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ENERGY CONSUMPTION IN PERPETUAL WIRELESS SENSOR NETWORKS

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ABSTRACT

Abstract: This paper investigates the amount of energy consumed in different configuration for perpetual wireless sensor networks. Wireless Sensor Networks (WSNs) represent an area of networking that become pivotal in many applications. The use of WSNs for the monitoring of environments, habitats as well as systems within industry and healthcare has made WSNs a crucial area of research within recent years. The principles behind WSNs involve the deployment of remote sensing and relay nodes, able to collect and transmit raw data for processing. Applications such as remote environmental monitoring present new challenges such as the prospect of developing networks that can operate perpetually to collect data for as long as possible. Simulation and theoretical analysis were done using the networking simulator DENSE. DENSE is presented to provide insight into what protocols and energy saving techniques can be employed to establish the possible feasibility of constructing PWSN. The results show that mesh is the most realistic due to its energy distribution and optimization over a large area for a great number of nodes; however, a small single hop based network can provide good result for energy consumption and packet success rates.

1. INTRODUCTION

Wireless Sensor Networks (WSNs) allow for the autonomous collection of data and can be implemented for a number of purposes, such as factory and process automation, health monitoring, tracking and environmental monitoring [1,2,3]. The need for the operation of perpetual WSNs has naturally become more prevalent as a result of their popularization within many different fields. Indeed, in environments where human impact must be kept to a minimum or the environment, constructing WSNs with the characteristic of operating indefinitely is very lucrative. The lifetime of a particular node in a network depends on how often it is collecting, sending or transmitting data as well as the amount of energy that is available for it to consume. WSN nodes typically operate off batteries due to their relatively high energy density compared to solutions such as super capacitors [4,5,6]. Energy capacity is perhaps the most pressing limiting factor in terms of node lifetime and on-going research is being done involving node energy harvesting to try and mitigate energy consumption in nodes and increase network lifetime. This paper investigates the power consumed by WSNs overheads. This is achieved using network simulation within different climates and by developing algorithms for energy harvesting and energy reduction to increase the lifespan of WSN nodes. The reminder of the paper is organised as follows: section II deals with overview of the wireless topology while testing and evaluation of various topologies were discussed in section III. The paper is concluded in section IV.

2. Overview of Wireless Topology

The section provides an insight into several common place network topologies that can be considered for constructing an energy efficient network, such as Mesh and Clustered-Hierarchical topologies:

2.1 The Star Network Topology:

The star network topology uses a central network node known as the Personal Area Network (PAN) coordinator as shown in Fig 1. The job of the PAN coordinator is to control the routing within the network. Other nodes in the network are often placed around the PAN coordinator. If one of the outer nodes dies or becomes faulty, the other nodes in the network are not affected as data can only be routed through the PAN coordinator.

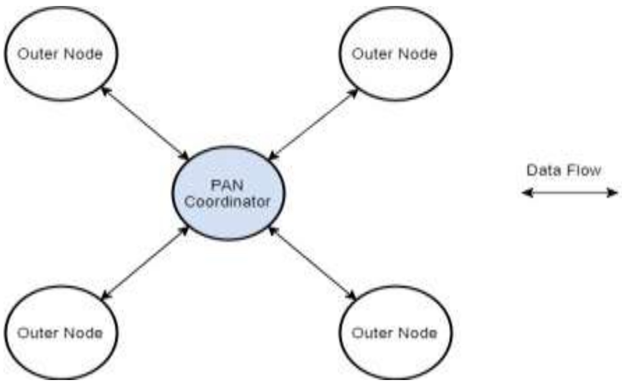

Figure 1: Example of a star network using a PAN coordinator as adapted from [6].

According to [6], the typical separation distance between any given node is 30-100m, but this is subject to change depending on the application and the respective transmission/reception powers of the nodes within the network. The star topology is one of the most common home and for businesses due to its simplicity when compared to other network topologies. An example of a medical application is given in [6,7] whereby a PAN can aggregate data such as blood pressure/glucose levels from the other nodes in the star network and transmits to a doctor on duty. Although, a star network benefits from short transmission distances to the PAN coordinator, it also limits how far the nodes can potentially be. Increasing the distance of the nodes can lead to greater transmission powers, making the network more inefficient. A possible solution to this is however, to employ a series of nodes between the outermost nodes and the PAN coordinator and use a multi-hop routing protocol. Another more immediate disadvantage is the reliance on the PAN coordinator as a routing node; if the PAN coordinator were to die/malfunction, the entire network would be compromised. This also links to the disadvantage associated with energy consumption, moreover when the PAN communicator is moving data between nodes/receiving packets it is using more energy in total than the other nodes in the network meaning it is more likely to die faster. A solution to this problem would be to increase the energy supply within the PAN coordinator compared to the other nodes.

2.2 The Ring Network Topology

The ring network is less popular in modern applications compared to others such as the star network topology. A ring topology has a group of nodes connected closely in a ring formation, whereby only neighbouring nodes can communicate. Within a ring network, there is no PAN coordinator or lead node, instead each node has the same function within the network as shown in Fig 2.

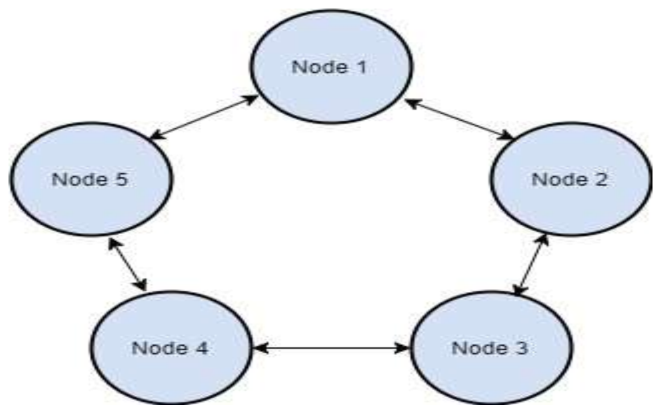

Figure 2: A ring-based network [5].

A ring is ideally used for devices that do not have main data sink and can be more easily implemented when compared to star and mesh. One of the main advantage of a ring network topology is the fact that energy consumption of the nodes are relatively uniform when compared to mesh and star topologies, where the data sinks and the nodes closest to the sinks tend to expend their energy faster due to the amount of traffics the nodes transit. Another advantage is that the flow of traffic on a network is more controlled when compared to star or mesh. For instance, some ring networks do not allow bi-directional flow of traffics, hence, reducing the number of collisions that may occur in the network. Other ring topologies allow bidirectional travel to increase network reliability.

The largest issue associated with the ring network topology is the fact that if one node dies, the entire network can be affected. This is less prevalent in ring network topologies that are bidirectional, however if two nodes were to die in the network, potentially half the nodes would not be able to communicate. Another disadvantage is more specific to the shape of the topology; it may not be ideal for monitoring larger areas due to the lack of nodes in the middle of the network. Propagation delay to a destination node is also potentially another issue in larger ring networks using a multiple hop protocol compared to mesh, which has more freedom in terms of how the packets can travel across the network.

2.3 The Mesh Network Topology

A mesh-based network usually is composed of a dense layout of nodes of varying distances from each other. Mesh-based topologies like star have a data sink or aggregation point where information is sent to a base station. Unlike other topologies such as star, there are multiple routes that can be taken to reach the PAN coordinator/aggregate node. The mesh topology is usually a multi-hop topology which can span larger distances when compared to other topologies.

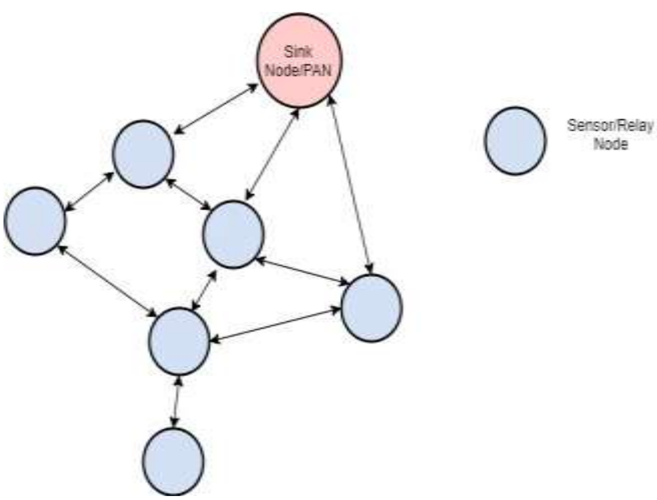

Figure 3: Example of a ring-based network where nodes require multiple hops to communicate.

A mesh is often a popular choice with regards to WSN's. Mechin *et. al*[7], gives examples of a QoS (Quality of Service) multi-operator-based mesh networks used in applications and business such as tourism, online gaming with minimal delay and mobile business usage.

The advantage of a mesh-based network when compared to previous scenarios is its reliability due to the many connections that each node has available to it to reach the destination node. If one node in a mesh network were to fail (so long as it is not the sink node and the nodes surrounding it) then there are alternative ways of reaching the sink through other routes. Also, mesh-based network is simple to deploy in a remote environment, for example the nodes could be deployed from a plane or helicopter using the Uniform Airdrop Deployment method [7,8] and can therefore be arranged in no specific order, if they are within the correct transmission range.

One issue with a mesh-based topology is associated with propagation delay. Due to the multi-hop nature of a mesh-based network, the time it takes for a packet to reach its destination is potentially greater than other topologies such as the star. Also, star and ring-based network topologies as seen previously have specific transmission distances defined by the node distance from the sink whereas mesh networks tend to be more disorganised, so the transmission power is not so easily defined, however this could be mitigated with an intelligent protocol able to alter the transmission power based upon node location/coordinates. Collisions are also a problem with mesh-based networks; if nodes have a specific number of hops then there could be issue with packets hopping to the same node from neighbouring nodes.

2.4 Clustered Network Topologies

Clustered network topologies involve groups of nodes within a network forming clusters. Each cluster has a cluster head which can communicate with other clusters and the rest of the network. Clustering algorithms such as Low Energy Adaptive Clustering Hierarchy (LEACH) [9, 10] and Threshold sensitive Energy Efficient Sensor Network protocol (TEEN)

[11] have been designed to operate with such topologies. Within LEACH for instance, the cluster head can be randomly selected within a cluster as to reduce the overall energy consumption of a clustered group and therefore the network [8].

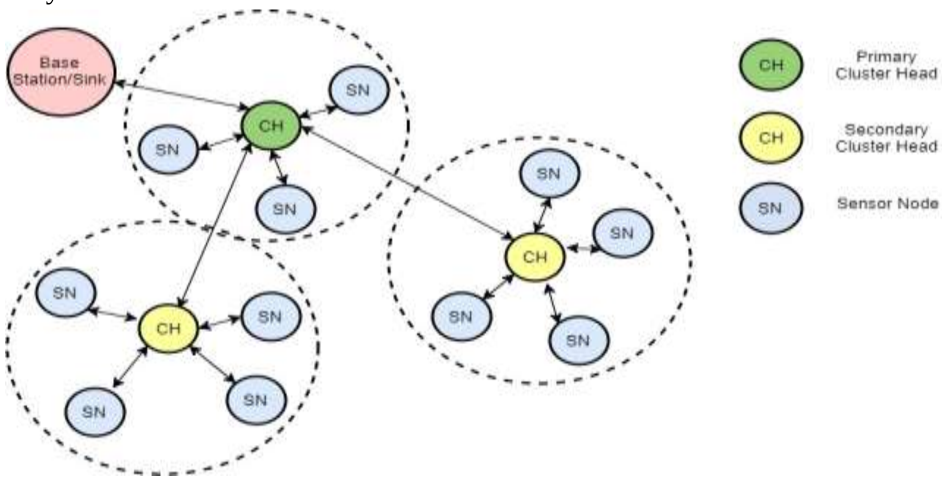

Figure 4: An illustration of a cluster-based network as adapted from [9] .

Clustered networks are used to help minimise the overall energy consumption of a network and increase network scalability over large distances [12-13,14]. It is a topology principally designed to maximise network efficiency. It has the advantage as it is clustered hierarchy-based networks with reduced overhead associated with network routing. This is because of the cluster heads within these topologies acting as PAN coordinators for each cluster, routing data to and from outer nodes as necessary and transmitting collected data to a base station through adjacent node cluster heads. This reduces the size of any routing tables required within the network by generating small routing tables for each cluster[11]. The scalability of clustered networks is generally high with energy being saved using cluster head rotation (LEACH) and the control of traffic throughout the network, due to the cluster heads being the only nodes able to transmit data across the entire network.

Cluster head rotation in the case of the LEACH protocol introduces issues with regards to the amount of energy available to any given cluster head. It is possible through the randomisation of the cluster head nodes that a single node may be chosen to be the cluster head more often than the rest, thus reducing the amount of energy available to it. Having a node with a low energy capacity acting as the cluster head is inefficient. A more prevalent disadvantage associated with clustering is the failure of a cluster head. If a single cluster head were to perish for any reason, it could leave nodes stranded for a time until a new cluster head is established within the cluster. Having cluster head route information throughout a subset of nodes and throughout the network also presents an increased energy overhead for that node, however it is for this reason that in LEACH, cluster head rotation is carries out.

3. Testing and Evaluation of Various Topologies

DANSE is a user-friendly Ad-Hoc networking simulator developed by Dr David Pearce of the University of York. This paper have chosen to use this simulator as it already has several pre-programmed protocols as well as network layouts that can be tweaked to satisfy user requirements. The program provides a simple interface and allows the user to interact with individual nodes to view statistics such as the number of packets sent and received as well as the energy remaining and consumed.

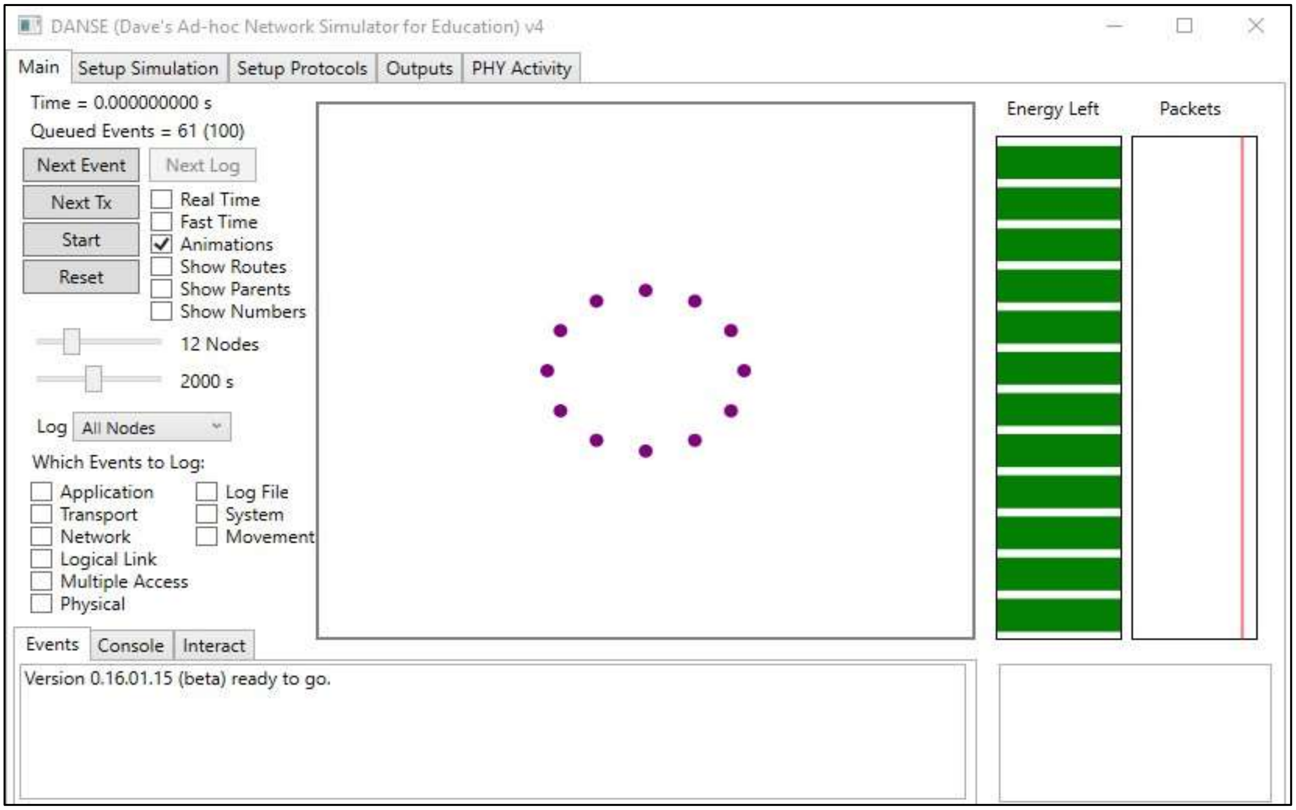

Figure 5: The DANSE Networking Simulator main window.

The centre shows a ring-based layout of nodes. The layout is very intuitive with parameters such as the number of nodes adjustable from the outset. The display area of the nodes represents a space of $200m^2$ area**.** Another advantage to using DANSE is that the simulator is able output node and packets statistics. The source code for DANSE is also open-source, allowing a user to download and modify the program for increased or specialist functionality. In this paper all testing unless stated otherwise is carried out in DANSE using batch files, specifically batches of 50 simulations are carried out to provide accurate mean results with little or no standard error/deviation. Each simulation is also carried out for a length of 100000s or approximately 27.8 hours as to mimic the operation of a network for a single day. The length of 100000s is the closest length of time to a day that can be chosen within the simulator.

Results from these batch simulations are output as text files which are analysed using MATLAB scripts. These scripts can extract the required data and perform predictions of life expectancy as well as provide mean values for throughput and packet cost. The type of node used within all the DANSE simulations is the Crossbow IRIS XM2110CA node [13]. The DANSE is based upon this node and so has been used been used as an example across all tests. The node is ZigBee based, however a ZigBee data rate was not used for any *testing* as it is not natively available within DANSE without recompiling the source code. It is small in form factor and has relatively low operating powers as seen in Table 1.

The node itself operated using two AA batteries operating from a nominal voltage of approximately 3V. Due to this, standard alkaline batteries have been used in all initial tests which have a standard operating voltage of 1.5V and a capacity of 1000mAh.

Table 1: DANSE Parameters

Operation	Power Consumption
Listening	24mW
Receiving	48mW
Sleeping	24µW
Transmitting	(0.03+10*TxPower)W
Receiver Off	6mW

(A) Star/Single-Hop Topology Testing

The following section illustrate the performance of a basic star network as shown in Figure 1 within DANSE. In this scenario, the central node is being used for data aggregation, acting as a data sink, whereby the surrounding nodes are only transmitting to the centre and to no other node in the network.

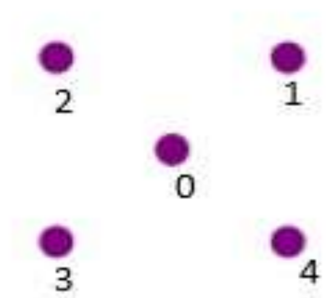

Figure 6. Star network within DANSE with the central node as a data sink.

The Node is symmetrical about the centre node and each node is equidistant from the central node at 20m with node Area of 800m^2 . The simulation parameters are as shown in Table 2.

A transmission power of -16dBm was used to allow each of the outer nodes to expend as little energy as possible through a single hop to the central data aggregate. This was determined using the following formula in equation (1) [13]:

$$P_{tx} = SNR + Nodal\ Noise + Signal\ Loss \qquad (1)$$

Where P_{tx} is the transmission power in dBm and SNR is the signal to noise ratio in dB.

Standard nodal noise in the case of the DANSE nodes is -50 dBm and signal loss is

$$40\log(N) - 30\ dBm \qquad (2)$$

Where N is the Nodal distance in meters. The SNR is defined by the bit rate and a bit-rate. In this work a bit rate of 1000 $bits/s$ was used. This gives an SNR of 10dBm. From these values, it can be calculated that a minimum P_{tx} of -17.96dBm is required; however, this has been increased to -16dBm for increased packet reception rates. For all following calculated P_{tx}, this also applies unless stated otherwise.

Table 2: Simulation Parameter for Star/Single-Hop topology

DANSE Layer	Protocol/ Services	Additional Settings
Transport	Best Effort	-
Logical Link	Best Effort	-
Network	Direct	-
Multiple Access	ALOHA	Init Max Wait= 0.200
Physical	Default	• Power (dBm) = -16 (due to distance) • Detect = 10dBm (Alleviate energy consumption through detection) • Bit-Rate = 1000bits/s • Preamble = 4 bytes

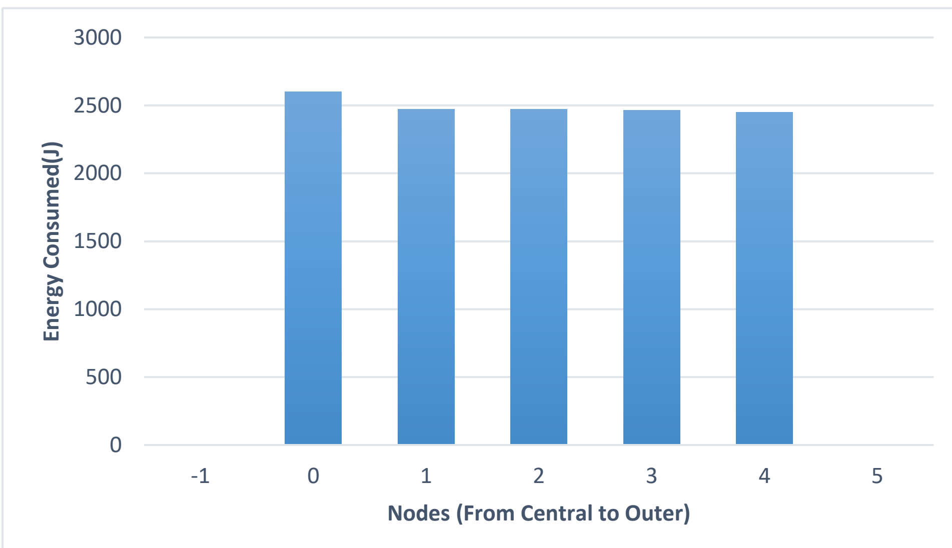

Figure 7: Energy Consumed in 5 Node Single Hop Topology

The result in Figure 7 shows that the node energy consumption is greatest in the central node and more evenly distributed across the outer nodes. By extrapolating the data linearly, it can be predicted the network would cease to function after approximately 5.10 days from activation using the formula in equation (3):

$$Life\ Expectance\ of\ a\ WSN = \frac{Mean\ time\ for\ node\ energy\ deplation\ (s)}{Lengh\ of\ a\ day\ (s)} \quad (3)$$

The lower the cost of a successful delivery, the more efficient the network is in terms of consumption. As stated previously, one of the larger problems with a star network is the amount of distance that such a network can cover, with the total area of coverage in the simulation being $400m^2$. This coverage could be ideal within a building or a small open area but would not be practical in covering a larger area, such as the caldera of a volcano for instance for environmental monitoring. For a larger area, multi-hop star-based network might be employed. Hence we investigate it.

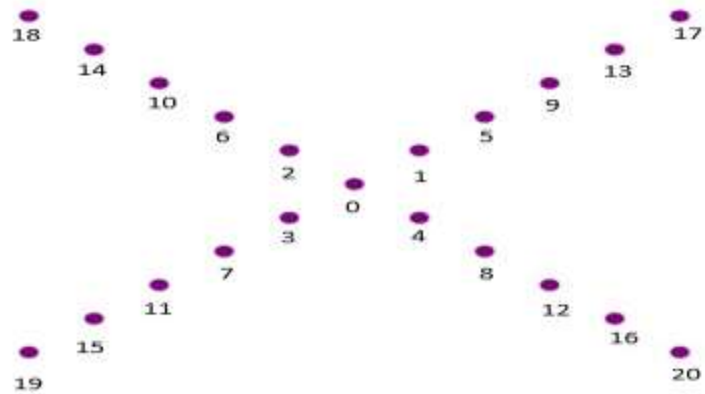

Figure 8: A branched star-based network topology with a centred data sink using 21 nodes and multi-hopping

For this scenario, the network layer has been adjusted to use a flooding routing protocol with a maximum hop count of 5. This is enough for the outer nodes to reach the central sink node. The distance between each node remains 20m, so the transmission power has been adjusted. Figure 9 shows the result of the total energy consumed from each node in the network with 95% confidence limits:

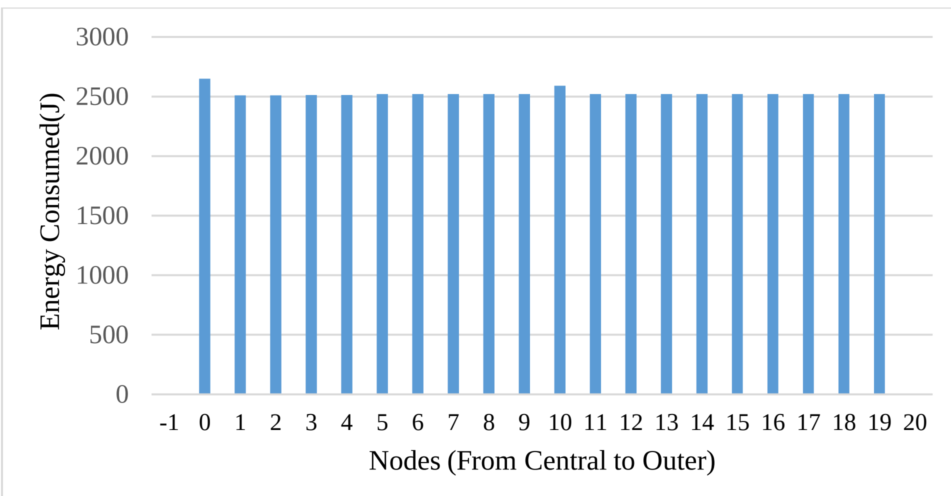

Figure 9: A graph of energy consumed using a 21 Node Star topology Using Centre flooding

As seen from figure 9, the amount of energy consumed increased with an increase in nodes, and the distribution of energy consumption can be more easily identified, with the central nodes representing the LHS of the graph and the outer nodes representing the RHS. An interesting distribution can be seen whereby the branching nodes linking to the centre show an increase in energy consumption, as the central branch nodes must deal with outer packet hopping as well as the transmission of their own packets the centre. The increase in outer node energy consumption is likely due to the outer nodes hearing the packet transmission from the inner nodes and routing them back and forth until the data has arrived at the sink. The decrease in packet success increases the cost of a successful transmission and is caused primarily by collisions at a physical level. These collisions could be reduced perhaps by using a channel listening protocol at the MAC layer, such as CSMA.

This topology however does only serve to increase the area covered by the network, with a total coverage greater than 20 times the previous topology at approximately 18000m^2 (based upon area covered by nodes and reception distance, excluding blind spots between each branch). The life expectancy of this network is also lower than the smaller 5 node star topology, likely due to collisions and energy wastage. Another risk that should also be addressed is that failure of any one of the nodes in a single branch would lead to a significant loss in area coverage as well as 'stranded' nodes. The issue of energy consumption at the centre node is also still prevalent and is in fact exacerbated.

Another test was carried out using the topology shown in Figure 10 to show how the energy consumption and packet success rate of the network is altered as the number of nodes increased. The result in Figure 11 shows a single hop star-based network with an increasing number of nodes around the outer sink node. The transmission power is higher in this instance due to increased node distance.

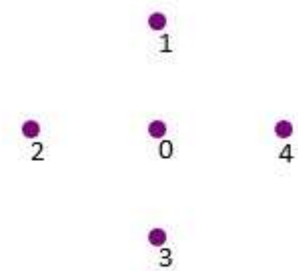

Figure 10: A single hop topology with a centred sink node (0) and four outer nodes.

This network is symmetrical about the centre node and each node is equidistant from the central node at 30m and the Node Area is 3600m^2. The parameters are same as those provided in table 2 except that the power level is -9.6 dBm and this is due to the distance.

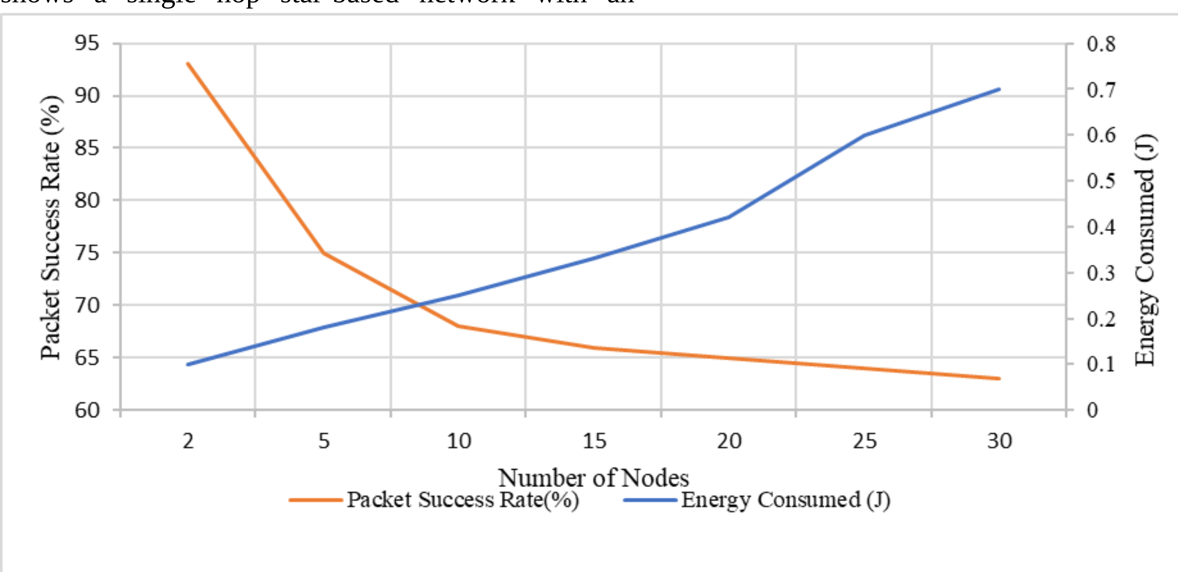

Figure 11: Total energy consumed in the network against packet success rate

Figure 11 indicates that the packet success rate remains relatively high with an exponential decay down to a packet success rate of 63% across the tests. The amount of energy consumed increases linearly however, indicating that more nodes decrease the efficiency considerably. The amount of area covered by the nodes alone is always approximately 3600 m^2 despite the increase in nodes. The transmission distance increases the area depending on the node position. There is no benefit in terms of energy or range in having more than 4-5 node in this configuration. The packet success rate/throughput remains high due to the lack of collisions as there is no need for multiple hops in this scenario. In small configuration of 4 nodes as seen previously, it is very efficient, but for the range to be increased, the transmission power must be increased, or there must be several relay nodes that can send data to the sink using multiple hops.

(B) Ring Topology Testing

Figure 12 provides typical illustration of a 5-node bidirectional ring-based topology using DANSE. In this scenario, there is no sink node and each node can communicate with its neighbours, as is the standard with most conventional ring-based topologies.

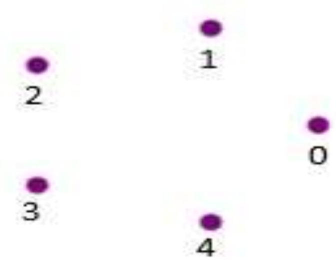

Figure 12: Example of a ring network within DANSE.

In this example every node has two neighbours equidistant at $35.26m$. Each node can communicate clockwise or anticlockwise and the node area is $2827.4m^2$. In this case the transmission power of -7dBm was chosen using the same method as previously mentioned, with a slight increase in the transmission power to accommodate any propagation loss. Figure 13 shows the energy consumed across every node in the simulation and therefore the overall energy distribution. As with the star simulations, 50 tests were carried out over a simulation period of $100000s$.

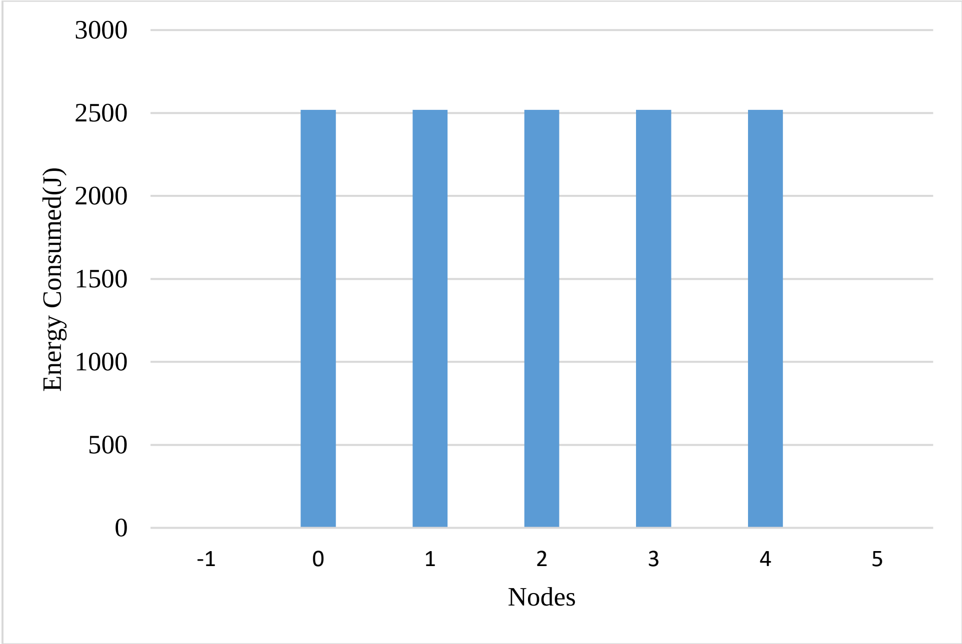

Figure 13: Energy Consumed in 5 Node Ring topology using flooding

The result shows an even distribution of energy across the nodes, however packet success overall is not particularly high when compared to a similarly sized star network topology with a sink. This is due to collisions associated with each nodes ability to transmit packets in both directions, clockwise and anticlockwise. Another issue is the predicted network life expectancy, which is poor when compared to the previously tested star topology. The amount of area that the network can cover is an issue that this topology shares with the star topology, at a circular area of $2827.4m^2$, greater than the initially tested star topology, but is still limiting. More nodes would be required to increase the area that this topology covers. Unfortunately, the option of having a ring network in that spans a wider area is not readily available within DANSE without extensive configuration. As the area cannot be easily increased, it is futile to test the ring topology with a greater number of nodes and perform a scalability test as carried out before. This will only serve make the network expend energy faster and will also increase the number of collisions on the network unless the transmission power is changed throughout testing. An alternative scenario would be to implement a small ring-based network topology with a single data sink. This scenario would be more realistic for an environmental WSN using a data aggregate that can communicate with a base station. With this proposed second scenario, the only difference made to the simulation was to change the target node to the zero node, which acts as the data sink.

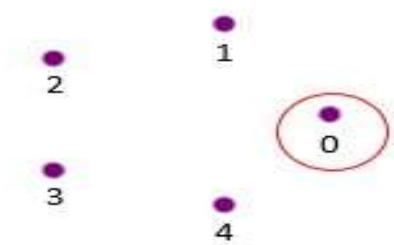

Figure 14: Example of a ring network within DANSE with node 0 highlighted as a data sink.

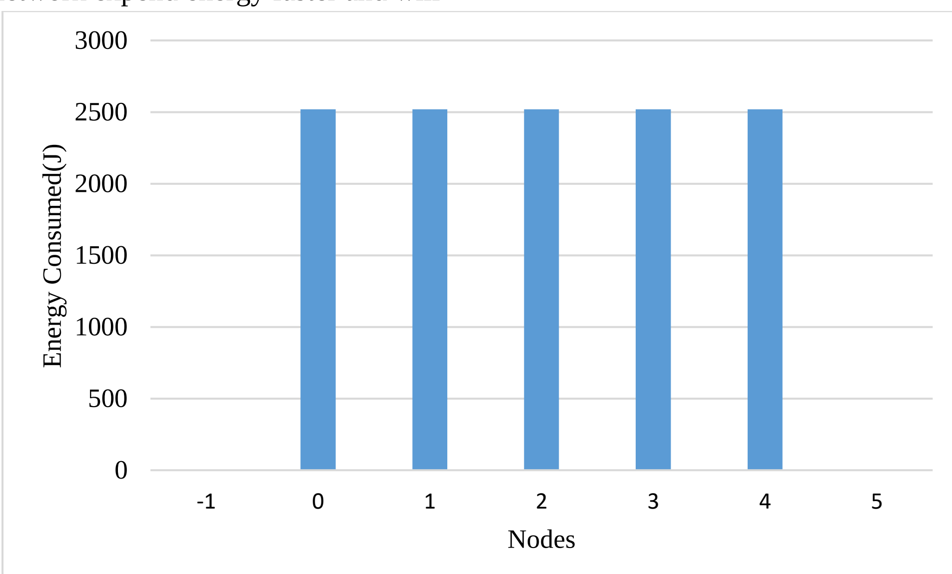

Figure 15: Energy Consumed in 5 Node Ring Topology using Flooding with Data Sink

Figure 15 indicates the differences between node energy distributions. It is clear to see that the sink consumes the least amount of energy in the network, with the two outer nodes 2 and 3 consuming more than the innermost, 1 and 4. The use of a data sink in this case does not improve the performance of the network in any discernible way, with the packet success rate remaining the same as the previous scenario. The network life expectancy has been reduced marginally through the inclusion of a sink. Efficiency of the topology based upon the cost a successful packet transmission is also the same. Overall, through research and simulation, the ring-based topology is consistent with regards to efficiency, energy consumption, life-span and packet success. When compared to a large star network however, the only discernible benefits are the efficiency and energy consumption. It is a good topology in terms of energy regulation when a sink is not in use but is less equally distributed with a data sink. The packet success of the ring network also indicates that it may not be the best choice of topology when trying to design a reliable network, being outperformed by both the larger star and smaller star topologies. This could be mitigated in some way by letting traffic from nodes only travel in one direction but reduces the reliability if a node were to fail. A ring could be more easily deployed than a large star-based topology, but a large portion of area is left blank with a ring based network in the centre, which is likely not ideal for collecting data. These results show that a ring-based topology would be appropriate for a Perpetual WSN.

(c)Mesh/Multi-Hop topology testing

Figures 16 and 17 are results from DANSE based upon random mesh topologies with a single data sink. In the following cases, both the batch and configuration files were altered to force DANSE to test across the same randomly distributed topologies. The simulations are also multi-hop as with the other tests. The first scenario uses 5 nodes.

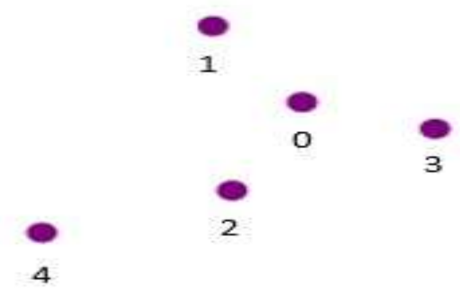

Figure 16: The randomized 5 node topology selected within DANSE.

The nodes are randomized, however adjacent nodes are no further than approximately 30-35m . One data sink node randomly selected (in these paper it is node 0) and the node area is 2693m^2

The value of -10dBm was obtained as a transmission power using 31m, however this was increased slightly as with the other tests to -9.6dBm, which yielded the best initial test results before batch testing. The simulation time was 100000s and results and confidence limits were taken from 50 tests. Below is a bar chart showing the node energy distributions with node 0 as the sink:

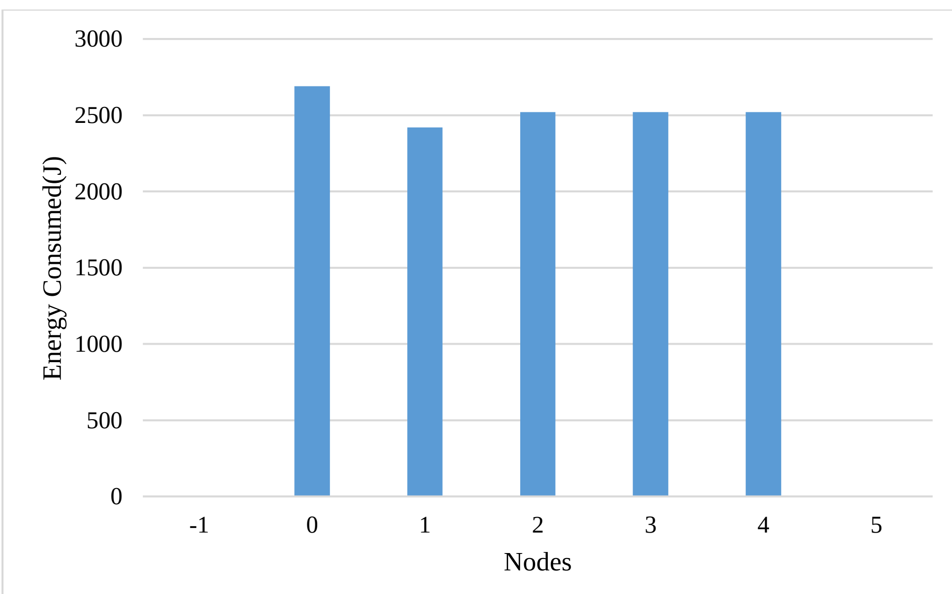

Figure 17: Energy Consumed in 5 Node Mesh Topology Using flooding with Data Sink

Node 1 consumes the least amount of energy. This is due to node 1's placement from the diagram. The consumption of node 3 is greater than that of node 1 due to it being within reception distance of node 2 when it is transmitting, whereas 1 is not, this makes a sizeable difference. Node 1 is also only able to communicate with node 0 at its distance. The packet success rate is higher than that of the ring topologies and is essentially equivalent to the 5-node star topology in figure 6. The efficiency as indicated by the cost per successful packet is also less than the ring topologies and once again, very much comparable to the results obtained from the 5-node star topology. In comparison to a well organised star-based topology of roughly equal size, the success rate and energy efficiency of the networks appear to be very similar. For a smaller network, it could be argued that a star topology would be better for energy efficiency and throughput.

A larger based mesh topology using 20 nodes is also tested in the following section of this report to be compared against the multi-hop star topology and the smaller 5-node mesh counterpart.

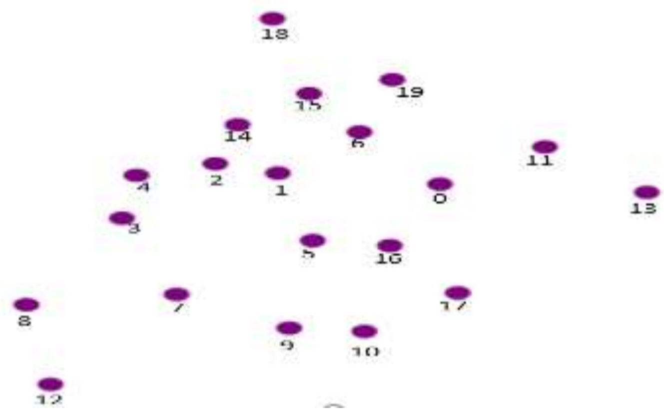

Figure 18: Randomized 20 node topology generated and tested within DANSE.

The simulation parameters remain the same other than hop count, which has been changed to a value of 12, which is more than enough to cover the topology from at any given source node to sink. Figure 19 shows the energy distribution of the nodes.

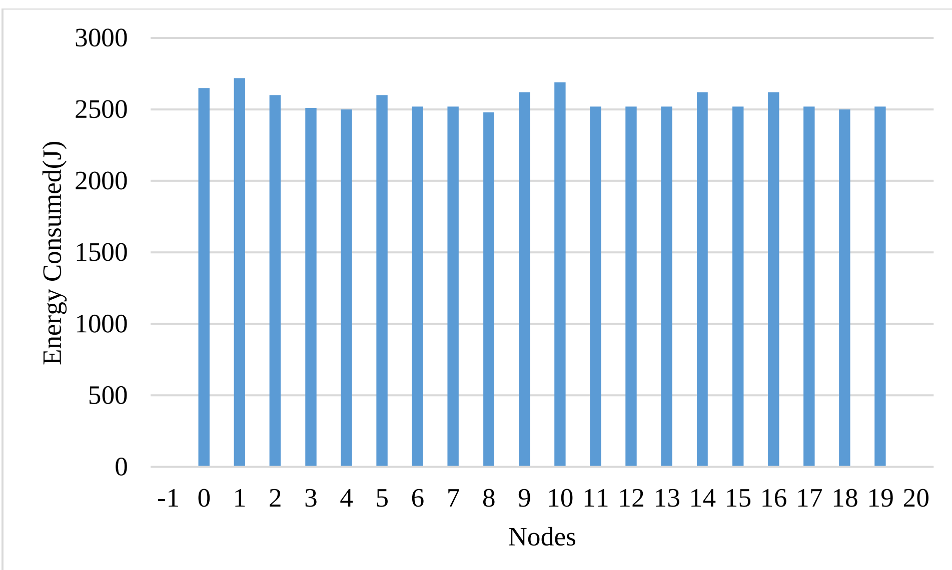

Figure 19: Energy consumed in 20 Nodes Mesh Topology using Flooding with Data Sink

In figure 19, the life expectancy is like that of the 5-node mesh network and does not indicate a significant decrease as opposed to the multi-hop 21 node star topology, which showed a decrease in life expectancy of 5 hours. The efficiency has been decreased due to the reduced packet success rate, likely due to collision when transmitting across the nodes to the sink.

As before, the overall scalability of the network has been tested by using different numbers of nodes at a fixed transmission power which is the same as in the above tests. The hop count in this case was set to 13 (and similar to the previous results as the maximum number tested is 30 nodes), greater than the star topology due to the placement of node 0 (sink), which in the case of a random mesh-based topology could be anywhere within the network. Below is the graphed result:

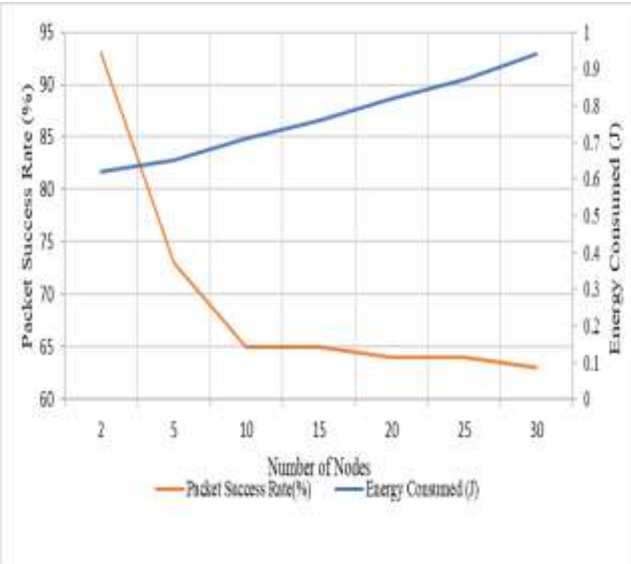

Figure 20: Total energy consumed in the network against packet success with an increase in nodes.

Figure 20 shows a more predictable pattern with regards to the network scaling, with the energy consumption increasing as the number of nodes increases and packet success rates declining, most likely due to interference as with the star topology. There is no packet success rate increase however after a certain number of nodes, most likely due the mesh layouts within DANSE which are usually relatively dense and can only accommodate nodes a maximum distance apart. When compared to the 21-node star topology tested, there does not appear to be a statistical advantage to the mesh-based network other than a potential consistency in life expectancy across a larger area and subsequently a larger number of nodes. The energy distribution across the 20 node mesh topology is again erratic when compared to the 21-node star topology, but the minimum energy consumed is lower which is due to how little certain nodes are ever transmitting and receiving packets. The 21-node star topology had an energy consumption distribution that was greater at the central nodes within the network branches. This is concerning as it threatens the outer nodes trying to deliver packets to the central aggregate node. The scalability indicates that the performance of the star-based multi-hop topology appears to be far better than mesh-based networks. This is most likely due to the node distribution, which is far more uniform in the star topology and more conducive to fixed transmission powers when compared to a meshed-based topology. Implementing dynamic transmission powers based upon adjacent node distances could be beneficial for a mesh-based network. The amount of total area that can be covered by both 21node star and 20-node mesh is similar, but greater in the mesh due to the star network blind spots making it a more likely candidate for deployment in the environment. Packet success decline in the mesh network is most likely due to over-transmission and collisions across the nodes. With a protocol aware of its surrounding nodes, the transmission power and collisions potentially reduced as a result. A channel sensing protocol would also be beneficial for this topology also. One of the biggest drawbacks with a mesh-based network over the multi-hop star network is that network packet propagation delays can be easily predicted whereas in a mesh network this is not easily achieved due to the number of available paths. This could also potentially be mitigated using route storage at the network layer, something that has been absent in the above testing scenarios.

IV. Conclusions

This paper has investigated three well established network topologies in order estimate their overall efficiency and functionality, and whether they would be good candidates for consideration within a PWSN. The clustered network topology was omitted due to time constraints Overall, out of the topologies tested it seems that mesh is the most realistic due to its energy distribution and optimisation over a large area for a great number of nodes, however a small single hop based network is provides good result for energy consumption and packet success rates. Using more advanced networking protocols, it can be expected that the performance of the mesh topology will increase. Energy harvesting techniques can be employed on such a network to further increase the life expectancy and shall be explored. For a small network, a star topology is most likely the most ideal solution, with ring being the second choice for this scenario with consistent energy consumption, but lower packet success and overall efficiency.

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