

# Improved Adaptive Routing for Multihop IEEE 802.15.6 Wireless Body Area Networks

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**Abstract**— Wireless Body Area Network has the ability to collect and send data on body measurement to the server through PDA or other device. Nodes (sensors) collect vital signs from the body or environmental factor and check them. In IEEE 802.15.6 routing is discussed as a part of the link layer where multihop is not fully considered. Improving network performance, reducing energy consumption, thus extending the network lifetime is the main challenge in BANs. Several studies mention that multihop for BANs helps for achieving network performance, reducing energy consumption and extending network lifetime. One work presents the Adaptive multihop tree-based Routing (AMR) protocol that is extensively evaluated in a real testbed deployment. They use fuzzy logic to combine all metrics they use. Another limitation is that they have used Prim's algorithm which is not a realistic approach. So in this work we have improved their multihop tree-based Routing (AMR) protocol using Kruskal's algorithm instead of Prim's algorithm. The time complexity of Kruskal's algorithm is way less than Prim's algorithm. We have used network simulator 3 (NS3) to simulate and found that our algorithm is better than AMR if many of nodes.

**Index Terms**— WBAN, BAN, Routing, Multihop, Prim's Algorithm, Kruskal's Algorithm, Fuzzy Logic

## I. Introduction

Wireless Body Area Network (WBAN) is composed of miniature sensor nodes that are capable of taking

vital signs from human body and sending to a central node. A central node can process this data and pass it to the specialists via Internet [1]. In WBAN nodes are capable of sampling, processing vital signs of the body such as blood pressure, temperature, sugar level, location, oxygen level etc. Elderly and handicapped people can be easily monitored by using WBAN. They don't need to stay in hospital beds anymore. So WBAN makes life easy. Other applications of WBAN ranged from video games to military application.

IEEE 802.15.6 talks about BAN's physical and medium access layer [2]. They proposed a star architecture and a small area. Here the nodes are directly connected into a central node. But this star architecture is not enough for WBAN, especially if WBAN is in time varying condition [3]. To provide robustness, star architecture has to be replaced by another algorithm. This algorithm can be mesh, tree or cluster based algorithm. These mesh, cluster or tree is called multihop architecture. Multihop usage can also reduce power consumption.

WSN is a common term in networking. Several works have been done on it. WSN has several protocols [4]. These protocols are energy-efficient [5]. Though WBAN is specialized from of WSN but these protocols cannot be used in WBAN due to special properties of WBAN. WBAN has some limitations such as low energy, short communication range, irregular traffic etc. But recently several protocols have been proposed for WBAN [6] [7] considering the limitations of WBAN and how to deal with it.

As nodes of WBAN are miniaturized and battery-powered, energy consumption is a major fact in WBAN.

So with a view to saving energy the physical device, network device, protocols and application should be energy-efficient. Most of the existing protocols which are so-called energy-efficient choose a static optimal path to the sink node and they don't save power in real life. This leads to unbalanced energy distribution among sensor nodes. This unbalanced energy consumption reduces network life time and causes network disconnection [8].

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**Algorithm 1** AMR tree construction

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1.  $U \leftarrow \{v_s\}, E' \leftarrow \emptyset$
  2. Select the lowest cost edge  $e = \{i, j\} \in E$  such that  $i \in U$  and  $j \in V \setminus U$
  3.  $E' \leftarrow E' \cup \{e\}, U \leftarrow U \cup \{j\}$
  4. if  $U = V$  then finish
  5. else go to line 2
  6. output:  $M = (V, E')$
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IAMR is more cost-effective than AMR. And almost work the similar way as AMR works. In the next few sections it is discussed how this protocol works. In background studies the working procedure of AMR and its routing metrics; message formats and its details are depicted. In the next section IAMR along with its all routing metrics are discussed. In the simulation it is shown how IAMR is better than AMR.

## II. Background Studies

### 2.1 Network Model and Tree Construction

If we assume that  $v$  is the Set of vertices which represents the nodes in the network and  $E$  is the set of edges which represent network communication topology then WBAN can be modeled as  $G = (V, E)$ , here  $G$  is undirected graph. Now an edge  $(v_i, v_j) \in E$  if and only if  $v_i, v_j$  are in each other's communication range. The central node is defined as  $v_s$ . The resulting multihop routing tree constructed by AMR,  $M = (V, E')$  is a spanning tree, which has all the vertices of  $G$  and  $E' \in E$ , represents the subset of edge that are included in the tree depending on the metric used. This operation follows the prim's approach to construct spanning tree [9] as illustrated Algorithm 1. After adding the central node to the tree, edges are iteratively selected in BFS based on the adopted parent selection metric until all nodes have been added.

In order to communicate with nodes AMR use some messages. They are as follows-

**HELLO:** this message triggers the discovery process. Upon receiving this message, nodes start the parent selection process.

**JOIN:** when selecting a parent node, say node  $b$ , a node, say node  $a$ , sends a JOIN request to the candidate parent  $b$ . The node  $b$  will send back an ACCEPT message to node  $a$ .

**ACCEPT:** parent-child associations are acknowledged in order to ensure child nodes successful association and routing tables are updated.

**LEAVE:** a node having selected a parent may have to change it due to low residual energy. Nodes will consider the residual energy, and *time to die* will be estimated. If this *time to die* is lower than a prefixed threshold (i.e., the energy needed to finish the current round), nodes having a parent without enough residual energy to finish the current round, will send a DEL message (i.e., leave request) and will select as parent any other node with enough residual energy to finish the current round.

**DATA:** after selecting and associating to a parent, nodes can start sending data packets that include body measurements.

### 2.2 Routing Metrics

Though AMR can adapt many metrics, we use hop count using SPT, RSSI, and battery level. We further use fuzzy logic to combine these three metrics similar to our provided work [10].

**Shortest Path Tree (SPT):** SPT is a tree based network in which all nodes have the lowest number of hop count to the central node. This metric is directly related to end to end delay. But node overload in relaying node supporting a high number of child nodes may cause data loss and network connectivity failures.

**Received Signal Strength Indicator (RSSI):** The use of the high RSSI link ensures the correct communication between nodes in the network.

**Residual energy (Battery):** In BAN it is important to increase network and battery lifetime. Energy consumption must be balanced across the network to ensure maximum network lifetime.

**Fuzzy Logic:** Fuzzy logic is a decisive approach that enables the efficient combination of different parameter that can be used as a single metric [11]. It is widely used in machine control. The term itself inspires certain skepticism, sounding equivalent to "half-baked logic" or "bogus logic", but the "fuzzy" part does not refer to a lack of rigor in the method, rather to the fact that the logic involved can deal with concepts that cannot be expressed as "true" or "false" but rather as "partially true". Although genetic algorithms and neural networks can perform just as well as fuzzy logic in many cases, fuzzy logic has the advantage that the solution to the problem can be cast in terms that human operators can understand, so that their experience can be used in the design of the controller. This makes it easier to mechanize tasks that are already successfully performed by humans.

Table 1: Fuzzy rule set

Number of Hops	Residual			RSSI
	Low	Medium	High	
near	bad	bad	median	poor
near	bad	median	good	average
near	median	good	good	good
medium	bad	bad	bad	poor
medium	bad	median	median	average
medium	median	median	good	good
far	bad	bad	bad	poor
far	bad	median	median	average
far	median	median	median	good

A typical FLS, widely used in fuzzy logic controllers is composed of fuzzifier, fuzzy rules, inference engine and defuzzifier. The operation of an FLS can be summarized as follows: crisp data are fuzzified and converted into fuzzy values. These fuzzy values are evaluated by the inference engine by considering a set of rules that relates the input and output variables. The output value obtained in the previous step is then defuzzified, providing a numerical value that can be used as a metric by the external system. The computational requirements of an FLS are usually lower than conventional mathematical operation such as arithmetic operations [12]. The variables considered for this work is as follows-

**Number of hops:** it represents that how many times a packet does have to be transmitted to another node to reach the destination node.

**Residual energy:** since nodes are using battery so the parameter must be considered in order to save energy and increase lifetime.

**RSSI:** nodes with high RSSI will prefer because the quality of receiving signal is important to ensure correct data reception.

Input parameters are characterized into a set of linguistic values: *Number of hops*  $\subset \{near, medium, far\}$ , *Residual Energy*  $\subset \{low, medium, high\}$ , *RSSI*  $\subset \{poor, average, good\}$ , and *Output*  $\subset \{bad, median, good\}$ . Linguistic input values are related to output values following the rules defined in Table 1, which represents rules such as: *IF Number of hops is medium AND Residual energy is high AND RSSI is good THEN Output is good.*

An illustrative example of the membership functions for the input and output parameters used in our FLS is given in Fig 1. For example, considering the number of hops, label1 corresponds to near, label2 to medium and label3 too far. The values  $X_0$  to  $X_4$  have been adjusted according to each input variable, for example, for residual energy,  $X_0 = 0\%$ ,  $X_1 = 25\%$ ,  $X_2 = 50\%$ ,  $X_3 = 75\%$ , and  $X_4 = 100\%$ , considering 100% when node batteries are fully charged.

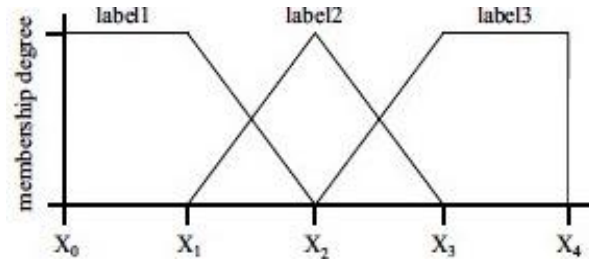


Fig. 1: Membership function example used to define input and output in fuzzy set

### III. Proposed Protocol

To construct routing tree we assumed an undirected graph  $G = (V, E)$  where  $V$  represents the number of nodes and  $E$  represents the communication topology. Here everything is same as our base algorithm on which we are working on. But we choose Kruskal's algorithm instead of prim's algorithm to generate the minimum spanning tree. Let assume a set  $A$  which start as an empty set and select at every stage the shortest edge that has not been chosen or rejected, regardless of where this edge is situated in the graph, as illustrated in Algorithm 2. After adding the central node to the tree edges are iteratively selected in BFS approach. The message format will be same as AMR.

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#### Algorithm 2 IAMR tree construction

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1.  $A \leftarrow \emptyset$
  2. for each vertex  $v$  in  $G$   
do MAKE-SET( $v$ )
  3. sort  $E$  into nondecreasing order by weight  $w$
  4. for each  $(u, v)$  taken from the sorted list  
do if FIND-SET( $u$ )  $\neq$  FIND-SET( $v$ )  
then  $A \leftarrow A \cup \{(u, v)\}$   
UNION ( $u, v$ )
  5. Output:  $A$
- 

The operation of AMR can be divided into two phases, considering nodes inside and outside the sink coverage. First, the sink node broadcasts a HELLO message, and nodes receiving this message send a JOIN message to the sink in order to associate themselves. The sink node will acknowledge these nodes by sending (unicast) an ACCEPT message. Upon receiving the ACCEPT message, nodes update their routing tables and broadcast a HELLO message. Nodes outside the sink coverage will eventually receive a HELLO message and wait for time  $t_{wait}$  to receive HELLO messages from other neighbor nodes. After  $t_{wait}$ , nodes select their parents based on the selected metric. When a parent is selected, a JOIN message is sent, and if no ACCEPT is received from the selected parent, the JOIN message is resent. After receiving the ACCEPT from the selected parent, nodes send a HELLO message and are ready to send/relay DATA packets. In case of parent node  $p$  not having enough residual energy to finish the current round, if it has any child  $c$  already associated top,  $c$  sends a LEAVE message to  $p$  and selects another parent node with enough residual energy. The operation

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#### IV. Simulation

Using different approach that is Kruskal's algorithm instead of Prim's algorithm does not effect on other performance. If we look into Fig 2 we can observe that both of the AMR and IAMR constructs the same tree. They both use same metrics that are hop count, RSSI and battery level. Only one thing that makes them different from one another is time complexity.

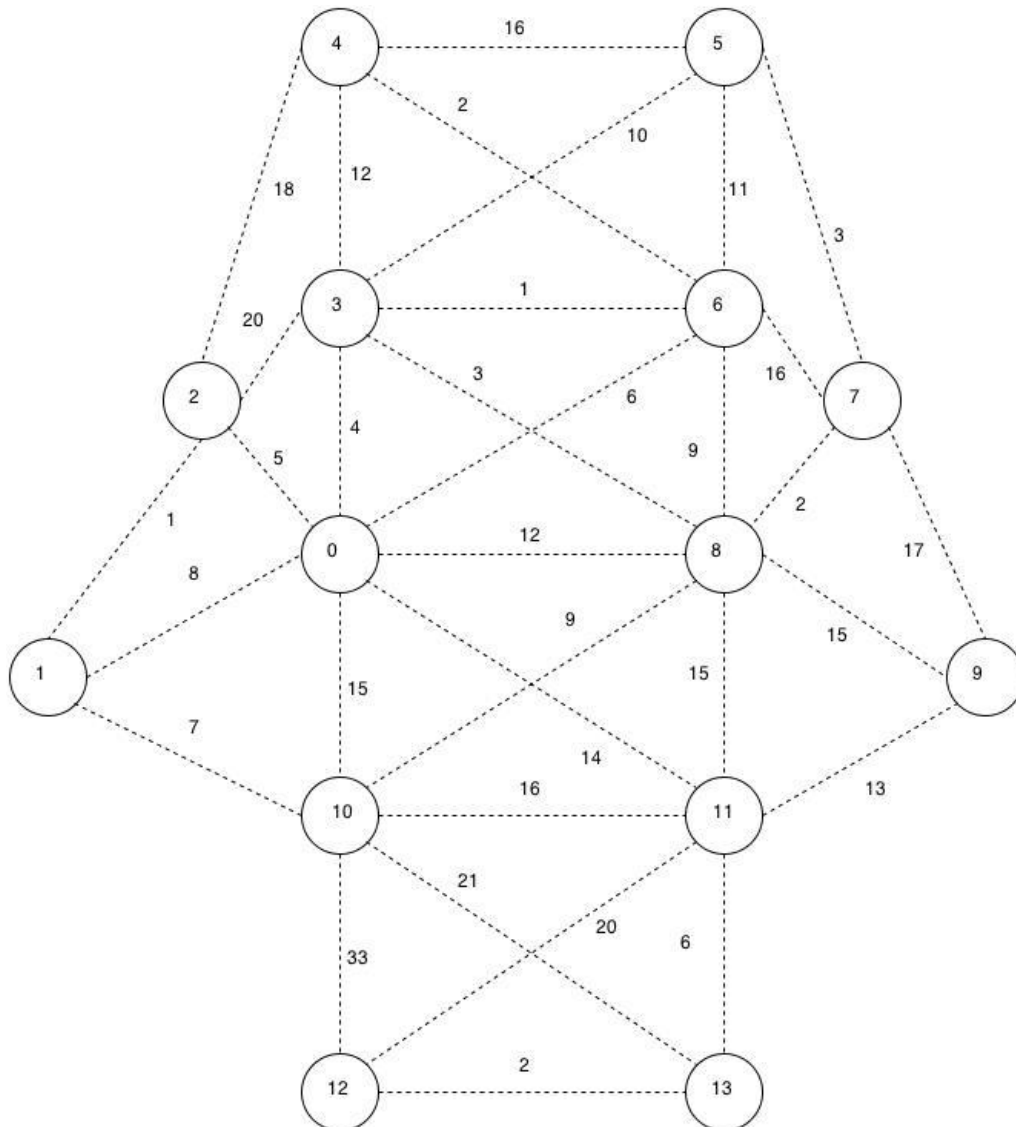


Fig. 2: (a)

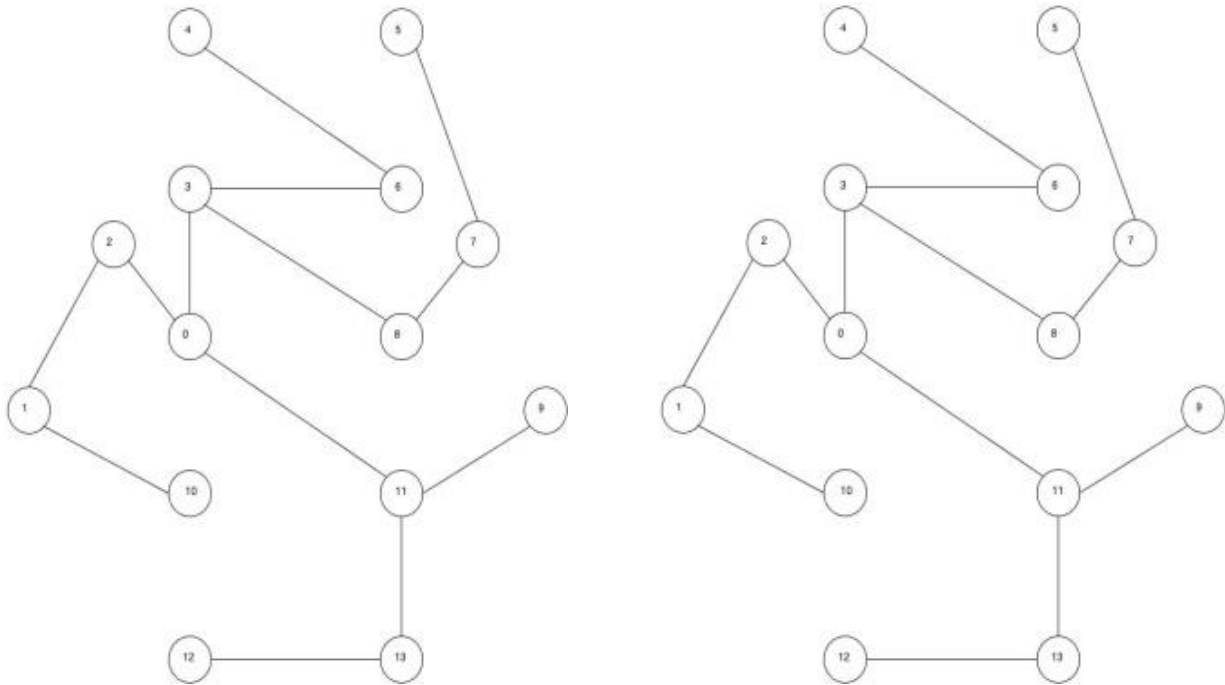


Fig. 2: (a) Present node position in the body (b) Tree using AMR (c) Tree using IAMR

By simulating and using mathematics we can conclude that our proposed algorithm is better than AMR. If we look to Table 2 we can see the difference between the two algorithms. If we assume that there are

more than 100 nodes then we can conclude that AMR takes 960 milliseconds where IAMR takes only 36 milliseconds. If number of nodes is less than 10 then the difference between time complexities is almost zero.

Table 2: Difference between time complexities of two algorithms

No. of nodes	10	25	50	75	100	125
AMR	27	41	150	400	960	1800
IMAR	27	30	32	34	36	40

From the table, with an order of 10 the results were almost identical. When the order was increased to 25, slight differences became apparent and it appeared that Kruskal’s algorithm was the fastest. For an order of 50, Prim’s algorithm took almost five times the time than during an order of 10. While Kruskal’s had increased by just five milliseconds. The next columns proceed in the same fashion and in the final graph test with an order of 125 vertices it took Prim’s algorithm nearly two seconds to complete, while Kruskal’s algorithm completed the same task in just 40 milliseconds.

If drawn on a graph, with order in the x-axis and also being the independent variable and y-axis as the dependant variable time, the plot would look as follows-

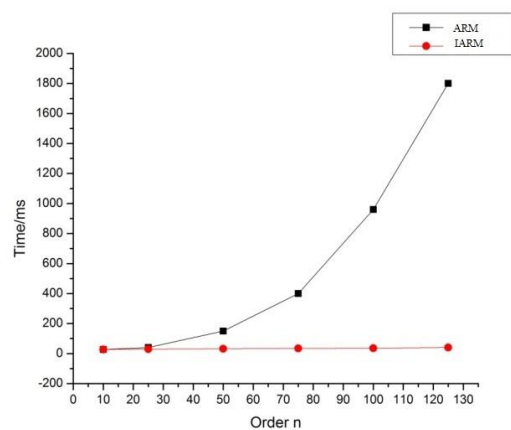


Fig. 3: Difference between time complexity between AMR and IAMR

Fuzzy logic balances the network load better than any other metrics that we proposed. Thus it achieves longer network lifetime. This is shown in Fig 4. This graph is shown in two central locations. In this graph fuzzy logic has better performance. On the other hand battery power metric obtains shortest network lifetime.

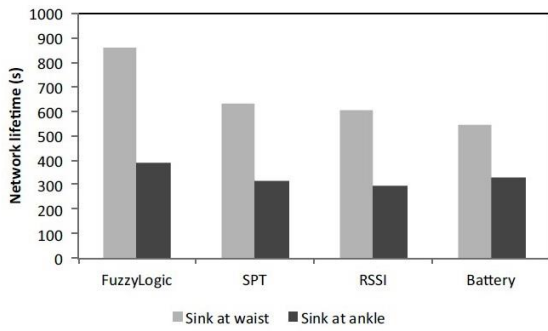
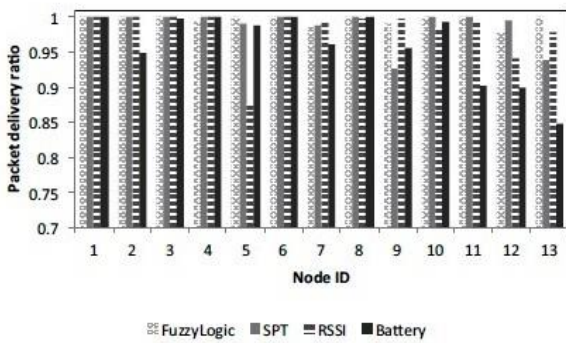
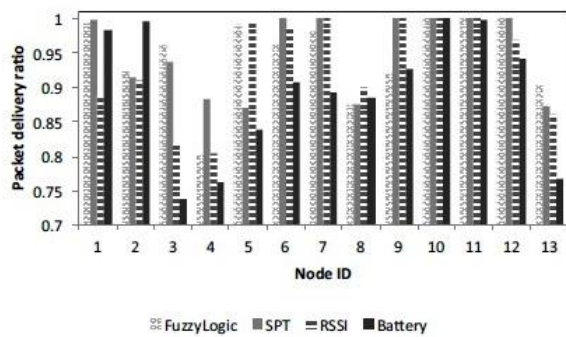


Fig. 4: Network life time for each metric

Fig 5 shows per node Packet Delivery Ratio (PDR). Here also fuzzy logic obtains better overall behavior than the other metrics. Paths that are created by fuzzy logic are more robust. Again battery shows the worst result in the PDR.



(a) Sink at waist

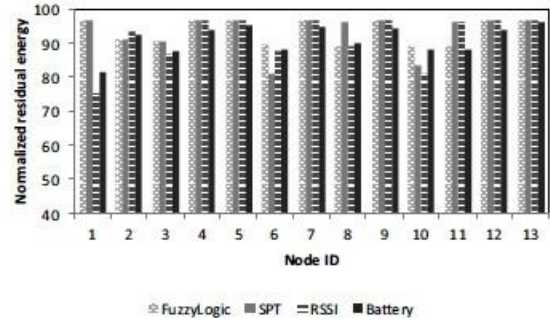


(b) Sink at ankle

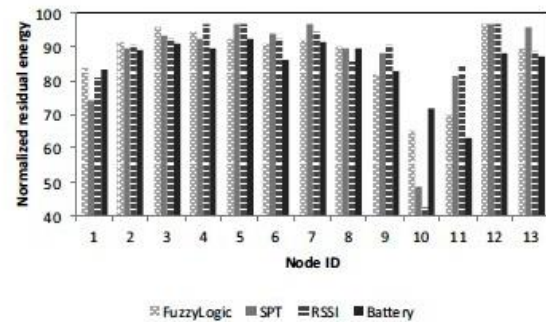
Fig. 5: Per node packet delivery ratio (PDR)

The normalized residual energy for all metric is illustrated in Fig 6. Hop count, RSSI actually does nothing to balance out network load. So nodes will drain their battery energy faster than other node cause network partition. But fuzzy logic and battery metric are able to handle network load and balance it. For example when the sink node is located at ankle, most of the network traffic has to be relayed by nodes 10 and 11, fuzzy logic and battery metrics are able to balance out the network load and keep both nodes with around the

same residual energy level, while SPT and RSSI exhaust node 10, making it to rapidly decrease its residual energy level. Routing overhead is directly related to energy consumption.



(a) Sink at waist



(b) Sink at ankle

Fig. 6: Residual energy distribution of nodes

Now in Fig 7 the average number of transmissions per delivered data packet is shown. SPT obtains the lowest number of transmissions per delivered packet, as packets are forwarded in shortest path. But other metrics may incur longer paths when they provide better overall network performance. For this experiment battery metric performs the worst.

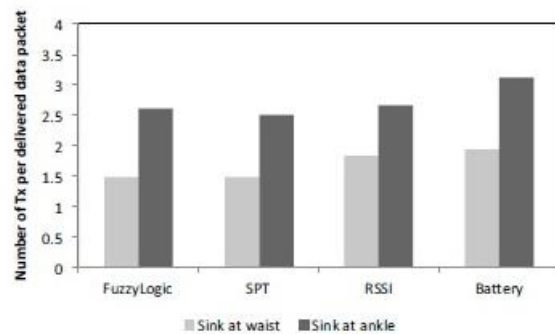


Fig. 7: Number of transmissions (Tx) per delivered data packet

V. Conclusion

IEEE 802.15.6 is defined for physical and data link layer for BANs, however, multihop routing is not fully

discussed. AMR is an adaptive network discovery and routing tree construction protocol for BANs that take into account several metrics in selecting the routing path to the sink or central node. Several routing metrics i.e. number of hops, RSSI, battery level are combined using fuzzy logic. AMR is tested using 14 TelosB based nodes testbed. Like an AMR, IAMR works with same metrics and all the work procedures are same but it has improved in performance. Only one change has been done in IAMR that is using Kruskal's algorithm instead of the prim's algorithm. No effects on used metrics occur because of this change. IAMR just improved time complexity of AMR where we assumed that number of nodes is higher.

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