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IJIE

Journal homepage: http://penerbit.uthm.edu.my/ojs/index.php/ijie
ISSN : 2229-838X e-ISSN : 2600-7916

The International Journal of Integrated Engineering

Novel Wireless Sensor Network Routing Protocol Performance Evaluation using Diverse Packet Size for Agriculture Application

Amierul Syazrul Azman[1], Mohamad Yusry Lee[1], Siva Kumar Subramaniam[2*], Farah Shahnaz Feroz[3]

[1]Fakulti Kejuruteraan Elektronik dan Kejuruteraan Komputer,
Universiti Teknikal Malaysia Melaka, MALAYSIA

[2]Advance Sensors and Embedded Controls System (ASECS),
Fakulti Kejuruteraan Elektronik dan Kejuruteraan Komputer,
Universiti Teknikal Malaysia Melaka, MALAYSIA

[3]Pervasive Computing and Educational Technology (PET),
Fakulti Kejuruteraan Elektronik dan Kejuruteraan Komputer,
Universiti Teknikal Malaysia Melaka, MALAYSIA

*Corresponding Author

DOI: https://doi.org/10.30880/ijie.2021.13.04.002
Received 7 April 2020; Accepted 25 March 2021; Available online 30 April 2021

Abstract: As the wireless sensor networks (WSNs) progress with newer and more advanced technologies, so do the demands for them in a growing number of applications. Precision agricultural environment monitoring is one of the most prominent applications that require feasible wireless support systems, particularly in the protection and condition control of the crops. This paper focuses on the grid nodes arrangement of WSN, considering the wide dissemination of the plantation areas in the agriculture industry. Due to the different types of sensors used and their data size, the study on the impact of the varied packet size on the performance of the small and large network has been carried out using AODV and OLSR routing protocols. No significant differences in terms of performance can be seen as the packet size is varied. However, compared to the small network, more performance issues have occured in the large network, such as more packet loss, higher throughput degradation, higher energy consumption, worse unfairness, and more overhead production. The OEG routing protocol has been proposed to enhance the network performance by reducing the strain due to the saturated traffic. When solely compared to AODV, OEG routing protocol is able to enhance the network performance with at most 27% more packet delivery ratio, 31kbps more throughput, and 0.991J lesser energy consumed in the network.

Keywords: WSN, wireless sensor network, routing protocol, agriculture, grid

1. Introduction to Wireless Sensor Networks on Agriculture Industry

In recent years, the demands for WSNs in numerous applications have surged due to their handiness, flexibility, and low cost, particularly in precision agriculture. WSNs are made up of a group of sensor nodes which form a network where the sensor nodes are made up of several sensors connected to the controller and wireless devices, such as Bluetooth, WiFi, or ZigBee. In precision agricultural environment monitoring, WSNs are useful when it comes to collecting real-time physical data and providing useful information to the farmers, which helps to minimise the

**Corresponding author: siva@utem.edu.my*

accounted workload [1]. Some systems with higher intelligence and more sophisticated algorithm can process and evaluate a substantial amount of data before making a decision [2, 3]. Such an advancement helps the industry to prevent the loss of revenue, which is mainly due to the weather, infection, and pest invasion.

Since most of the industrial farms involve extensive stretches of cultivation area, it would be more troublesome for the farmers to monitor the condition for each plant manually. In 2017, the palm plantations covered 46.6% of the peninsular region of Malaysia, with a total area of 2.71 million hectares [4]. In the event of pest infections, condition monitoring activity will not only be time and cost-consuming, but the farmers will also have to wait for the symptoms of the disease to appear. If the symptoms are overlooked, the quantity and quality of the crops will be severely affected [2]. According to the study by Kings College London, the coconut plantation industry in Sri Lanka suffered an estimated damage of 16.6 million US dollars due to the red palm weevil infection in 2015 [5]. Thus, with a single sensor node, the whole monitoring process can be automated while reducing the need for human intervention. For example, the farmers will be able to assess the surrounding condition when the node is equipped with sensors, such as humidity, luminosity, temperature, and air quality sensor. These sensed data can be used to automate an irrigation system to achieve the required moisture content of the soil and to achieve optimum quality of the end products [6]. These benefits are multifold if a greater number of sensor nodes are deployed, particularly in a wide cultivation area. However, a greater number of sensor nodes introduces numerous issues to the network.

This paper briefly describes the benefits and potential needs of WSNs in precision agriculture applications. The focused scope of this paper is limited to the investigation and improvement on the third layer of the Open Systems Interconnection (OSI) model, which is known as the network layer in accordance to IEEE 802.11 wireless standard. IEEE 802.11 has the highest technology emerging rate compared to other IEEE wireless standard. IEEE 802.11 also offers larger bandwidth, where more packets or larger packet size can be transmitted into the traffic, particularly when the network size or density is large [7]. These characteristics are beneficial to the network for precision agriculture application where large packet size is involved, such as oil palm pest infestation monitoring. IEEE 802.11 is also widely used in commercial and industrial applications, with the starting price of $2 [8]. This paper also focuses on the grid node arrangement with one sink point, as illustrated in Fig. 1. The challenges and limitations of WSNs are investigated through some of the past research papers. Next, background works are presented with an in-depth explanation of the techniques used. Finally, a novel algorithm is proposed with an improvement on the network layer. The contributions of this paper consist of:

- demonstrating the problems faced when the packet size varies in the low-sized and large-sized network
- proposing a routing algorithm to improve the performance of the network above using a novel odd-even technique to distribute the strain due to the packet congestion in the traffic

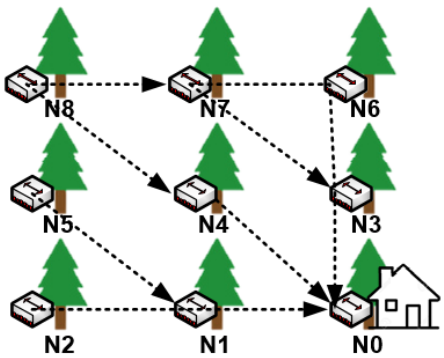

Fig. 1 - Grid node arrangement with one sink point

2. Needs and Requirements of WSNs in Agriculture Industry

A few decades back, wired technologies were known as the most feasible solutions for most of the industrial applications. Although wired solutions are beneficial in many ways, wireless solutions are capable of offering a lot more benefits compared to wired solutions. Apart from their inflexibility, wired solutions also require comprehensive installation preplanning. Besides that, the engineers will also find it hard to locate any fault during the maintenance process [9]. Wired solutions can also be easily damaged, primarily due to the weather, vandalism, sabotage, and vibration. These issues have caused most industries to migrate to the wireless solution, considering the high complexity, implementation cost, and maintenance cost.

WSN has been beneficial to the world in various aspects. Due to their flexibility, the nodes can be easily fixed or randomly placed at any location without detailed preplanning. Hence, it reduces the time and labour required during the installation, especially in high-risk and remote areas [10]. Compared to the wired solution, WSN is more reliable in terms of nodes failure, where the network can maintain its connectivity even when there are broken communication links. WSN also includes a wide range of sensors that can be used to capture ambient conditions that are vital in agriculture monitoring, such as vibration, thermal, humidity, temperature, and weather [11]. These sensors help in the detection of the condition of the plants or crops by promptly notifying the farmers of any significant changes in condition. The sensor data can be sent using various wireless technologies, such as WiFi, ZigBee, Bluetooth, and LoRa, depending on the requirements of the application. These technologies offer different types of characteristics, as shown in Fig. 2. Besides that, the wireless devices used these days are smaller than the size of the palm. Hence, these devices can be easily installed at any location with any type of topography, especially in areas where wired technology cannot be used.

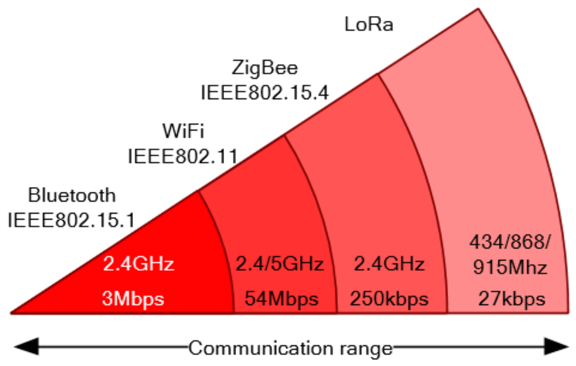

Fig. 2 - Characteristics of Bluetooth, WiFi, ZigBee, and LoRa

These characteristics help in the advancement of precision agriculture in terms of scaling, where more sensor nodes can be installed for larger plantation area. However, larger scale nodes deployment introduces more load to the network since more control and data packets are generated by the nodes. As such, an investigation has been done with varying number of nodes and packet sizes. It can be observed that a high amount of packets in the traffic can lead to congestion and bottleneck in the network performance. Thus, a tailored routing algorithm is proposed in this paper to better suit the precision agriculture with improved network performance when the load varies.

3. Challenges and Limitation of WSNs

While the implementation of WSN in the agriculture industry has shown excellent practical results, there are some challenges and limitations that most engineers have to deal with. These challenges include the energy constraint, robustness, scalability, and security of the network.

Most of the deployed devices in WSNs are battery-powered since it is more practical to install and relocate them. The energy usage depends on the requirements of the application itself. In a critical precision agriculture application such as mushroom farming, the real-time data is crucial, where the data has to be regularly updated every minute. As a result of that, the energy required for such an application is tremendous due to the high number of packets that are generated and transmitted. Poor energy consumption can potentially collapse the network as node failure can happen in the network.

In WSN-based applications, robustness is the ability of the network to tolerate any error that can happen due to node failure, topological update, and cyber-attacks. The poor energy consumption and surrounding conditions, such as exposure to high temperatures, can reduce the network's lifetime. Apart from that, the robustness can also be affected by interference, where the communication signal can be attenuated due to the presence of entities in-between the sender and the receiver. This limitation can be seen in high-density plantation areas and underwater applications.

Tiny devices provide more room for more installation, particularly in wide plantation areas, such as palm and rubber tree plantations. A scalable network is a network that is able to retain its performance when increasing loads are introduced, such as the number of nodes, packet size, and data rate. Since more sensing points are incorporated, there will be more packets enqueued and more processing time required, which then leads to congestion in the traffic. Hence, numerous performance issues have occurred due to the packet queue limit, time-to-live, and increasing distance between the sender and receiver.

Precision agriculture is the technique to ensure a sustainable cultivation process and to ensure the end products are produced in the highest quality possible. In recent years, precision agriculture emerged with the Internet of Things (IoT) technology to enable internet connectivity between the equipment, device, and smartphone. However, in any network communication, security has always been an issue. Various attacks, such as wormhole, eavesdropping, sinkhole, eavesdropping, or signal jamming, can be launched by the culprit to threaten the industry. From a technical perspective, these attacks lead to communication destabilisation, such as data loss, bandwidth exhaustion, or poor energy consumption in the network. From an industrial perspective, these attacks lead to the loss of revenue due to the false interpretation of data that disrupt the smart decision-making systems and affect the whole agricultural operation.

4. Research Background

This paper focuses on the wide distribution area of WSN in agriculture plantation, where the nodes are sorted in a grid arrangement such that the total number of nodes is equal to the multiplication of the number of nodes in the x-axis with the number of nodes in the y-axis. Several performance issues arise as the number of nodes increases, which cause more packets to be introduced in the traffic. Hence, various types of routing protocols have been proposed by past researchers to define the technique to determine the path of the packets from the source nodes to the destination node. Different routing protocol offers different characteristic and mechanism in delivering the data packets to the destination. There are three types of routing protocols, which are proactive, reactive, and hybrid routing protocol [11, 12].

Proactive routing protocol uses a table-driven mechanism where the routing information is regularly updated in the routing table [13, 14]. This information consists of the next hop, previous hop, number of hops, sequence number, and time to live [15, 16]. Optimized Link State Routing Protocol (OLSR) is one of the examples of the proactive routing protocol [17, 18]. By regularly updating the routing table throughout the network, the packet can be sent from the source to the destination in a timely manner. However, this method draws a substantial amount of control packets and overhead.

On the other hand, a reactive routing protocol is known as an on-demand protocol where the route is established when needed [19]. Since reactive routing protocol does not store the routing table and it is only occasionally updated, less routing overhead is produced in the network. Ad-hoc On-Demand Distance Vector (AODV) is one of the examples of the reactive routing protocol [20]. The sources have to broadcast the route request (RREQ) packet during the route discovery process, and the destination has to unicast the route reply (RREP) packet as the acknowledgement to the sources. One of the major drawbacks of the reactive routing protocol is the latency that is introduced during the route discovery process [21].

The combination of proactive and reactive routing protocols produces a new type of routing protocol, namely the hybrid routing protocol. Zone Routing Protocol (ZRP) is one of the examples of the hybrid routing protocol that implements the features of reactive and proactive routing protocol [22]. ZRP reduces the control overhead from the proactive routing protocol and the latency from the reactive routing protocol, particularly during the route discovery process. In this paper, the ZRP routing protocol will not be the focus since it is a cluster-based protocol, while AODV and OLSR are flat-tier-based routing protocols.

Regardless of what types of routing protocol are implemented, the greater the number of nodes deployed, the more the control packets introduced in the network. This statement can be deduced as in Equation 1.

$$P_{total} = \left[\left(DP_{\alpha} + CP_{\alpha} \right) + \sum_{\beta=\alpha+1}^{Nn} \left(DP_{\beta} + CP_{\beta} \right) \right] \leq IfQlen \qquad (1)$$

Where $Nn=N-1$, N is the total number of nodes and P_{total} is the total packets produced by the nodes in the network. However, P_{total} is bounded by the interface queue length (*IfQlen*) limit, where any data after the *IfQlen* value will be dropped from the traffic. DP_{α} and CP_{α} represent the data packets and control packets at node 0 respectively, assuming that $\alpha=0$. DP_{β} and CP_{β} represent the data packets and control packets at the rest of the nodes, starting from node 1 until node Nn ($1 \leq \beta \leq Nn$).

Authors in [23] have proposed an algorithm for precision agriculture, namely Terrain based Routing using Fuzzy rules. This algorithm involves three operational stages, which are Terrain formation stage, Terrain Head appointment, and Terrain based Routing stage. Terrain formation operates by equally dividing the nodes in the plantation area into small-sized areas, namely terrains. Terrain Head (TH) is chosen according to the set of fuzzy rules with the consideration of the distance to the sink station and residual energy. In Terrain based Routing stage, TH relays the information to its neighbouring TH, which is also known as a relay node, till the information arrives at the base station. The relay node is chosen according to the fuzzy rules by using the residual energy, degree of the neighbouring TH, and the distance to the sink station, as the fuzzy inputs. The proposed algorithm improves energy consumption and extends the network lifetime.

Researchers in [24] have developed an enhanced Protocol for Low power and Lossy Networks (RPL), namely Partition Aware-RPL (PA-RPL). PA-RPL manages data aggregation by building a tree-like topology called Destination Oriented Directed Acyclic Graph (DODAG). The nodes in the same parcel (plantation area) are grouped in the same sub-DODAG. The data packets of the nodes are sent towards the sink node. If the sub-DODAG is further away from the sink node, the accumulated data are relayed to the nodes in the neighbouring sub-DODAG in the direction of the sink node. The authors highlighted that this aggregation method helps in reducing energy consumption and congestion in the traffic when the data are monitored simultaneously.

The authors in [25] have proposed a cluster-based routing protocol known as Gateway Clustering Energy-Efficient Centroid-based Routing Protocol (GCEEC). GCEEC chooses and rotates the cluster head (CH) between the nodes with high residual energy in the cluster (high energy density area). The CH collects the data from its cluster member and elects a gateway node in the area where two clusters overlap in the direction of the base station. This key feature helps in reducing the load between the CH, increasing the network lifetime, and increasing the network throughput..

5. Methodology

The proposed OEG routing protocol is a reactive-type routing protocol that has been developed to reduce the queue and strain in the traffic. Two types of packets are used during the route discovery process, which is the route request (RREQ) packet and route reply (RREP) packet. The RREQ packets are broadcasted in the forward direction according to the (1) odd-even criterion as shown in Fig. 3, (2) distance between the source node and the destination node, and (3) route freshness [15]. The distance between the source and destination is measured using the hop count, while the route freshness is determined using the sequence number.

The odd-even criterion is the path-choosing mechanism based on the Internet Protocol (IP) address of the source; odd or even. This condition is not applicable if the validated node is the source or the destination. However, if the node is the intermediate node, this odd-even mechanism validates the address according to the odd-even condition in the x and y-axis (Omni-direction). If the source is odd, the intermediate node with odd address forwards the RREQ packet to the odd neighbouring node and vice versa, until the packet arrives at the destination, else the packet is dropped. During this process, the routing table entry is updated at the same time.

Once the destination received the RREQ, packet interchange occurs where the RREQ is dropped, and the destination starts sending the RREP packet to the respective RREQ source in the reverse direction. The RREP packet also uses odd-even criterion using the same process as in the forward path discovery using RREQ, but the path of choice might differ to the RREQ path. Once the RREP arrives at the source, it will be dropped, and the data packet will be finally sent (second packet interchange) to the destination using the forward route [26].

Fig. 4 illustrates the even-numbered IP address of node N12, demonstrating the route discovery process to the destination node (ND) using the distance between nodes of *d* and communication range of *2.5d* for each node. The RREQ packets are broadcasted to the neighbouring nodes N11 and N10 in the y-axis direction. Since N11 is an odd-numbered node, the odd-even condition is not satisfied, and the RREQ is dropped. For N10, the RREQ is forwarded to the next neighbouring node since it satisfies the odd-even condition. These processes happen until RREQ reaches the ND. Once the ND receives the RREQ, the RREQ is dropped, the RREP is generated by ND and sent to the source N12. The RREP uses the odd-even criterion to reach the ND in the reverse direction and the route of choice is assumed to be the same as the forward route. Once the RREP arrives at the source N12, the RREP is dropped, and the data packet is generated (second packet interchange) to be sent to the ND using the created route, which is route 1.

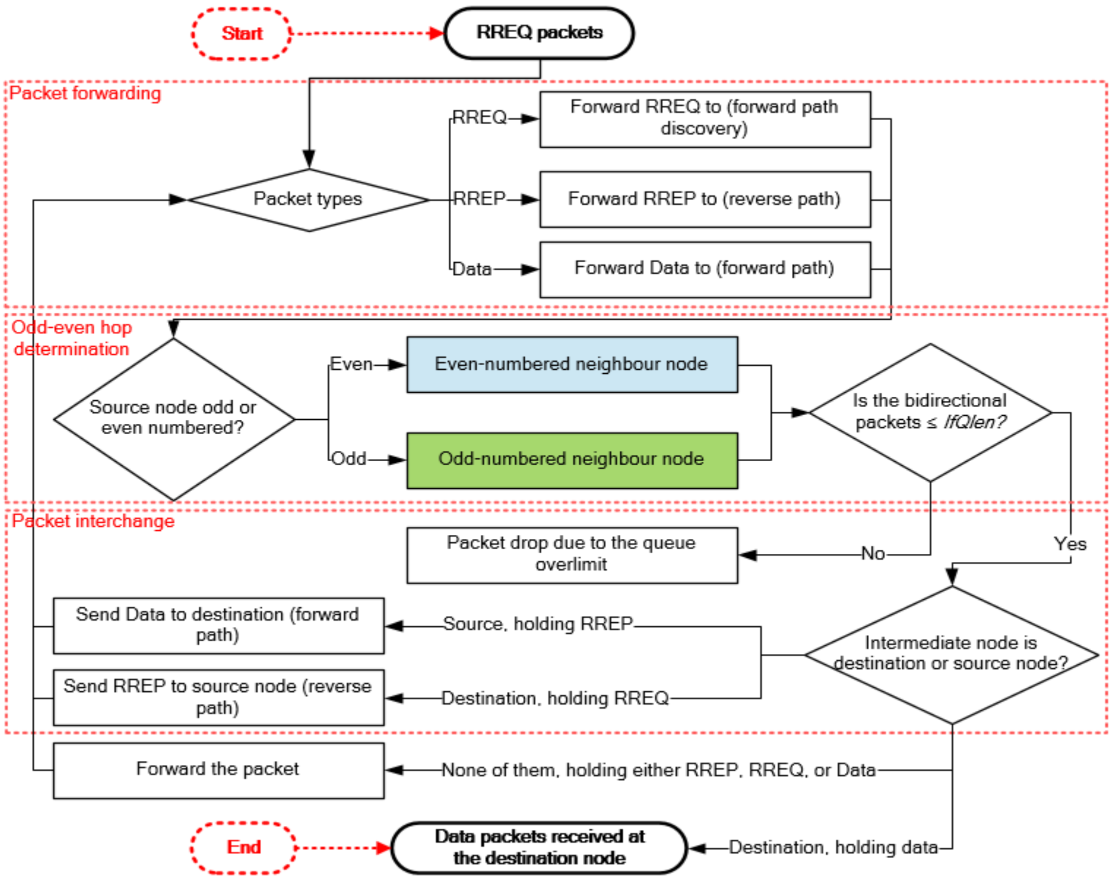

Fig. 3 - OEG routing algorithm

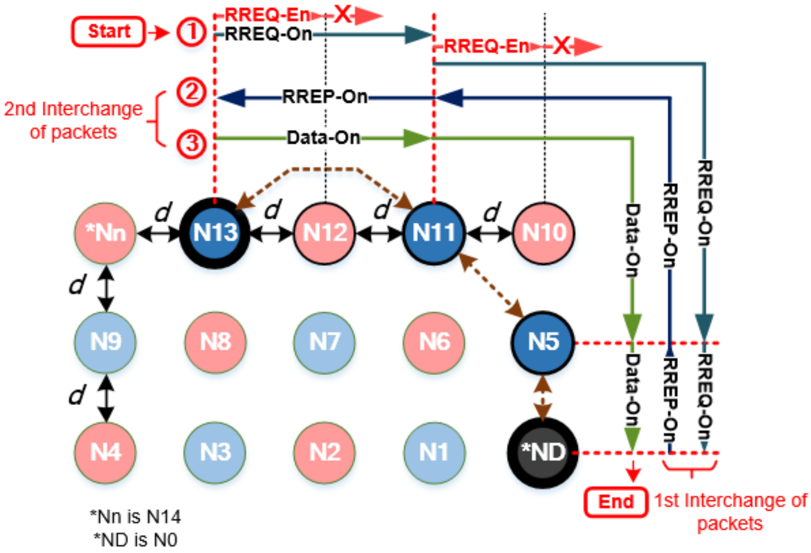

Fig. 4 - Routing demonstration using OEG algorithm

The network traffic for OEG is eventually divided into two; odd traffic and even traffic. Total packets queued in each particular traffic is bounded with $IfQlenE_n$ and $IfQlenO_n$. The accumulation of packets in even traffic can be defined in Equation 2.

$$. PE_n = \left[\left(DP_{2\alpha} + CP_{2\alpha} \right) + \sum_{\beta=\alpha+1}^{n_1} \left(DP_{2\beta} + CP_{2\beta} \right) \right] \leq IfQlenE_n . \qquad (2)$$

$$n_1 = \begin{cases} \dfrac{Nn}{2}, if\, Nn\, is\, even \\ \dfrac{Nn-1}{2}, else\, if\, Nn\, is\, odd \end{cases} \qquad (3)$$

PE_n is the total packets generated in the even traffic, considering the queue limit is $IfQlenE_n$. $DP_{2\alpha}$ and $CP_{2\alpha}$ is the data packets and control packets respectively for node 0, assuming $\alpha=0$. $DP_{2\beta}$ and $CP_{2\beta}$ is the data packets and control packets respectively for the rest of the even-numbered nodes 2β until n_1, where $1\leq\beta\leq n_1$. The accumulation of packets in the odd traffic can be defined as in Equation 4.

$$PO_n = \left[\left(DP_{2\alpha+1} + CP_{2\alpha+1} \right) + \sum_{\beta=\alpha+1}^{n_2} \left(DP_{2\beta+1} + CP_{2\beta+1} \right) \right] \leq IfQlenO_n \qquad (4)$$

$$n_2 = Nn - n_1 - 1 \qquad (5)$$

PO_n is the total packets generated in the odd traffic, considering the queue limit is $IfQlenO_n$. $DP_{2\alpha+1}$ and $CP_{2\alpha+1}$ is the data packets and control packets respectively for node 1, assuming $\alpha=0$. $DP_{2\beta+1}$ and $CP_{2\beta+1}$ is the data packets and control packets respectively for the rest of the odd-numbered nodes $2\beta+1$ until n_2, where $1\leq\beta\leq n_2$. The total packets accumulated in the whole traffic can be defined as in Equation 6.

$$P_{Total} = PE_n + PO_n \leq IfQlen \qquad (6)$$

P_{Total} is the total packets with the queue limit of $IfQlen$. PE_n is the total packets in the even traffic while PO_n is the total packets in the odd traffic. It can be observed that with the proposed OEG protocol, the traffic load can be reduced and more data flow can be achieved. Hence, the congestion and the accumulation of the packets also can be reduced, which promotes smoother and better network performance as compared to the conventional protocol that has been defined as in Equation 1. A number of simulations have been run to prove these statements and recorded in the next section.

6. Simulation Setup

A number of simulations have been done using a network simulation software, namely Network Simulator version 2.35. The simulated routing protocols are AODV (reactive), OLSR (proactive), and OEG (reactive) routing protocol. The distance between the nodes is 50 meters to imitate the distance used by most of the plantations in the industry. The communication range of each node is 125 meters since most of the common IEEE 802.11 devices are equipped with this value. In addition, this value also is used to cover the communication of two nodes. Transmission Control Protocol (TCP) and Constant Bit Rate (CBR) is used as the transport agent and the traffic type respectively. The packet interval for each packet is 2 seconds. The seed used for the simulation is 1 to 7. The results were then averaged from the best 5 out of 7 randomly generated scenarios. The remaining parameters used during the simulation are presented in Table 1.

Table 1 - Simulation parameters

Parameters	Value
MAC	IEEE 802.11
Routing protocols	AODV, OLSR, OEG
Packet queue length	50
Packet size	32, 128, 256, 512, 1024 bytes
Topology	Non-cluster grid with nodes arrangement of 6x4 and 18x16
Number of nodes	24 and 288
Interface queue type	DropTail/PriQueue
Simulation time	500s
Propagation model	Two ray ground

7. Results and Discussion

The performance of AODV, OLSR, and OEG routing protocols are analyzed and evaluated based on the energy consumption, throughput, packet delivery ratio, routing overhead, passive nodes, and fairness index of the network. Since most of the applications in the agriculture industry require constant condition monitoring, any missing data can lead to the immaturity of the gathered information. The loss of data issue is the worst issue to happen in most of the industry in the world. Hence, the packet delivery ratio is organized as the first results as follows.

7.1 Packet delivery ratio

The packet delivery ratio is a fraction of the total number of the successfully received packet to the total number of the transmitted packet, as shown in Equation 7.

$$PDR = \frac{\left(\sum_{i=1}^{N} \frac{RP_i}{SP_i}\right) \times 100\%}{N} \qquad (7)$$

Where RP_i is the total data packet received and SP_i is the total data packet sent.

A lower packet delivery ratio indicates more packet loss in the network [27]. As shown in Fig. 5, AODV24, OLSR24, and OEG24 are the charts showing 24 nodes deployment with the respective routing algorithm implementation. AODV288, OLSR288, and OEG288 are the charts showing 288 nodes deployment with the respective routing algorithm implementation. There are no significant differences between the packet delivery ratios using those three routing protocols in the small-sized network (24 nodes). However, the difference in the packet delivery ratio between the small-sized network and the large-sized network (288 nodes) is at least 46%.

In terms of packet size, it can be seen that the packet delivery ratio is getting slightly lower as the packet size increases. The proposed OEG algorithm outperforms AODV and OLSR with at most 27% and 36% of improvements respectively on the packet delivery ratio in the large-sized network.

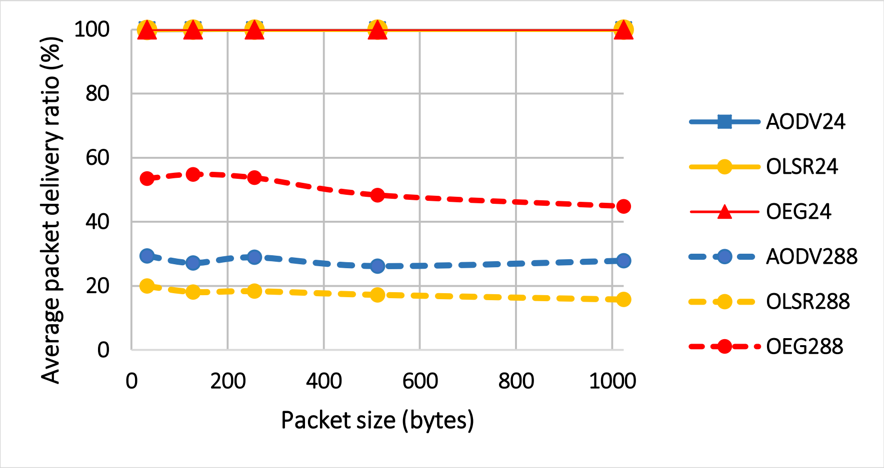

Fig. 5 - Average packet delivery ratio versus packet size

7.2 Throughput

Throughput is the rate of the successfully received bits in one second (bps). Throughput is often related to the implemented packet size, where the higher the packet size, the more throughput, as shown in Equation 8.

$$Throughput = \frac{\sum_{i=1}^{N} (P_{size} \times 8 \times RP_i) \Big/ T_{end} - T_{start}}{N} \qquad (8)$$

Where P_{size} is the size of the packet and $T_{end} - T_{start}$ is the total amount of simulation time.

Throughput is also related to the packet delivery ratio of the network, where the higher the packet delivery ratio, the more packets or number of bits received per second. As shown in Fig. 6, the throughput increases proportionally to the packet size, where the larger the packet size, the more throughput achieved. However, there are no significant differences between the throughputs for those three routing protocols in the small-sized network. In contrast, in the large-sized network, the differences are notable, where OEG able to deliver at most 31kbps and 48kbps more throughput compared to AODV and OLSR respectively.

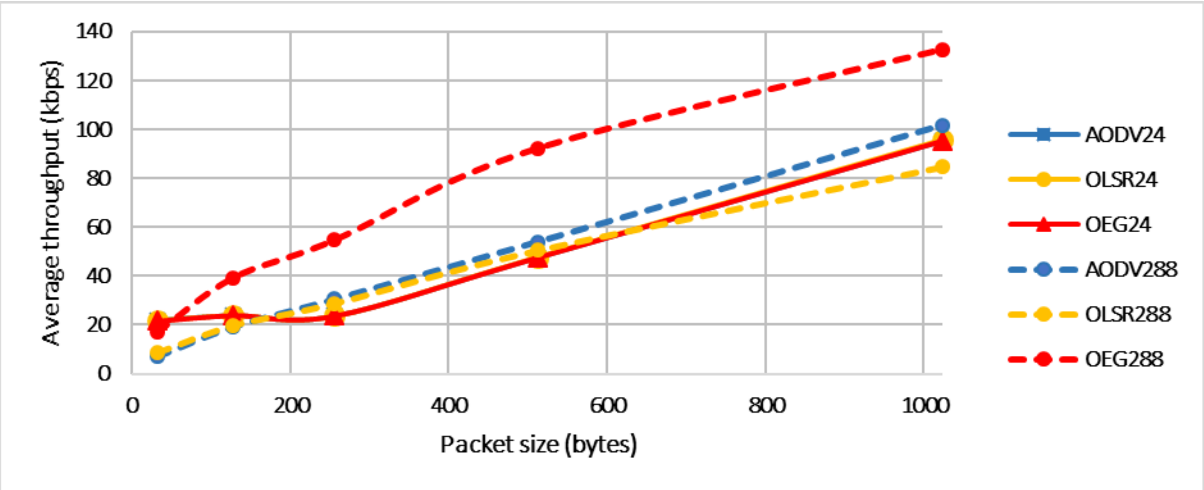

Fig. 6 - Average throughput versus packet size

7.3 Energy consumption

Energy consumption in Joule (J) indicates the energy usage of the nodes during the sending and receiving of the packets, as shown in Equation 9.

$$E_{packet} = \frac{E_{total}}{RP} \qquad (9)$$

Where E_{total} is the total energy consumed in the network for packet transmission and reception.

Energy plays an important part in sustaining network connectivity. Hence, a routing protocol that able to consume the energy at a low rate is considered a good choice since it helps to extend the network lifetime [28]. As shown in Fig. 7, the nodes in the small-sized network consume the energy at a lower rate as compared to the nodes in the large-sized network. This issue can be justified with (1) the increasing distance between the source and the destination node, (2) the increasing number of hops, and (3) the increasing number of packets introduced in the network. Apart from that, the larger network causes (4) more packet loss (refer Fig. 5), which leads to (5) more packet re-transmission. As a result, a substantial amount of energy used is wasted due to these unnecessary activities.

In Fig. 7, the proposed OEG routing protocol shows better energy consumption as compared to AODV and OLSR routing protocols in the large-sized network. OEG outperforms AODV with at most 0.991J and OLSR with at most 1.081J less energy consumed. Apart from that, the larger packet size causes more energy to be used. OEG works the best among the other routing protocols, even with the implementation of large packet sizes.

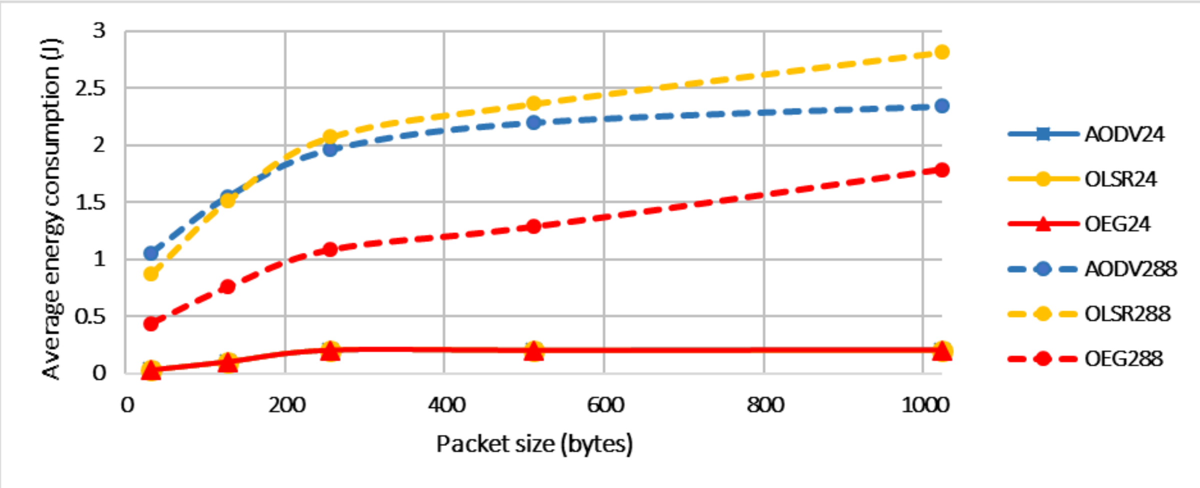

Fig. 7 - Average energy consumption versus packet size

7.4 Normalized Routing Overhead

The normalized routing overhead is the ratio of the total routing overhead to the total packets received, as shown in Equation 10.

$$NRO = \frac{TRP}{RP} \qquad (10)$$

Where *TRP* is the total number of routing packet.

Routing overhead is required during the data transmission, but the overproduction of routing overhead leads to the waste of network resources and energy (see Fig. 7) [29, 30]. Hence, a good routing protocol should be able to produce low routing overhead. As shown in Fig. 8, the differences between the routing overheads produced for all three routing protocols in the small-sized network are insignificant. However, the OEG routing protocol shows the fewest routing overhead produced in the large-sized network with the differences of at most 29×10^3 and 15×10^3 fewer packets when compared to AODV and OLSR respectively. Apart from that, it can be seen that if the packet size used is smaller, the fewer the normalized routing overhead is produced.

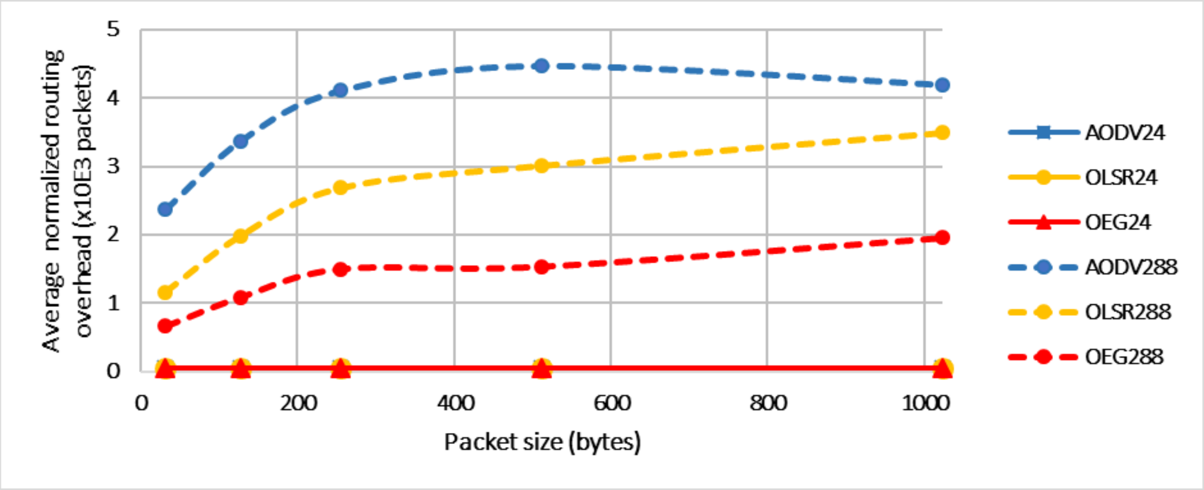

Fig. 8 - Average normalized routing overhead versus packet size

7.5 Fairness Index

The fairness index is the measure of equality of the network resources distributed over the network [31] as shown in Equation 11.

$$Fairness = \frac{\left(\sum_{i=1}^{f} T_i\right)^2}{N\sum_{i=1}^{f}(T_i)^2} \qquad (11)$$

Where T_i is the throughput and f is the total number of flows.

As illustrated in Fig. 9, the fairness index for the small-sized network is better than the fairness index for the large-sized network. The distance between the source node and the destination node in the small-sized network is smaller than the large-sized network. Hence, the reachability for the large-sized network is lower, where the nodes that are closer to the destination have more traffic than the nodes that are further from the destination. Such an event is known as the hotspot issue, which contributes to the energy hole issue [32, 33]. However, it can be seen that the proposed OEG routing protocol outperforms AODV and OLSR with at most 0.1207 and 0.1345 of improvement respectively on the fairness index in the large-sized network.

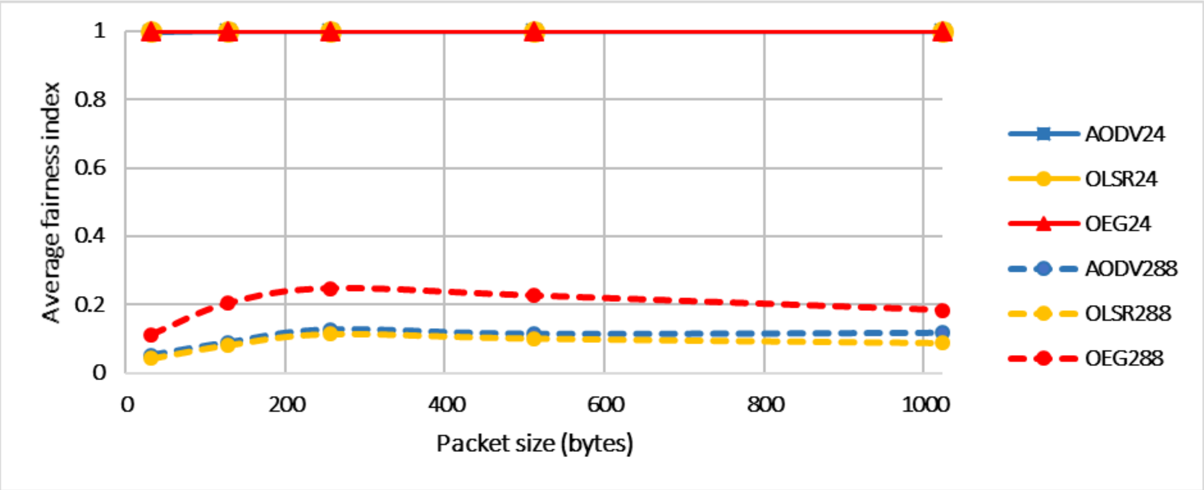

Fig. 9 - Average fairness index versus packet size

7.6 Passive node

A passive node is a node in the network that has no chance to transmit its packet due to the saturated traffic. The percentage of passive nodes in the network can be represented as in Equation 12.

$$PN\% = \frac{PN}{N} \times 100\% \qquad (12)$$

Where *PN* is the total number of passive nodes in the network.

The presence of the passive node is also due to the insufficient network resources and overproduction of routing overhead. Theoretically, the higher the overhead produced, the higher the wastage of the resources, the worse the fairness, and the more passive node present. Conversely, as shown in Fig. 8, AODV produces more routing overhead but results in fewer passive nodes in the network than OLSR. This situation shows that AODV performs better than OLSR. As shown in Fig. 10, the proposed OEG routing protocol outperforms AODV and OLSR with at most 30% and 48% reduction of passive nodes respectively.

According to the packet size, the trend pattern for the routing overhead, fairness index, and passive nodes are almost the same. The smaller the packet, the fewer space and network resources required. As can be seen in Fig. 8, Fig. 9, and Fig. 10, less normalized routing overhead, higher fairness index, and less number of passive nodes resulted in the network with the usage of smaller packet sizes.

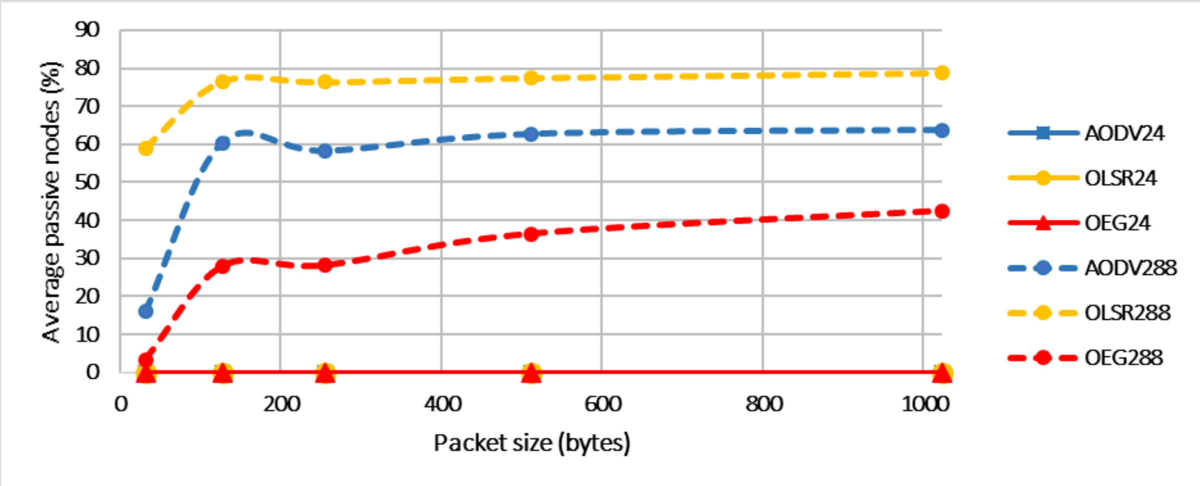

Fig. 10 - Average passive nodes versus packet size

8. Conclusion

The demands for WSN in precision agriculture has increased in the past few years due to its flexible, cheap, and efficient solution. It has benefited most of the industrial application that requires constant and efficient monitoring to ensure the machinery, crops, or the end-product in good condition. A wide area of plantation requires a wide sensing point area and a high number of sensor nodes. Moreover, since most of the plantation implements the grid arrangement of the plants, so the nodes have to be arranged in the grid arrangement as well. Types of sensors used in this industry are varied, ranging from the temperature sensor up to the image sensor. Thus, this paper presents the network performance using AODV, OLSR, and OEG routing protocols with two environments; different packet sizes and different network sizes. The impact of the packet size towards the network performance is insignificant, starting at the usage of 256 bytes of packet size onwards.

In large-sized networks, performance issues such as packet loss, energy and resource wastage, throughput degradation, and high routing overhead production are easily notable. The proposed OEG routing protocol divides the traffic into two; odd and even traffic. This technique has helped to distribute the strain in the network traffic. As a result, OEG routing algorithm able to introduce at most 27% and 36% more packet delivery ratio, 31kbps and 48kbps more throughput, 0.991J and 1.081J less energy consumed as compared to AODV and OLSR respectively. OEG routing protocol also able to reduce the routing overhead and the number of passive nodes. However, the achieved fairness index is still below the expected value for the large-sized network and is highlighted as the limitation of the proposed routing protocol. Thus, the recommendation for future work is to focus on the improvement of network fairness, mainly for the large-sized WSN

Acknowledgement

The authors would like to thank the Ministry of Higher Education - Malaysia, Universiti Teknikal Malaysia - Melaka for their support, lab facilities, sincere encouragement, and assistance.

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