layer are being covered in the IEEE 802.15.6 standard [2]. Usually there is central node which is a coordinator and is connected with nodes in a star topology. But considering dynamic scenarios, star topology is not adequate[3] . Thus, multi-hop architecture has been introduced such as tree, cluster or mesh where a node can communicate directly with the sink or have the relaying nodes transfer the message to the sink.

2. RELATED WORK

Many routing schemes have been proposed in recent years in medical field related to the networking world. The concentrate on survey [4] wireless body area networks in the area of medical patient monitoring and [5] the FrameComm Protocol Designed for elder Patients those age must be above then 65 years and useful for Data Management. We describe some of these here which are more relevant to our work. In their work [6] authors use a single hop as the way of communication for sending data from sensor node to sink node. Although the timing of the proposed scheme is good but energy efficiency is not taken into account. The work in [7] proposed Wireless Autonomous spanning tree protocol (WASP) where the message is broadcast from parent node to the child nodes; this protocol can achieve low delay and a high network reliability. The work in [8] proposed an Environment Adaptive routing (EAR) protocol which uses single as well as multi-hop communications. But the problem with this protocol is to maintain a routing table which is a difficult task in dense WBANs. In their work [9] Use the priority based tree algorithm for WBANs. Proprietary channels are being used for emergency data and as soon as emergency data is delivered then normal data can be forwarded. But the problem with this protocol is that in the scenario where proprietary channels fail, the available resources are wasted .The work in [10] proposed transmission of Patient vital Sign Using Wireless body area Network for end to end and Reliability requirements. The work in which [11] Controlling message to combine important information for the sensors into single message. The work in [12] proposed system architecture for body area sensor network which based on software and hardware for health monitoring .EBRAR that work on the real time and intricate conditions on roaming data from different body sensors among the Body area Network [13] and considers a route that is selected Based on remaining energy. They achieved a good energy output but some sensor nodes experience long path (more hops) to reach the sink node. The work in [14] presents protocol in which standard type of both single hop and as well as multi hop communication were used. Preference based routing is used for normal transmission and critical data transmissions. Routes are choosing according to the minimum hop count which reduces delay in transmission. But still there is a space for improvement in energy management. In body area networks many researchers trying to explore this domain of area according to their own interest especially in the field of medical for patients. BAN is enhanced in the sensor network for [15] counting the sensing value for biomedical in the territory of the sensors for the practical world of medical. For our proposed work we studied the following more researchers work.

Bykowski et al.[16] He introduced ingenious approach for network topology in body area network. The network topologies that all are managed widely as for point to point, such like mesh,star,tree,hybrid topologies.

Elias et al. [17] He investigate the optimal Design of WBAN by researching the collecting data routing and find out the location problems in a wireless body area network, in the series to improve the network duration for lifetime. This model Energy Efficient as well for cost effectual wireless body area networks.

Ge et al.[18] He examine the architecture of network under the measurement emulate for wireless body area network. Specific exhibition for star as well as Multi-hop. He found out the experimental results in the architecture of network, like collection of delay, Energy Consumption rate and also balancing energy as well.

Nadeem et al.[19] He presented a reliable, energy efficient/high throughput protocol for WBANs. He used the multi-hop topology technique to obtain the less energy used and long lifetime for network stable. That proposed protocol name is SIMPLE-stable increased multi-hop protocol link Efficiency.

Tanveer et al.[20] He introduced cluster based protocol SEA-BAN for wireless body area networks. Its joint the direction transmission of network and Multi-hop of transmission pattern, it depends into level of energy and vector information of the nodes in the body.

Arbia et al.[21] He proposed critical and rescue operations using wearable WSNs (CROW).He point out the Reliability challenges in a wireless independent communication system in regard to offload data from the disaster place and return back to the command center. The Goal of proposed work is too positioned saviors should be extended over networks and the internet.

In our Paper work we Proposed a lightweight, dynamic Protocol for Wireless Body area network (WBAN) with heterogeneous nodes using the Adaptive heuristic critic (AHC) and Temporal Difference (TD) learning which consider the factors like Residual energy of neighboring node, Link reliability, free queue size available and minimum distance from one node to the other node till Packet reach destination.

3. BODY AREA NETWORK ARCHITECTURE

In BAN the implants and wearable sensor nodes send their data to a central device known as body coordinator which is further connected to a static coordinator through a WLAN. Data collected from these sensors are used by medical doctors for real-time diagnosis, or to maintain a medical database for patient records. BAN architecture can be defined with a three tier design where Tier-1 is Intra-BAN communication, Tier-2 is Inter-BAN communication and Tier-3 is Beyond-BAN communication [22].The intra BAN communication collects the sensory data from different nodes on the human body and direct it to its body coordinator. In Inter communication there is static coordinator which communicates with one or more body coordinator. The static coordinator acts as the gate way or access point to be connected to the internet where it can be analyzed by doctor or can be saved in the database for the History of Patients. The BAN communication can be centralized BAN communication or a distributed communication as shown in figure 1.

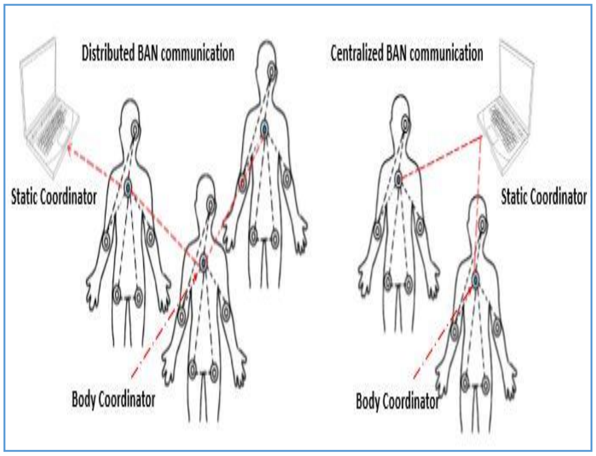

Figure 1. Centralized and Distributed BAN communication network

In centralized BAN communication the body coordinator of every patient is connected to the static coordinator, but conversely in distributed communication between a static and body coordinator runs through intermediate body coordinator. Centralized communication scheme is much easier to manage whereas distributed communication scheme can be established where the body coordinator are out of range of the static coordinator. Hence distributed coordinator is more flexible and also increases the communication range. Due to the limitations such as energy constraint and also the short range communications between the nodes, multi-hop communication is adopted and thus the nodes can produce as well as forward the data to other nodes. Some of the characteristics of BAN are as follows: 1) Wireless links between nodes are not stable which leads to instability of the selected path further contributing to increase the Packet Error Ratio (PER) thereby making the communications unreliable and prone to errors. 2) Network topology may change dynamically due To the mobility of nodes and also depending on scenario in which they are deployed. 3) Nodes are battery powered and the key component of a network is to extend its life-time by using the energy of nodes efficiently. 4) Data collected are of heterogeneous nature. Nodes deployed for monitoring the health of patient collect different kinds of data depending on their specific application. 5) The computational power and memory in nodes is limited thus posing a challenge in designing routing algorithm and hence a light-weight protocol with low computational as well as energy requirement is needed.

In this work, we assume knowledge about geographical information of the neighboring sensor nodes, sink or the coordinators. It is a valid assumption because mostly in hospital environment, with static nodes, it is known that where is the patient location. And, considering dynamic nodes, the nodes have the facility of distributed localization services which will indicate us the location of nodes. The neighboring nodes can exchange information by using a beacon exchange so this implies that each node is aware of its location and as well as of its immediate neighbors.

4. OVERVIEW OF ADAPTIVE HEURISTIC CRITIC (AHC) AND TEMPORAL DIFFERENCE (TD)

Adaptive heuristic critic (AHC) and TD are model free components of Reinforcement Learning (RL). Within RL. We consider an agent and the environment. The agent learns from the environment through perception and affects it with an action. At each time step, agent receives an input and a state s which is the current state of the agent and then it takes an action a to generate the output. After taking the action a the agent gets some reward r from the environment. The agent tends to choose the actions which will give them the maximum reward. The AHC is a type of strategy repetition where the cost function is no lengthier executed by resolving a set of linear equations but instead computed by an algorithm called Temporal Difference (TD). TD is a model free learning method in which learning is achieved by experience. The AHC and TD components are shown in the Figure 2.

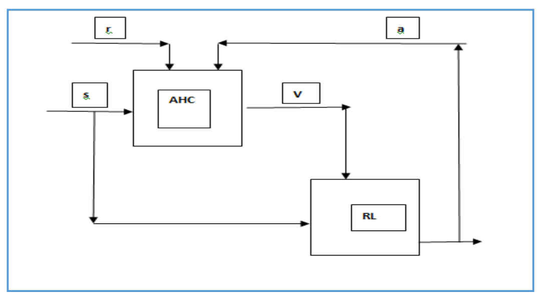

Figure 2. The general design of AHC and TD model

It comprises of two parts: a critic (labeled AHC) and as well as reinforcement-learning component (labeled RL).The reinforcement learning part can be initiated to handle with multiple conditions and non-stationary rewards. In the RL part, instead of maximizing the reward, we maximize a heuristic value v which is to be computed by critic. The critic uses the external signal to study to allocate their conditions to the expected discounted values given the current policy instantiated in the RL component. In other words, these two blocks work in alteration. The policy is implemented by RL and then critic is used to learn value function for that policy.

Now the critic is fixed and RL learns a new strategy that exploits the value Function and the process continues. The critic can learn the value of a policy defining a tuple (s, a, s', r) of experience in a single transition in the environment. Where s the current state of the agent is, $a$is the action to be taken, r is the instantaneous reward r it receives and s' is the resulting state. The value of policy is updated using the following update rule given in Equation(1).

$$V(s,a) = V(s,a) + \alpha(r + \gamma V(s',a') - V(s,a)) \quad (1)$$

Whenever a state s is visited it gets closer to the where $v(s, a)$ is the estimated value of the next state. The term is the sample values of $v(s)$ drawn from the real world and are likely to be correct since they contain the reward value $r. alpha$ is the learning rate at which the mode updates the $v(s, a)$ values and if it is adjusted properly (i.e. continuously decreasing) under a policy then TD is assured to congregate to an optimal value function. Hence, $v(s, a)$ denotes the quality of action taken at state s.

5. THE DESIGN OF PROPOSED ROUTING PROTOCOL

The proposed protocol is distributed in nature at any given node, the initialization information needed by the protocol consists of location information of the neighboring nodes and for each neighbor it also takes into account the respective link quality, residual energy, queuing delay and the minimum number of hop count from that neighbor to the destination. The routing decision is taken independently at each node until the packet reaches its destination. Thus, the protocol is highly dynamic and considers the aforementioned QOS matrices while forwarding each packet to the next hop. In our proposed protocol, current node is represented by a state s and an action a which determines packet forwarding to the neighboring node given by the state s' which effectively is the next state for the current node. $v(s, a)$ Determines the quality of the action taken in the current state s. After taking the action the agent will receive either a positive or a negative reward. Thus depending on this reward the agent will learn the environment and will update the $v(s, a)$ values of the state under that particular action. For the WBAN network the states, actions and the rewards are defined as follows State: Each node in WBAN is a state s . Mathematically it can be written as s, s_i here i is the number of nodes in the network action: Action a can be defined as the sending of Packet between neighboring nodes s and s' which are in range of each other. Reward Function: The reward function is defined in equation 2.

$$r_t = P_a^s(s,s')r_a^{s'} + (1 - P_a^u)r_a^u(s,s') \quad (2)$$

Where: P_a^S is the probability of sending the successful packet between the neighbor nodes s and s'. r_a^s is the reward function of successful transmission which can be described in Equation 3.

$$r_a^s = \lambda_1(E_r es) + \lambda_2 Linkr_{i,j} + \lambda_3 Q_t + \lambda_4 H_{dis} \quad (3)$$

Where $\lambda_1, \lambda_2, \lambda_{3,}, \lambda_4$ is the weighted sum of the Residual Energy , Link Reliability $linkr_{i,j}$ The free queue size of node Q_t and H_{dis} are the minimum distance from current node to the next node. The weighted sum of the entire constant will be 1.Inorder to compute the $lamda$ values the $E_r es$ and $linkr_{i,j}$ are two important parameters as compared to another two parameters so they are given the high weight in the model. In future simulation part the tradeoff between these Parameters can be demonstrated by different graphs. The residual energy $E_r es$ of node is given in equation 4.

$$E_{res} = E_{init} - E_{con} \quad (4)$$

Here E_{con} is the energy consumed inside the current node. The total energy consumed in a node can be calculated as the sum of transmission and reception energies as shown in equation 5.

$$E_{res} = E_{init} - E_{con} \quad (5)$$

Where a and b are the number of bits transmitted and received in the node. This effectively addresses an aspect of heterogeneity in the nodes because different application has different number of bits to be transmitted or received. E_{tx} And E_{rx} are given as in equation 6 and 7.

$$E_{tx} = E_{txelec} + E_{amp} \times d^2 \quad (6)$$

$$E_{rx} = E_{rxelec} \quad (7)$$

The Link reliability $linkr_{i,j}$is an important QOS parameter. When the link between nodes is not reliable then packets may not be delivered and thus will be retransmitted thereby consuming more energy. The link reliability is calculated using an exponentially weighted moving average as illustrated in equation 8.

$$Linkr_{i,j} = (1-\gamma)Linkr_{i,j} + \gamma\left(\frac{T_{x_{i,j}}}{T_{total_{i,j}}}\right) \quad (8)$$

T_{xsucc} Is the number of packets successfully transmitted between neighboring Nodes. T_{xtotal} Is the total number of transmission and re-transmission attempts for all packets and γ is the average weighting factor. In order to calculate the free queue size of node we can employ a simple strategy where a counter is incremented each time a packet is buffered inside a node thus knowing the maximum buffer size, it is straightforward to work out the free space available in the queue. This knowledge can help reduce the end to end delay. Now in order to choose the expression for the minimum distance to the next node from current node is the value along the straight line from one node to the next receiver. The next node is chosen which have the minimum distance from the current node and also have the node to which Packet is forwarded to the destination node. As we already assumed to know the location of the neighboring nodes from the current node so we can use the minimum Euclidean distance between nodes to get them H_{dis}.

$$H_{dis} = \min_{\forall i \in s'} \sqrt{(x-x_i)^2 + (y-y_i)^2} \quad (9)$$

$r_a^u(s, s')$ Is the reward function for unsuccessful Packet Transmission. As the packet is not received so this action should be punished by a constant Y. So this will indicate not to send the packet to those which are either in sleeping mode or have low v values.

$$r_a^u(s,s') = -Y + \lambda_1(E_r es) + \lambda_2 Linkr_{i,j} + \lambda_3 Q_t + \lambda_4 H_{dis} \quad (10)$$

To summarize the working of the protocol, each node sends the V values being appended in the beacon and circulated among the neighboring nodes. V values indicate the quality of actions taken while considering all the QOS design parameters such as link reliability, the residual energy of nodes, the queuing delay and the minimum number of hop-counts to the destination. Packet from one node is forwarded to another node which has the optimal v values and this process continues till the packet reaches its destination. The scalability issue is also resolved in the way since each node has to know the V values of its neighbors only so this protocol is easily scalable to the larger networks.

6. SIMULATION RESULTS AND PERFORMANCE EVELOUTION

Here for the simulation purpose MATLAB is used for the comparison parameters. The table below show the parameters used for simulation purpose.

Table.1 Parameters for simulation

Parameters	Values
Total number of nodes	15
Placement in human body	1.7m
Wireless Channel Capacity	2 Mbps
Link Capacity	1 Mbps
Maximum Acceptable data rate	512Kbps
Minimum Acceptable data rate	128Kbps
Energy of battery	2 joules

The normalized residual energy per node is shown in figure 4.It is evident that normalized energy varies from 0.2 to 0.92 for PSR routing strategy, 0.58 to 0.74 for EBRAR routing strategy and 0.52 to 0.76 for Proposed routing strategy. The variance of residual energy for PSR, EBRAR and Proposed routing protocol are 0.075, 0.004 and 0.008 respectively. So it is concluded that energy balances in EBRR, imbalance in PSR and moderately balance in proposed protocol.

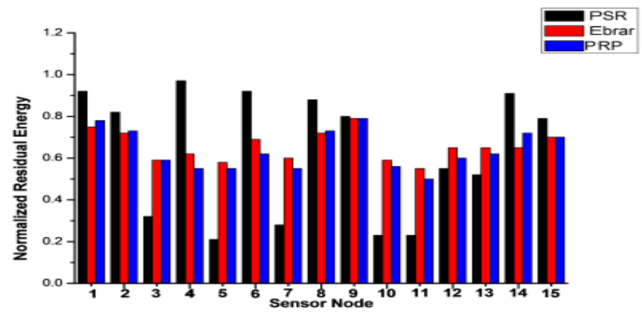

Figure 3. Residual energy distribution

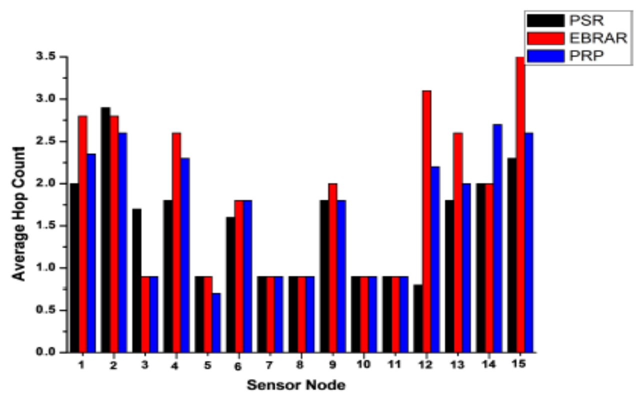

Fig. 4. Hop-count per node

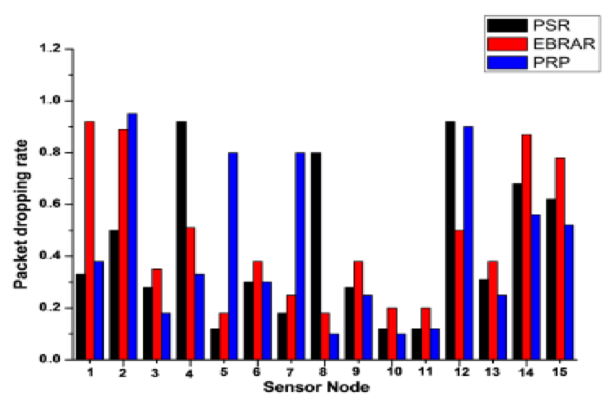

Figure 5. Packet dropping per node

In figure 4 the average hop count per node to send packets to sink node. It is clear that average hop count is 2.5 for PSR, below 3.0 for the proposed protocol and also above 3.0 for EBRAR. If we observe and consider the worst case scenario then EBRAR is the one which took longer path as compared to other two approaches. The packet dropping rate of the three worst case nodes 2, 14 and 15 of the network, the average packet dropping rate of PSR, EBRAR and QRP is 0.62, 0.81 and 0.53 respectively. So it is clear that EBRAR is much higher than the other two approaches. The main reason for packet loss is that weak links between the sender and the receiver or also due to the inability of the node to select the best path. Actually the PSR and EBRAR routing schemes comply with the extreme approaches. The basic idea behind PSR is that it only focuses on the minimization of the path length so as the result the energy is imbalance for the whole network. While EBRAR concentrates only on the evenly distributed of the energy but as the result the delay between the messages from sender to the receiver is too high. So the Proposed protocol is the compromise between these two which make decision on the four factors. Now the impact of the weight factor for selection the next hop to route the packet from the initial/source to the final/destination end. If one have been given the high weight rather than other so the node will make decision on that particular factor and in some cases behave like PSR and EBRAR routing strategy.

7. CONCLUSION

We have proposed an idea of applying a Machine Learning algorithm called adaptive heuristic critic and TD learning for a dynamic routing protocol. In this protocol every node makes an independent decision regarding where to forward the packet while considering different QOS parameters such as link reliability, residual energy, queue delay and the minimum distance of one node to next node. Hence, this protocol is expected to satisfy different QOS metrics in a dynamic environment. The simulation results shows that the PRP is a compromise between two Protocols and have performed better in terms of residual energy, no. of hop counts and also the packet dropping ratio. A potential future work, we can adopt a multi-agent approach where all the sensor nodes cooperate to determine the QOS routes collectively to improve the performance of the network instead of considering every node independently.

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