IMPLEMENTATION OF BIOLOGICAL ROUTING PROTOCOL IN TUNNEL WIRELESS SENSOR NETWORK (TWSN)

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ABSTRACT

A routing protocol is a core issue in Wireless Sensor Network (WSN) especially on undetermined situation and crucial condition to guarantee the transmission of data. Therefore, any implementation of routing protocol in a tunnel environment will suit with their application to minimize dropped data in its communication. This paper presents a biological routing protocol named as Biological Tunnel Routing Protocol (BioTROP) in Tunnel Wireless Sensor Network (TWSN). BioTROP has been tested with four challenging situations for marking its standard soon. By setting it in low power transmission, all nodes appear as source node and intermediate nodes concurrently, faster transmission rate and free-location setup for each node; these conditions make BioTROP as an ad-hoc protocol with lightweight coding size in tunnel environment. This protocol is tested only in real test bed experiment using 7 TelosB nodes at a predetermined distance. The results have shown more than 70 percent of the transmitted data packets were successfully delivered at the base station.

KEYWORDS

Routing Protocols, Tunnel Wireless Sensor Network, Biological Inspired Techniques, Ant Colony Optimization

1. INTRODUCTION

As one of the areas under Wireless Underground Sensor Network (WUSN), Tunnel Wireless Sensor Networks (TWSN) have different propagation characteristics of EM waves due to confined space condition although the signal propagates through the air. The structures of the mines and road or subway tunnels can contribute to refraction and reflection effect to create an unbalanced communication which leads to early invalidation of nodes close to the base station [1][2]. On the other hand, multi-path fading phenomenon and material absorption will contribute to extreme path loss in TWSN communication.

Apart from the challenging environment, TWSN area also circles by the limitations of sensor nodes manufactured setup such as low memory computational and limited battery usage. Therefore, most of the researchers come with unique and special method in developing routing protocol. A lightweight routing protocol is a major scheme chosen by certain researchers to minimize the power consumption and total coding size in sensor node. Even though in reality, the detail and various problem handler schemes in proposed routing protocol will contribute inversely to tackle thousands of possibilities and unexpected risk situation.

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Otherwise, the researcher set the different active time of sensor node as well as limits the number of the source node to control the signal traffic. However, it is quite tough in the installation process and not maximizes the sensor nodes that distributed. Therefore, the ideal routing protocol must have nature awareness, reliable in heavy source node, effective in ad hoc situations and faster transmission rate with lower power consumption. Although many kinds of application occur in a tunnel underground such as environmental monitoring, infrastructure monitoring, location determination, and security monitoring, the core challenging problem in TWSN is how the routes in the network maintain and reliable in multi-hop communication.

Based on the challenging issues that discussed, the proposed routing protocol must ensure the secure communication and connection to send the data from source node to base station. In this project, it is envisaged, the proposed routing protocol, Biological Tunnel Routing Protocol (BioTROP) shall be an easier method than previous model done in various approaches. This is considered an ant's behavior concept that will try to find any way to reach the food area. Besides that, the ant agent is guided also by optimal forwarding calculation to determine the best next hop neighbour.

2. SYSTEM DESIGN OF BIOTROP

By the awareness of more refraction and reflection of signal occurred in tunnel condition, TWSN needs the simple technique and practice to suit the limited memory and storage space in the wireless sensor device. Therefore, BioTROP uses the cross-layer interaction [3] in its design process to achieve high gains in the overall performance. The concept of cross-layer design for sharing information among two or more layers for adaptation purposes is to increase the inter-layer interactions [4, 5, 6]. BioTROP uses communication between physical layer and network layer in order to select the next hop forwarding as shown in Figure 1. The process at the network layer consists of the discovery of an optimal neighbouring node based on calculated optimal forwarding progress value via physical parameters translated as metrics. The physical parameters are the signal strength, link quality indicator (LQI) and remaining power. The forwarding metrics are used in routing management module to determine the next hop communication.

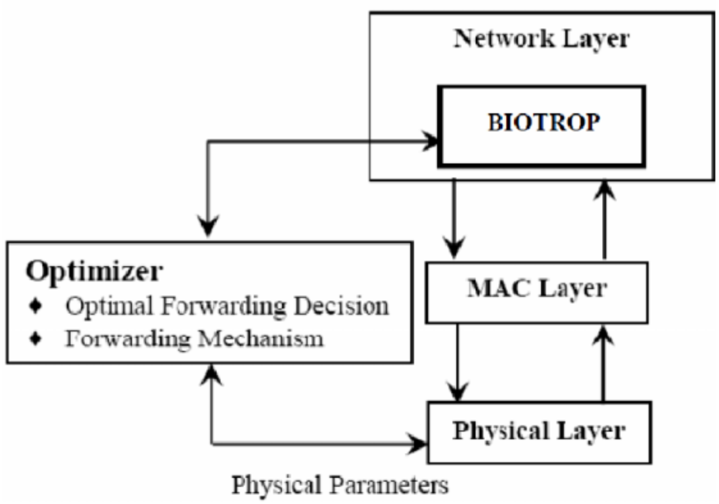

Figure 1. Cross-layer concepts in BioTROP

Based on BioTROP's role played in design approach, it consists of two functional modules that include routing management and neighbourhood management as shown in Figure 2. The neighbourhood management discovers a subset of forwarding candidate nodes and maintains a neighbour table of the forwarding candidate nodes. The routing management determines the optimal route to the destination and forwards the packet based on the unicast forwarding mechanism. If any problem occurs while routing the data packets, the routing management

implements routing problem handler. Unicast forwarding mechanism is used to forward the data packet to best next node towards the destination.

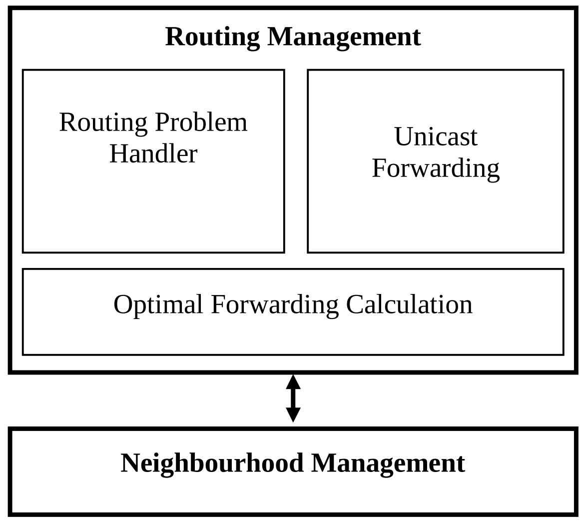

Figure 2. Functional Components of BioTROP

2.1. Routing Management Module

As a main role in BioTROP, routing management supports three sub functional processes; optimal forwarding calculation, unicast forwarding mechanism and routing problem handler as shown in Figure 2. The selection of next hop node determined by optimal forwarding calculation that considers three parameters or criteria which are packet reception rate (PRR), link quality indicator (LQI) and remaining power level. The routing problem handler is used when the sender node does not receive Backward Ant agent. Figure 3 shows the state machine diagram of the routing management.

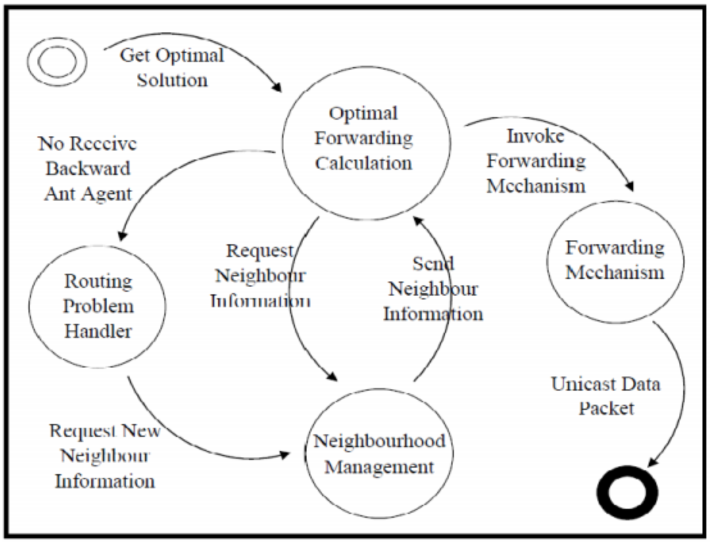

Figure 3. State Machine Diagram of Routing Management Module

The routing management module starts when the sensor node sends or receives a Request to Reply (RTR) packets to or from its neighbour nodes. Each node was set with 1 packet per second on their transmission rates and will broadcast the RTR packets twice at the earlier of 2 second. At the same time, each node will be on the alert to receive any RTR packets and reply to the sender immediately with three parameters. Therefore, there are different role played in searching the optimal neighbour node at an earlier stage. Based on TelosB datasheet, the transmit data rate of TelosB node is 250 kilobits per second (kbps). So, this project allocates 2 second so that each source node has sufficient period in receiving, analyzing and re-sending process.

Refer to Figure 3, the optimal forwarding calculation task acts as the main role in routing management module. Each receiver node will prepare the forwarding metrics as requested from source node to get the optimal solution. For realizing it, the optimal forwarding calculation task will request the neighbour information twice in 2 second to obtain physical parameters such as packet reception rate, link quality indicator and remaining power. The calculation will follow as equation (1). The value of λ_1, λ_2 and λ_3 is determined by a table tabulated by Ahmed [7] using heuristic methods. Therefore, this project chose λ_1= 0.4, λ_2 = 0.3 and λ_3= 0.3. After receiving the needed parameters, the routing management stores the replies in the neighbour table. The router management will forward a data packet to the one-hop neighbor that has an optimal forwarding. The optimal forwarding (*OF*) is computed as follows:

$$\begin{aligned} &OF = \max[(\lambda_1 \times PRR) + (\lambda_2 \times LQI) + (\lambda_3 + Remaining\ Power)] \\ &where\ \lambda_1 + \lambda_2 + \lambda_3 = 1 \\ &\qquad \lambda_1 = 0.4,\ \lambda_2 = 0.3\ and\ \lambda_3 = 0.3 \end{aligned} \tag{1}$$

The forwarding mechanism will be invoked after routing management module selects the best progress neighbour in the optimal forwarding calculation. Finally, the data packets will be sent to the selected neighbour node by unicast forwarding mechanism. The complete finding of route from source node to destination node will be guided by the ant agent. However, the routing management module will invoke the neighbourhood management module again if does not receive Backward Ant agent after launched the Forward Ant. Therefore, if the connection between a source node and destination node is fine, the survey process only takes once and then will minimize the delay time to 2 second.

2.2. Neighbourhood Management Module

Refer to Figure 4, this module starts after routing management module requests neighbour information. First, it will request neighbour discovery by broadcast the RTR message. Any neighbour information received will be recorded in the neighbour table. Otherwise, this initiative was carried out 2 times to maximize the number of neighbour node that can be detected. Therefore, the neighbourhood procedure will update the neighbour table such as PRR, LQI and remaining power when receive the new ID of neighbour node and the neighbour table is less than 6 nodes. If the selected neighbour node at routing management module faces any problem, the neighbourhood management module will invoke neighbour replacement task to replace neighbour information. Finally, the neighbourhood management module will send the updated neighbour information to routing management module.

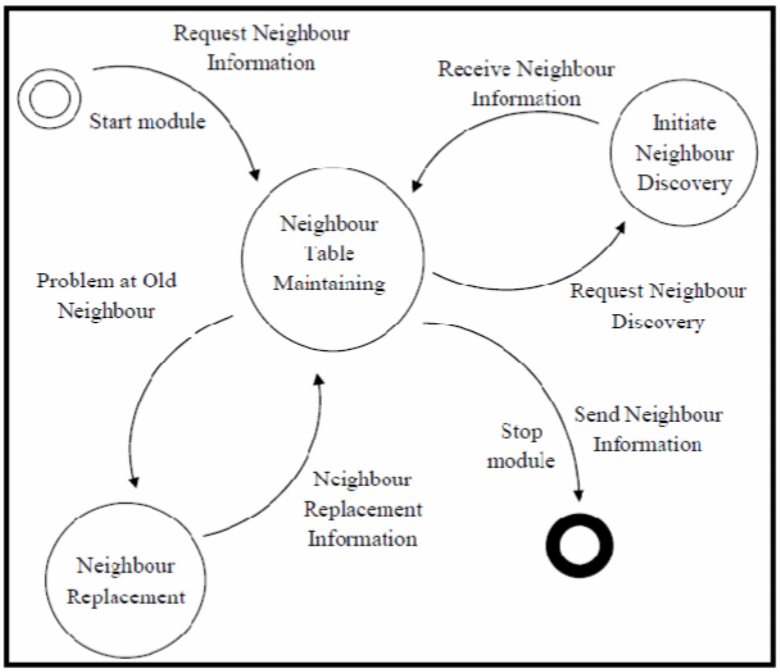

Figure 4. State Machine Diagram of Neighbourhood Management Module

3. METHODS AND EXPERIMENTAL SETUP

The tests were run using a simple network topology in one of the culverts at the Industrial Training Institute (ITI) Marang, Terengganu as shown in Figure 5. The BioTROP are embedded into 7 TelosB nodes and the nodes are sending at rate 1 packet per second, which is double with suggestion rate. According to TelosB's manufacturer, the optimum rate should be 0.5 packets per second, because higher rates can lead to congestion [8]. In this experiment, all of six nodes (Node 1 to 6) will send the data packets or acts as Full Function Device (FFD). Node 0 was set as the base station and each node might run as the intermediate node between a source node and base station node that created. Therefore, the role of each node will maximize to collect the data while in tunnel condition.

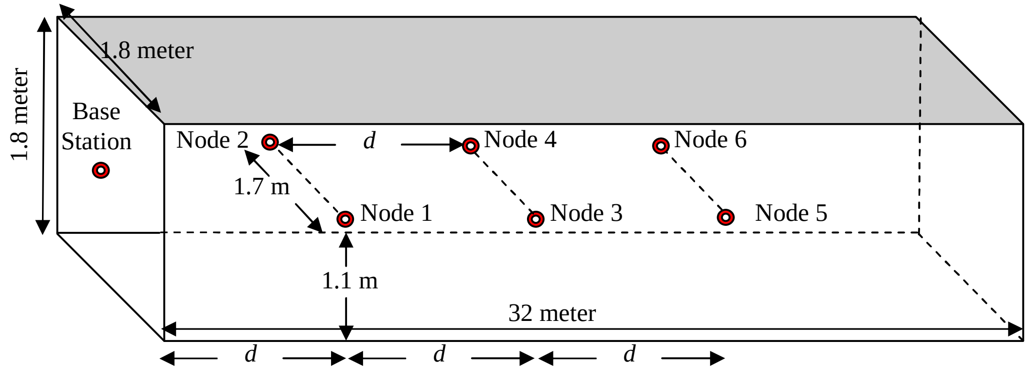

Figure 5. The view of experimental setup

The TelosB RF transceiver uses CC2420 component that compliant with IEEE 802.15.4. Therefore, there are 8 power settings transmission that are allowed as specified at Figure 6 [9]. For this project, the BioTROP is embedded with two different power transmissions which are -25 dBm and -15 dBm, where these are the two lowest settings in TelosB mote. Meanwhile, the distance between the nodes, *d*, was varied from two meters to eight meters. The performance will be in term of Packet Delivery Ratio (PDR), Packet Drop Ratio (PDropR) and Packet Reception Rate (PRR). These performances will be observed at the base station in 5 minutes. The analyzing of result between both power transmissions were done on the three performances.

PA_LEVEL	TXCTRL register	Output Power [dBm]	Current Consumption [mA]
31	0xA0FF	0	17.4
27	0xA0FB	-1	16.5
23	0xA0F7	3	15.2
19	0xA0F3	-5	13.9
15	0xA0EF	-7	12.5
11	0xA0EB	-10	11.2
7	0xA0E7	-15	9.9
3	0xA0E3	-25	8.5

Figure 6. Output Power Settings and Typical Current Consumption @ 2.45 GHz

4. RESULTS AND DISCUSSIONS

This section discusses the implementation's result of BioTROP in TWSN testbed. The three sub-section below has been designed to simplify the explanation and conclusion will be made.

4.1. Power Transmission of -25 dBm

In this subdivision, BIOTROP was tested on TelosB motes using power transmission -25 dBm or 3.16 μWatt. Refer to Figure 6, the transmission power was set to code 3 which is lower on the list. The graph in Figure 7 shows the percentage of packet delivery at the base station from each node in different distance. The detail value for each result is shown in Table 1.

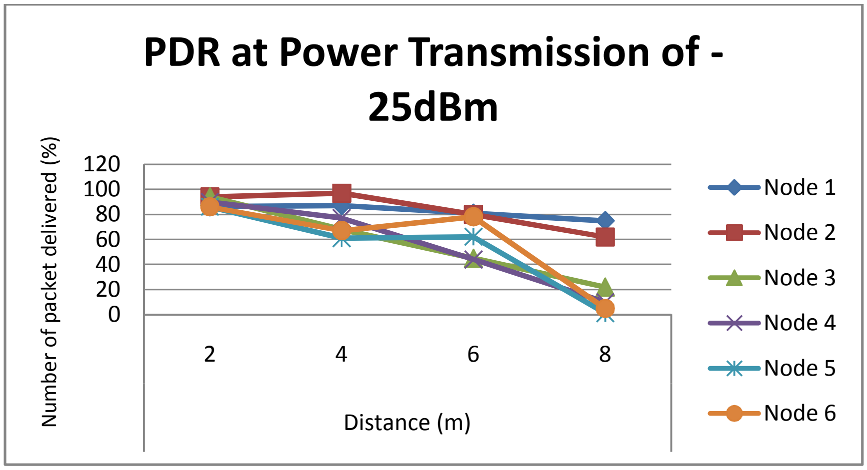

Figure 7. Packet Delivery Ratio (PDR) at -25 dBm power transmission

Table 1. The value of PDR (%) at -25 dBm power transmission.

Node / Distance	1	2	3	4	5	6
2 meters	86	94	94	90	86	86
4 meters	87	97	68	77	61	67
6 meters	81	80	45	44	62	78
8 meters	75	62	22	10	1	5

Since node 1 and node 2 are near to the base station, so the data packets delivered are high which exceed 80 percent at 2, 4 and 6 meters. Generally, all data packets from all nodes consistently deliver to the base station at 2 meters. This shows the BioTROP algorithm able to construct the entire available sender nodes at this distance. However, the PDR drops quite drastically at 6 meter especially on node 3 and node 4. The decreasing is happening due to the symptom of coverage loss that caused by interference and attenuation in the tunnel if compared to node 5 and 6 performances that farther located. Meanwhile at 8 meter distance, most of the nodes do not deliver well to base station node. The lowest power transmission in this setting might contribute to low PDR that obtained.

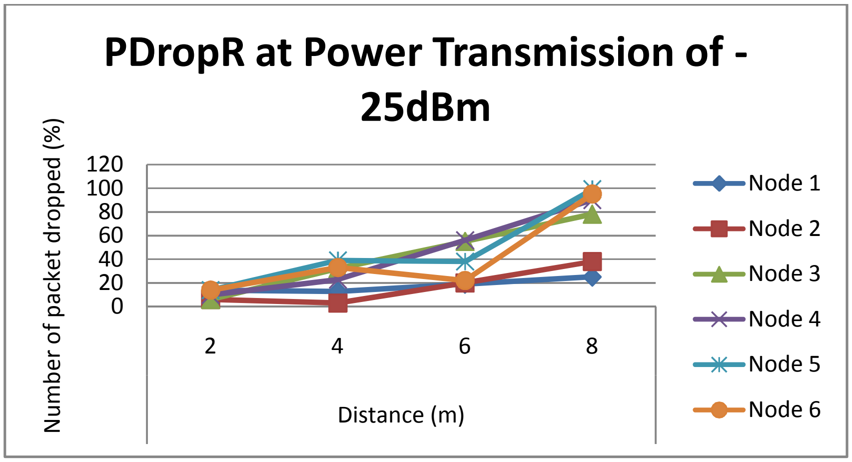

Figure 8. Packet Dropped Ratio (PDropR) at -25 dBm power transmission

The Figure 8 shows the percentage graph of the Packet Dropped Ratio (PDropR) meanwhile Table 2 shows the value for each result obtained. Refer to Figure 8 and Table 2, the data packets averagely dropped are 4 percent, 12 percent, 24 percent, 26 percent, 29 percent, and 34 percent respectively for node 1, node 2, node 3, node 4, node 5 and node 6 as the distance changes. Although most of packets sent dropped exceeds than 20 percent at 8 meters, it is not enough to evaluate the BioTROP algorithm totally. In lowest power transmission, the probability to detect the available neighbour nodes is low. Thus, this situation pushes the neighbourhood management module frequently to initiate new neighbour node discovery. Then, it will use the time located for searching process without sending any data packets as well as no neighbour node detected.

Table 2. The value of PDropR (%) at -25 dBm power transmission.

Node / Distance	1	2	3	4	5	6
2 meters	14	6	6	10	14	14
4 meters	13	3	32	23	39	33
6 meters	19	20	55	56	38	22
8 meters	25	38	78	90	99	95

Figure 9 shows the packet reception rate at the base station for each node with detail value in Table 3. As discussed earlier, the experiment sets the packets sending rate of 1 packet per second. Thus, the best performance of PRR at the base station for each node is 1 packet per second supposedly. As shown in Figure 9 and read in Table 3, all nodes achieve packet delivery more than 0.85 PRR (85%) at the closest distance. Meanwhile at 4 meters, only node 1 and node 2 perpetual achieve exceed 0.85 PRR. Meanwhile node 3, 4, 5 and 6 had started to decline to 0.68 PRR, 0.77 PRR, 0.61 PRR and 0.67 PRR respectively. From a distance of 6 meters, three different phenomena were observed. Node 6 shows increments of packet reception rate meanwhile node 5 maintains at 0.6 PRR. However, node 1, 2, 3 and 4 decreased to 0.81 PRR, 0.80 PRR, 0.45 PRR and 0.44 PRR respectively. At 8 meter distance, only node 1 and 2 still exceed than 0.5.

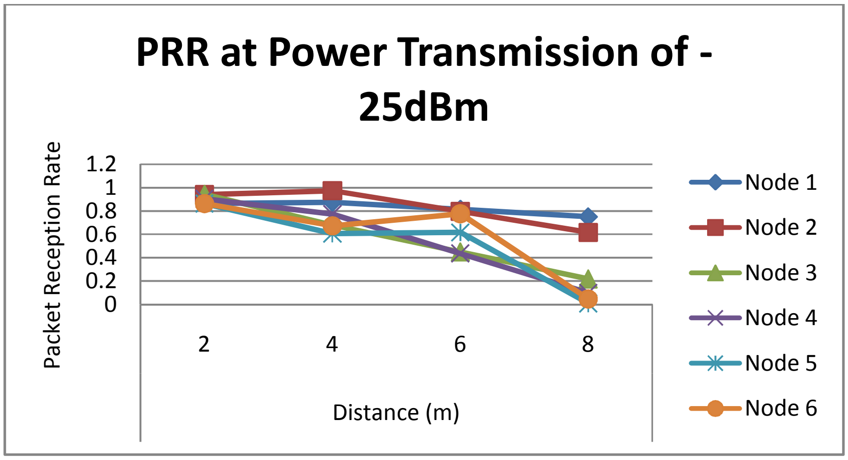

Figure 9. Packets Received Rate (PRR) at -25 dBm power transmission

Table 3. The value of PRR at -25 dBm power transmission.

Distance \ Node	1	2	3	4	5	6
2 meters	0.863	0.940	0.943	0.903	0.863	0.863
4 meters	0.873	0.973	0.680	0.773	0.607	0.673
6 meters	0.813	0.797	0.450	0.437	0.617	0.776
8 meters	0.750	0.617	0.220	0.100	0.010	0.047

4.2. Power Transmission of -15 dBm

This experiment sets the power transmission at -15dBm or 31.6 µWatt for all nodes with the same distance. As inferred in Section 4.2, the low power transmission setup will contribute to the decreasing pattern when the distance between source nodes is increased in the first experiment. Hence, this experiment is done to compare and analyze the performance with initial experiment. Otherwise, the more sources node can be detected by the base station and more precise conclusion can be made for both experiments.

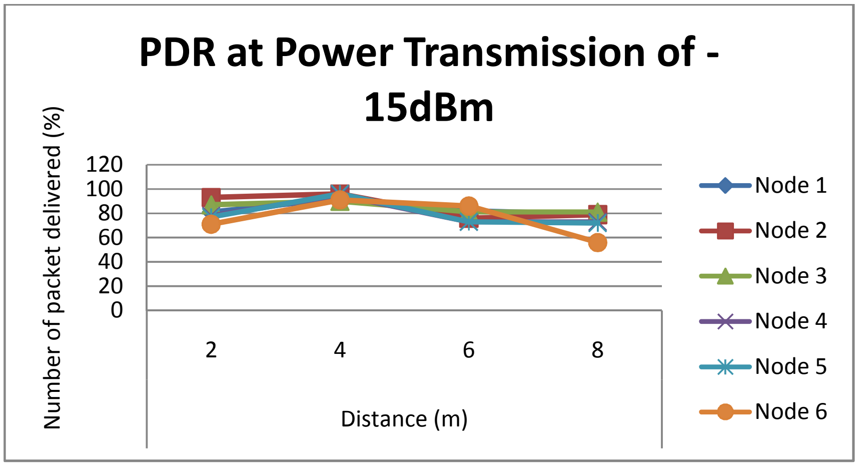

Figure 10. Packet Delivery Ratio (PDR) at -15 dBm power transmission

Figure 10 shows the consistent result of Packet Delivery Ratio (PDR) for each node at the base station. As can be observed in Table 4, the average of percentage packets delivered fluctuates slightly from 2 meters to 8 meter distance. In closest position, node 1, 2 and 3 shows that 81 percent, 93 percent and 87 percent of data packets delivered at base station respectively. Despite the distance of node 4 same with node 3, only 78 percent of data packets are delivered. Meanwhile, 77 percent and 71 percent of data packets delivered respectively for node 5 and node 6. This unbalance observation may be due to the physical condition of the tunnel that prevent certain signals cannot be achieved by most nodes. On the other hand, the result of each node for scenario 2 displays the excellent accomplishment. The entire node delivers the packet data successfully to base station more than 90 percent. Although the result for scenario 3 and scenario 4 decreased slightly for average node, the data packets delivered still exceed 70 percent. However, only node 6 given less than 60 percent at 8 meters. This might due to the distances and interference in the tunnel during an experiment.

Table 4. The value of PDR (%) at -15 dBm power transmission.

Node / Distance	1	2	3	4	5	6
2 meters	81	93	87	78	77	71
4 meters	92	96	90	95	96	91
6 meters	82	76	81	73	73	86
8 meters	79	79	81	73	72	56

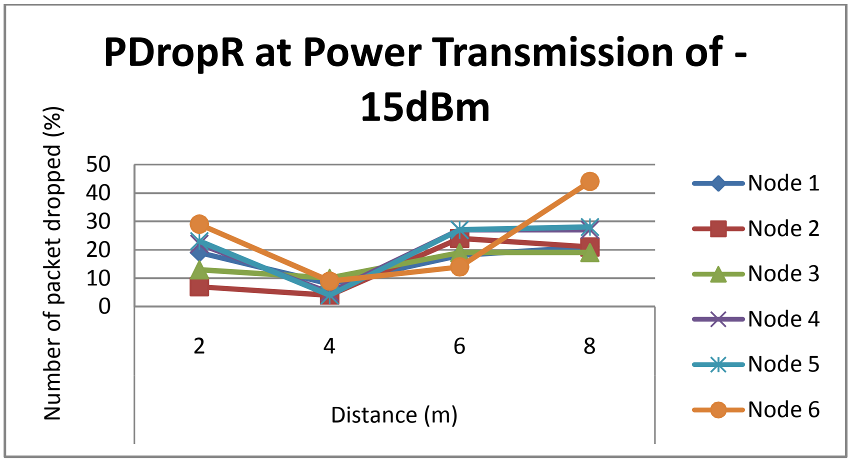

Figure 11. Packet Dropped Ratio (PDropR) at -15 dBm power transmission

Table 5. The value of PDropR (%) at -15 dBm power transmission.

Node / Distance	1	2	3	4	5	6
2 meters	19	7	13	22	23	29
4 meters	8	4	10	5	4	9
6 meters	18	24	19	27	27	14
8 meters	21	21	19	27	28	44

Figure 11 focuses on the Packet Dropped Ratio (PDropR) of each node at the base station. Similar to the initial experiment result discussed previously, the total of packets data supposedly sent minus to the packets delivered will produce the value of packets dropped. Based on the graph, all nodes only lost its data packets not more than 30 percent at 2 meters. However, excellent result showed at 4 meters where only minimum of 10 percent data packets dropped. Although there is slightly increasing of data packets dropped at 6 meters, it still lower than the maximum data packet drop at 2 meters. The result showed consistent at 8 meters where the range of data packets lost similar to 6 meters. Only node 6 shows an unpredictable result even though the distances setup same with opposite neighbour, node 5. Generally, most of nodes receive the other routes to forward and same time sends its data packets to the base station fluently.

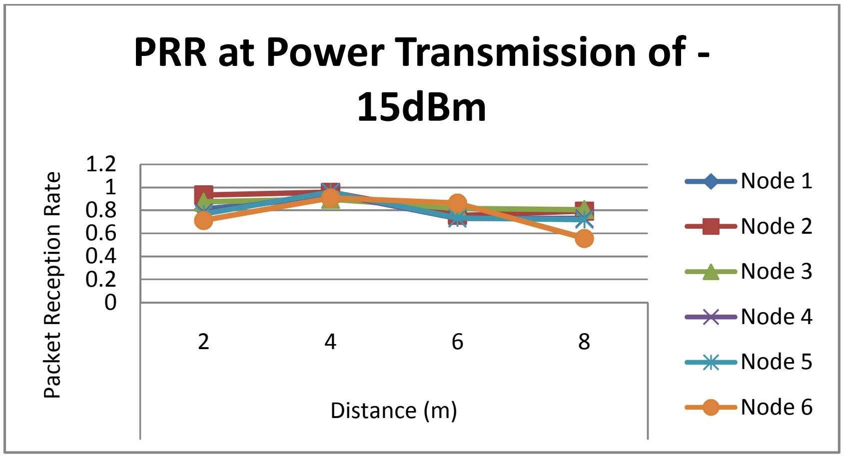

Figure 12. Packets Received Rate (PRR) at -15dBm power transmission

Figure 12 shows the PRR result of this experiment and Table 6 interprets the detail value. Referring to the result at 2 meters, the rate of packets received at the base station for each source node is more than 0.7. Even at the shortest distance setup, only node 1 and 2 can deliver almost all its data packet to base station. Differ at 4 meters, all nodes can interact between each other very well by producing more than 0.89 or 89 percent data delivered. However, the data packets of all nodes gradually decrease at 6 meters. Only node 1, 3 and 6 accomplish the data packets delivered more than 0.8. For farthest distance, the PRR of node 1, 2, 3, 4 and 5 is similar which is above 0.7 PRR. However node 6 was given less than 0.6 PRR.

Table 6. The value of PRR at -15 dBm power transmission.

Node / Distance	1	2	3	4	5	6
2 meters	0.810	0.933	0.873	0.783	0.770	0.713
4 meters	0.917	0.957	0.897	0.947	0.960	0.907
6 meters	0.817	0.757	0.817	0.730	0.733	0.863
8 meters	0.793	0.793	0.807	0.730	0.720	0.557

4.3. Comparison for Both Experiments

This section will discuss the comparison result between first experiment and second experiments by referring to the distances setup as follows:

Refer to the result of 2 meter setup in the first experiment, all nodes successfully deliver its data packet despite of the lower power transmission setup. This observation differs to the same distance in the second experiment as discussed previously where there are disorders in receiving data especially on node 6. Theoretically, when the power transmission increase, more neighbour node can be detected by source nodes at the same distance. Therefore, more signal of source node will be detected by the base station node. This phenomenon will contribute the lower result of PRR for node 5 and node 6 because of signal interference or high multi-path effect.

Furthermore, almost all node start decreases gradually at 4 meter setup for the first experiment. Only the closest node to a base station which node 1 and node 2 have shown very slightly increased. It happens due to lack of power transmission for others source nodes. Thus, signal interference for base station node in minimizes condition at this situation. For signal condition between node 3 and 6, more than one device transmits at the same time which can create co-channel interference [1]. As a result, signal attenuates and data packet cannot be sent. However, the result at second experiment gives the confident performance for BioTROP. All nodes sent successfully more than 89 percent PDR. These outcomes prove that the power transmission of -15 dBm is able to overcome the tunnel environment problem that occurred in the first experiment.
At 6 meter distance in both experiments, no nodes increase its packet reception rate at the base station besides on node 5 in the first experiment. However, the slight increasing of PRR on node 5 in first experiment still does not exceed the packet reception rate observed at each node in the second experiment. Other problems that have been discussed previously are environmental interference. Certain location node has unexpected surface such as small tree that grows in between the structure connector and also water hole. Thus, in a weak signal condition and more types of interference occurred, no more data packet can be sent at 6 meter distance.

The furthest distance, 8 meters imposes more challenges to BioTROP algorithm. Totally source nodes decreased drastically especially on node 3, 4, 5 and 6 in the first experiment. At this distance with lowest power transmission, the adjacent neighbours cannot be detected by source nodes to make guarantee connection. Thus, the complete route from source to destination node cannot be developed. On the other hands, it will be interesting to discuss the result at the same distance in the second experiment. As shown in Figure 4.8, most of nodes managed well to reduce the reduction of data packet dropped beside of node 6. Refer to the result of node 6 in previous distance setup, the increase or reduction of the graph not drastically as shown in 8 meter distance. Thus, it may cause of the software problem that happen in reading process.

As an overall, the results obtained at four different distance setup as discussed above attributed more to external factor only. By the way, there are neighbourhood discovery times in each node when the neighbour discovery module invoked. The finding of routes from source to destination by Ant Agent for each node was set to push the neigbour discovery module in 2 minutes at the starting point. Thus, it will maintain the neighbour table as long as the source node receives the Backward Ant before sending the data packets. If the source node does not receive the Backward Ant agent, the request to reply (RTR) message will broadcast again to find the new neighbour. Thus, it will take the time allocated for sending the data. If the more frequent unstable signal occurs and then the source node does not receive Backward Ant agent, it will cause the neighbor discovery module invoked much time. Nevertheless, BioTROP's performance showed can be improved by restructuring or minimize the timer of finding neighbor nodes.

5. CONCLUSIONS

The routing protocol developed in WSN area using two types of function nodes which are Full Function Device (FFD) and Reduce Function Device (RFD) [1] to create multi hop communication. FFD node will play two roles at the same time which are sourced node and intermediate node. Meanwhile RFD node just receives and forwards the data packet from source to destination. Both functions are implemented to reduce the congestion of the signal in order to guarantee the data packet delivered. Therefore, BioTROP challenged this limitation by setting all nodes as FFD and run in the confine region which is tunneled underground. Hence, the usage of sensor node is in fully functional condition to improve the effectiveness of sensing in any application. In addition, the proposed algorithm in BioTROP has been developed in simple programming codes in TinyOS 1.x. So, the further improvement and study will be easier and more flexible. Otherwise, BioTROP uses low power transmission to enhance the lifetime of sensor node in real implementations.

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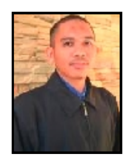

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