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REAL-TIME LOAD DISTRIBUTION VIA PARTICLE SWARM OPTIMIZATION FOR WIRELESS SENSOR NETWORK (WSN)

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ABSTRACT

Wireless sensor network (WSNs) are highly distributed self-organized systems. They rely on significant numbers of scattered low-cost tiny devices featuring strong limitations in terms of processing, memory, communications and energy capabilities. Sensor nodes collect measurements of interest over a given space, making them available to external systems and networks at special nodes designated sink nodes. In order to maximize the autonomy of individual nodes (and consequently the longevity of the network), power saving techniques are commonly implemented, causing nodes to sleep most of the time, complemented with low power communications that usually lead to multi-hop data transmission from sensor nodes to sink nodes and vice versa. While link reliability mechanisms can significantly reduce the end-to-end packet loss ratio, some critical WSN applications require high or even total end-to-end reliability, demanding the use of a reliable transport layer protocol. Therefore, the objective of this research is to develop and implement a reliable data transfer protocol that can provide an excellent reliability to packets from source to destination via hop by hop basis. The effectiveness of the proposed protocol is evaluated with different scenario parameters such as in terms of throughput, node reliability and energy loss in the network. The paper is organized as follows. Section 1 reviews overall wireless network groups and Section 2 reviews the Wireless Sensor Network (WSN) in detail. Section 3 discuss about the related work in the areas of real-time routing protocols in WSNs and specific problem statement. The Particle Swarm technique is presented in Section 4 while Section 5 covers real time load distribution concept and experiment setup. The paper is concluded with the analysis of the experimental results in Section 6 and the main conclusion in Section 7.

Keywords: wireless sensor network, particle swarm, optimization, link reliability, network lifetime.

INTRODUCTION

Wireless networking has revolutionized the way we communicate in the present time. Moreover, it has gone through a tremendous growth in recent years and has become one of the fastest growing telecommunication sectors [1]. Wireless network is divided into several categories according to the geographical area within which a user is still in the coverage of the network as shown in Figure-1.

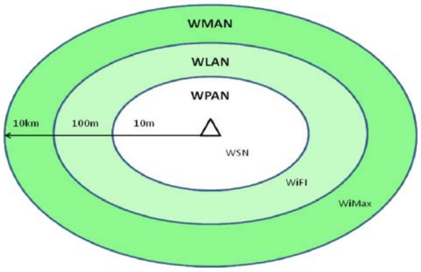


Figure-1. Wireless Network Groups [1].

There are four main groups; Wireless Wide Area Network (WWAN), Wireless Metropolitan Area Network (WMAN), Wireless Local Area Network (WLAN) and lastly Wireless Personal Area Network (WPAN), in descending order. The first group, WWAN covers up to 35 kilometres radius. This group employs mobile operators in the network infrastructure by means of which they provide wireless connection covering the widest area compared to the others. The next group, WMAN, which is commercially known currently as Worldwide Interoperability for Microwave Access (WiMAX) is used to connect user to the internet wirelessly but with a very high data rate (which is up to 2Mbps). The third group is the WLAN, where its coverage is approximately 30 meters indoors and 100 meters outdoors. WLAN is generally known as Wireless Fidelity (WiFI). Last but not least is the WPAN which has a maximal signal range of 10 meters and this network is used to interconnect the devices to one another. The Wireless Sensor Network falls under this category. Wireless Sensor Network (WSN) has evolved tremendously throughout the years. Furthermore, this process has been spurred by the creation of Micro-Electro-Mechanical Systems (MEMS) which brought about the development of smart sensors [3]. These sensors are manufactured to be small, with limited processing and computing resources, and they are cheaper compared to traditional sensors. The latter is extremely important, due to the fact that these sensors will be deployed in a very large amount (from ten to thousands of units) throughout the designated area in order to either monitor or track certain parameters or objects. More applications on WSN will be discussed in later chapters.

WIRELESS SENSOR NETWORK

A Wireless Sensor Network (WSN) consists of spatially distributed autonomous sensors to monitor physical or environmental conditions, such as temperature, sound, vibration, pressure, motion or pollutants and to cooperatively pass their data through the network to a main location [12].

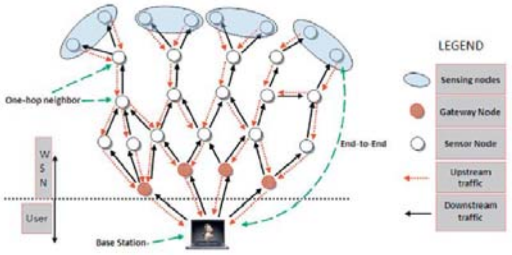


Figure-2. Wireless Sensor Network [12].

Basically, WSN is formed by several sensor nodes that form the backbone of the network. These sensor nodes can be divided into several groups such as sensing nodes, sensor or forwarding nodes and gateway or sink nodes. Sensing nodes are the main act in WSN whereby these nodes are programmed to sense the intended parameter, insert the data into packets and sent out the packets. Then, forwarding nodes are used to forward the packets to the target by choosing the best neighbor node to relay the packet. Meanwhile, the gateway or sink nodes are connected to base station via Universal Serial Bus (USB) connection or via wireless connection. These gateway nodes are used as intermediate between base station and the network. WSN has a great potential for various kinds of applications. Among the applications are military and agriculture. It could be either environmental application such as temperature or humidity monitoring, or even to the simple task as a switch to control the lights in a house (home application). To be more specific, WSN can be applied to several main fields including military applications such as battle field surveillance and the monitoring of friendly forces or the enemy troops. Besides military, WSN can also be used in health monitoring purposes; in example tele-monitoring of human data, and other commercial uses for instance, machine monitoring and traffic tracking [5]. Thus from these functions, the WSN can be classified into two categories: monitoring and tracking [3]. Monitoring covers aspects such as indoor/outdoor monitoring, power monitoring, factory and process automation, and seismic and structural monitoring. On the other hand, tracking includes the tracking of objects, animals, humans, and vehicles.

In using WSN, there are several general challenges for multi-hop network due to the characteristics of the nodes which are manufactured to be low powered, low rate, with limited computational capabilities and limited coverage. One of the most important issues that have to be managed is the minimization of the energy usage. Due to the power constraints, the power consumption has to be minimized, because the only source of power for the sensor nodes is the battery. The target of developing WSN is so that the batteries have to be replaced once every one or two years. Thus it would beat the purpose if the battery consumption is too high. Thus the proposed technique must consume minimum power. Most low-power wireless networks usually have unreliable links with limited bandwidth, and their link quality can be heavily influenced by environmental factors. Recent empirical results, obtained on the Berkley mote platform indicate that wireless links are highly probabilistic, asymmetric, and the link quality (i.e., packet reception rate (PRR)) depends on the transmission power and the distance traveled by a packet. As a result, communication delays in such system are highly unpredictable. Consequently, the link quality between sensor nodes in WSN should be considered while designing multi-hop routing in order to achieve high throughput for WSN [1]. Besides that, the limitations on the memory and computational capabilities restrict the size of the packets to be sent and the data rate used for packet transmission. Thus it is desirable to develop and implement a reliable real-time load distribution protocol that can provide a certain degree of reliability, with certain amount of delay or packet loss if any.

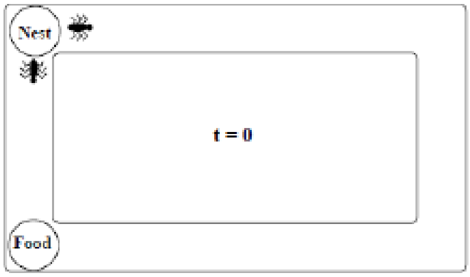
RELATED WORK & PROBLEM STATEMENT

Adel [5] proposed a Real-time Load Distribution (RTLD) technique where sensor node will have to query the health and the availability of the neighboring nodes each time it has data to be transmitted. This technique is not efficient as will cause the battery to drain out fast hence increasing the energy loss and decreasing the network lifetime. Zhang [16] proposed three ant-routing algorithms for sensor networks. The Sensor-driven Cost-aware Ant Routing (SC) , the Flooded Forward Ant Routing (FF) algorithm, and the Flooded Piggybacked Ant Routing (FP) algorithm. The SC algorithm is energy efficient but suffers from a low success rate. The FF has shorter time delays; however, the algorithm creates a significant amount of traffic. Despite high success rate shown by the FP algorithm, it is not energy efficient. An adaptive ant-based Dynamic Routing (ADR) algorithm using a novel variation of reinforcement learning was proposed by Lu [17]. The authors used delay parameter in the queues to estimate the reinforcement learning factor. Aghaei [18] proposed two adaptive routing algorithms based on ant colony algorithm, the Adaptive Routing (AR) algorithm and the Improved Adaptive Routing (IAR) algorithm. To check the suitability of the ADR algorithm in case of sensor networks, they modified the ADR algorithm (removing the queue parameters) and used their reinforcement learning concept and named it the AR algorithm. The AR algorithm did not result in optimum solutions. In IAR algorithm, by adding a coefficient, the cost between the neighbor node and the destination node, they further improve the AR algorithm. When [19] proposed a dynamic adaptive ant algorithm (E&D ANTS) based on Energy and Delay metrics for routing operations. Their main goal is to maintain network lifetime in maximum and minimize the propagation delay by using a novel variation of reinforcement learning (RL). Load distribution algorithm in the WSN is normally focused on clustering techniques where the protocol determines several nodes as cluster head nodes to take responsibility as system administrator. In LEACH [15], nodes periodically rotate cluster head responsibilities to balance their energy consumption. This rotation is governed by the remaining energy level. Nodes transfer data to parent nodes or the cluster heads which in turn will be conveyed to the sink node. Nodes with highest remaining energy level will be elected as cluster heads. PEGASIS [17] improves the protocol developed by [15] by preventing duplication of data transmissions among cluster heads and introduces aggregation of data at the cluster heads. Firefly protocols by [18] develop control messages in order to synchronise and coordinate network functions across the network while Heartbeat protocols by [19] are used to determine if the node is alive and reach ability of remote nodes.

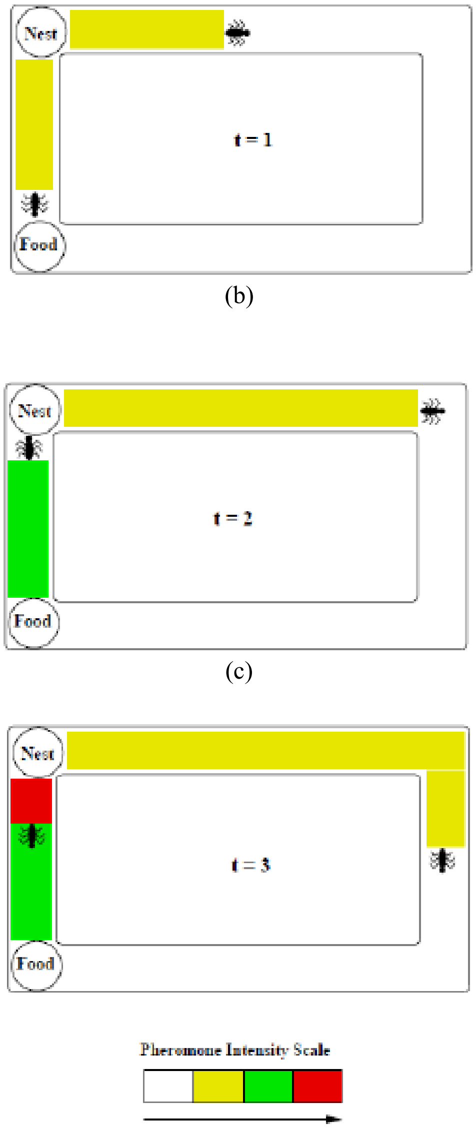
The main challenges that are tackled in this research are the increase of throughput and network lifetime where these two parameters are key in determining a successful wireless sensor network. Throughput determines the number of packets that are successfully transmitted from a sensor node to sink node within a period of time. In the meantime, the network lifetime will be increased tremendously if we can reduce the energy loss of a wireless sensor node. This will provide a huge contribution to operators of WSN as they don't have to change the batteries frequently. Apart from that, the research work also will focus on providing a certain degree of reliability by determining the best route for a packet to travel from source to destination.

PARTICLE SWARM OPTIMIZATION

Particle swarm optimization (PSO) technique is a method drawn upon some computing technique where several mobile agent-based paradigms were designed to solve control and routing problems in telecommunication and networking. The technique used in this research work mimics the ant's behaviour. Although by itself, an ant is a simple and unsophisticated creature, collectively a colony of ants can perform useful tasks such as building nests, and foraging (searching for food). The most interesting discovery is that ants are able to discover the shortest path to a food source and to share that information with other ants through stigmergy and pheromone laying [13].



(a)



(b)

(c)

(d)

Figure-3. Example of pheromone laying by ants.

Figure-3 shows in a schematic way how the effect of round-trip pheromone laying/sensing can easily determine the convergence of all the ants on the shortest between two available paths. At time *t* = 0 two ants leave the nest looking for food. According to the fact that no pheromone is present on the terrain at the nest site, the ants select randomly the path to follow. One ant chooses the longest and one the shortest path bringing to the food. After one time unit, the ant which chose the shortest path arrives at the food reservoir. The other ant is still on its way. The intensity levels of the pheromone deposited on the terrain are shown; where the intensity scale on the right says that a darker color means more pheromone. Pheromone evaporation is considered as negligible according to the time duration of the experiment. The ant already arrived at the food site must select the way back to the nest. According to the intensity levels of the pheromone near the food site, the ant decides to go back by moving along the same path, but in the opposite direction. Additional pheromone is therefore deposited on the shortest branch. At *t* = 2 the ant is back to the nest, while the other ant is still moving toward the food along the longest path. At *t* = 2 another ant moves from the nest looking for food. Again, it selects the path according to the pheromone levels and, therefore, it is biased toward the choice of the shortest path. It is easy to imagine how the process iterates, bringing, in the end, the majority of the ants on the shortest path [20].

The pheromone value is acquired using the probabilistic rule [4] as in equation 1 below. The pheromone value $p_{cv}^{k}(t)$ depends on metrics that includes velocity ***τcv***, packet reception rate (PRR) ***ωcv*** and remaining power ***ηcv***. *α, β* and γ are parameters weights that controls the priority according to the application needs where $p_{cv}^{k}(t)$ is the main entry required by Data Ant agent to move from current node, ***c***to neighboring node,***v*** with the help of***k*** which is the neighboring node ID.

$$p_{cv}^{k}(t) = \frac{[\tau_{cv}(t)]^{\alpha}.[\eta_{cv}(t)]^{\beta}.[\omega_{cv}(t)]^{\gamma}}{\sum_{h \in v_{c}^{k}}[\tau_{cv}(t)]^{\alpha}.[\eta_{cv}(t)]^{\beta}.[\omega_{cv}(t)]^{\gamma}} \qquad (1)$$

where

$$\tau_{cv} = \frac{V}{V_m} \qquad (2)$$

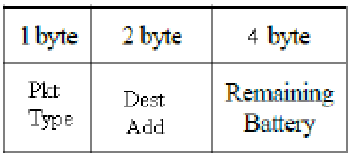
$$\eta_{cv} = \frac{V_{batt}}{V_{mbatt}} \qquad (3)$$

$$\omega_{cv} = \text{PRR} \qquad (4)$$

Vm is the maximum velocity of the RF signal that is equal to the speed of light. *Vmbatt* is the maximum battery voltage for sensor nodes and is equal to 3.3 volts [18]. The determination of PRR, battery voltage *(Vbatt*) and packet velocity (*V*) is elaborated in the following sections.

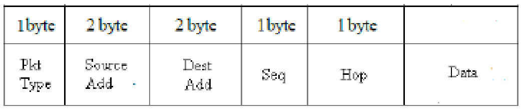
REAL-TIME LOAD DISTRIBUTION VIA PSO EXPERIMENT

There are 3 types of packets involved in this research work which are the control packet and reply packet in Figure-4 and data packet in Figure-5. Both control packet and reply packet is 7 bytes in length while data packets can go up to 100 bytes in WSN. Control packet is used to initiate the request for remaining battery power from neighboring node while reply packet is used to send the requested metric.



1 byte	2 byte	4 byte
Pkt Type	Dest Add	Remaining Battery

Figure-4. Control & Reply packet.



1byte	2 byte	2 byte	1byte	1byte	
Pkt Type	Source Add	Dest Add	Seq	Hop	Data

Figure-5. Data packet.

The experiment was conducted using a simple 4-node network where one node act as the source node, two nodes act as the intermediate nodes and lastly one as the sink node. This setup is shown in Figure-7.

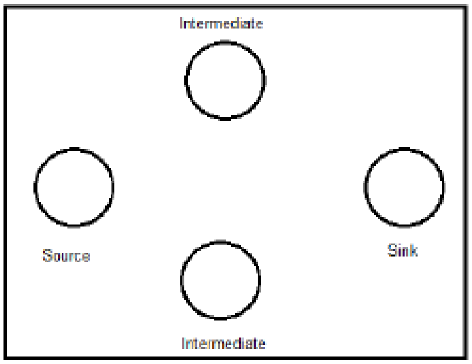


Figure-6. Experiment network setup.

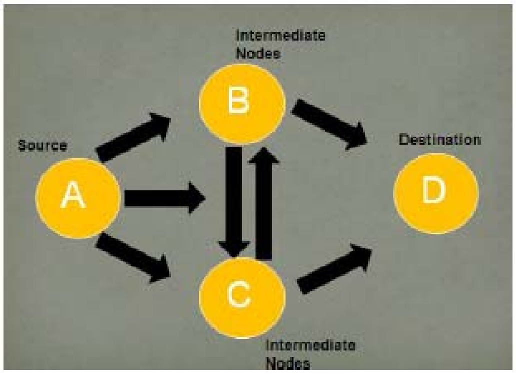


Figure-7. Initialization.

Figure-7 shows the network during initialization period where the network has just been set-up. Node A is the source node, node B and C is the intermediate nodes while node D is the destination node. The range between the nodes varies from 1 to 15 meters for analysis purpose. As the network has just been set-up, therefore there is no any neighborhood information available hence there is no data in neighborhood table. Hence, all the nodes except the destination node broadcast a control packet (shown as black arrow in figure above) requesting for remaining battery level. Once receiving the control packet, all the nodes will immediately reply the requested data with a reply packet (shown as red arrow) as in Figure-8.

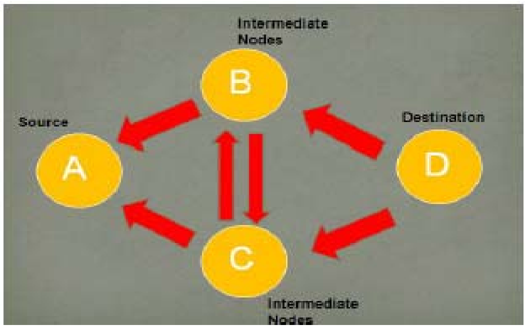


Figure-8. Nodes with reply packet.

From this reply packet, source node can compute the link rate quality which is calculated using the received signal strength (PRR) as in equation (5) while the end to end delay is calculated as in equation (6). Finally, these three parameters are combined in equation (1) in earlier chapter to acquire the pheromone value.

$$PRR = \left[1-\left(\frac{8}{15}\right)\left(\frac{1}{16}\right)\sum_{j=2}^{16}(-1)^{j}\binom{16}{j}\exp\left(20SNR\left(\frac{1}{j}-1\right)\right)\right]^{m} \qquad (5)$$

Where signal to noise ratio is calculated via:

$$SNR = P_t - PL(d) - S_r$$

$$Delay(S,N) = \frac{Round\_trip\_time}{2} \qquad (6)$$

Finally, the proposed work will undergo several analyses such as the packet loss against distance which covers range up to 15 meters. Then, the reliability of the protocol will be analyzed using equation (7) which is conducted to test how efficient the protocol is in delivering data. Apart from that, the other analysis conducted are the packet loss and energy loss of the entire network, using equation (8) and (9), whereby we assume packet loss is directly proportional to energy loss [1].

$$Throughput = \frac{packet\ received}{Packet\ sent} \qquad (7)$$

$$Packet\ loss = \frac{packet\ drop}{Packet\ sent} \qquad (8)$$

$$Energy\ Loss = \frac{packet\ drop}{Packet\ received} \qquad (9)$$

EXPERIMENT RESULTS & ANALYSIS

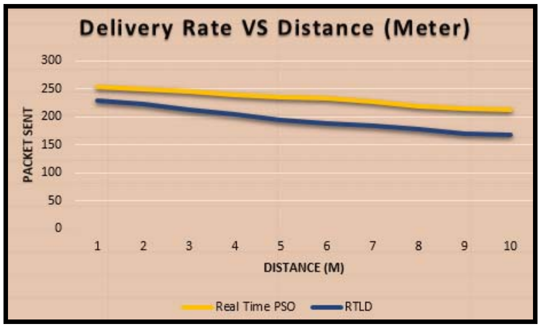


Figure-9. Packet delivery rate vs distance (meter).

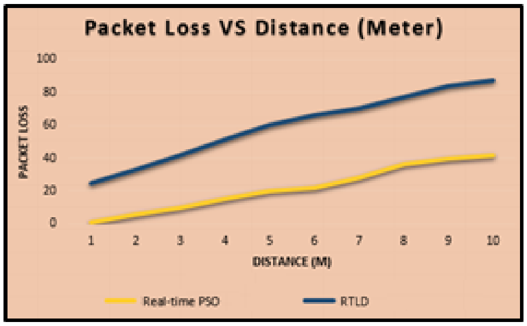


Figure-10. Packet loss vs distance (meter).

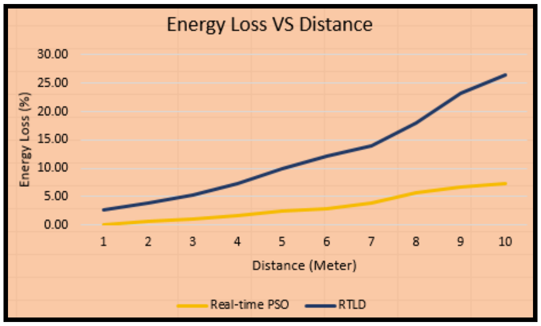


Figure-11. Energy loss vs distance (meter).

Figure-9, 10 and 11 shows comparison study between our proposed protocol against real time load distribution (RTLD) protocol. All the three results show that our proposed protocol performs much better in terms of throughput, packet loss and energy loss when compared to RTLD. It is also observed from those figures, the delivery rate of real-time load distribution via PSO is higher than that of RTLD of approximately 20%. The improvement in delivery rate is due to the successful delivery of packets from source to destination node by selecting the path based on signal strength, delay and remaining battery level of nodes. The reduction in terms of packet loss and energy loss of about 30% can be contributed to the efficient distribution of load from source node towards the sink node or in other words can be described as excellent route determination.

CONCLUSIONS

The finding shows that Real-time PSO is a self-organized routing protocol. This routing protocol enhances the previous works by [5] in order to achieve low packet loss, high reliability and efficient power consumption. Comparison was done with RTLD and can be said that the Real-time PSO outperforms RTLD of about 30% in terms of packet delivery rate, packet loss and energy loss. The main contribution of this work is also towards the improvement of network lifetime.

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