INTERNATIONAL JOURNAL OF INNOVATIVE ENGINEERING, TECHNOLOGY AND SCIENCE ISSN: 2533-7365 Vol. 10, No.1, January – June, 2026
A Publication of Faculty of Engineering Chukwuemeka Odumegwu Ojukwu University, Uli - Nigeria.

IMPROVING ENERGY CONSUMPTION SAVING IN LONG DISTANCE WSN INFRASTRUCTURE MONITORING USING ERROR DETECTION AND CORRECTION ROUTING ALGORITHM

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ABSTRACT

The growing demand for ubiquitous connectivity and new services in communication technology comes with an undesired consequence of increasing energy consumption. The nodes are the main components of a wireless sensor network WSN infrastructure and contributes majorly to the energy consumption of the network. Therefore, there is need for a well-designed and planned infrastructure to effectively serve customers to avoid incessant collisions and attacks. In this paper a cluster-based hierarchical routing algorithm with error detection and correction for detecting corrupted packets and aborting re-transmission, thereby improving energy savings of WSN, and prolonging the nodes lifetime was developed. Based on targeted 400 rounds of packets signal transmissions the performance of the algorithm was extensively tested. Whereas the conventional technique (non-hierarchical) has functional capacity that lasted 120 rounds of simulation during transmission (30% energy efficient), the developed technique lasted till an estimated value of 330 rounds of simulation during transmission (82.5% energy efficient). In packets delivery ratio evaluation criterion, the developed model achieved packet delivery ratio of 96% while the conventional model achieved 64%. The sensor network lifetime for the developed technique increased by 52.5% compared to the conventional technique, which implied better network performance. The contribution to knowledge is that a new routing algorithm incorporating error detection and correction scheme is a very reliable energy saving algorithm for long distance WSN infrastructure monitoring. Recommended for deployment to both ad-hoc and non-ad-hoc networks where a collection of wireless sensor nodes is part of as it will reduce energy consumption in those nodes.

Keywords: WSN, Routing Algorithm, Energy Saving, BTS, Packet Delivery Ratio, Clusters.

1.0 INTRODUCTION

The propagation of radio signals is affected by several factors that contribute to the degradation of its quality. Radios of low power category, typically used in wireless sensor networks (WSN), experience more significantly the effects of these factors when wireless signals are propagated with it, and this challenge drastically reduces the predictability of radio links in WSNs. In fact, their quality fluctuates over time and space, and connectivity is typically asymmetric (Srinivasan *et al*, 2016). Sensor networks and radio transceivers transmit low power signals and as such radiated signals from them are more likely to be affected by noise, interference, and multi-path distortion. Also, antennas with non-ideal radiation patterns are what they rely on for transmission and reception of signals. Sensor nodes interact with one another or with base transceiver station (BTS) through wireless communication media such as radio signals, infrared, or blue tooth which can be configured in either single-hop or multi-hop transmission modes. In a single-hop transmission mode, all the nodes send their sensed information directly to the base stations (Jadhav and Salunkhe, 2016; Din *et al*, 2020). In a multi-hop transmission mode, nodes transmit their sensed data to BTS through intermediate nodes (Din *et al*, 2020; Sarode and Bakal, 2018). Sensor nodes are operated on limited power and the battery is not replaceable. They consume much energy during their active periods, that is, while performing various tasks. A sensor network consists of an arbitrary large number of nodes (hundreds and thousands), randomly deployed in an outdoor area (Hamza and Alhayani, 2018). The nodes gather information from the environment and send the data to a few master nodes, called sinks, responsible for gathering the data generated by a cluster of nodes located close by. Such a scenario corresponds to the deployment of WSNs used for collecting data for applications, such as environmental or agriculture monitoring, observing enemy units in a military context, as well as measuring the parameters of a polluted or inaccessible region. In a networks infrastructure that involves sensor nodes, the nodes can fail due to energy utilization and malicious attacks among other factors. In terms of failure of nodes as a result of network energy utilization, the solution is to reduce energy consumption by the network. Some researchers have used various energy management concepts or techniques to reduce this consumption. In the work of Shio *et al* in 2015, a new model of an energy efficient transmission error recovery for WSN was used. In this model, packets of information in form of data were divided into small sub-packets and retransmission was done for only corrupted portion of the sub-packets. The model also helps in determining optimum size of the sub-packets. These resulted into minimum battery power requirement for the nodes and increased lifespan of the network. The results showed that more than 30% of the power savings was realizable by implementing the new model unlike in the conventional model of complete packet retransmission. In the work (Vorgelegt, 2017), an algorithm for exploiting the content of data packets and hence minimize packet transmissions volume, and thus the energy consumption, was developed and used. By means of in-network processing, correlated data may be combined and aggregated to a single packet that can then be forwarded on its own, instead of sending each packet individually. While such data aggregation can be used independently of the forwarding strategy, they pointed out that considering the effects of aggregation during the construction of forwarding paths is extremely beneficial. The algorithm consisted of single-link energy-efficient aggregation forwarding (SEEAF) and multi-link energy-efficient aggregation forwarding (MEEAF). Both strategies yielded forwarding paths with a high potential for aggregation, rendering the forwarding process much more efficient. They presented a mechanism to avoid forwarding cycles, which, if they are not taken into account, may otherwise occur during the construction of an aggregation tree. Both simulation and physical experimental results obtained by means of real-world test-bed, showed that energy efficient aggregation forwarding (EEAF) clearly outperformed ordinary energy efficient forwarding (EEF) in information delivery ratio and energy management. In a research work (Deqiang *et al*, 2011), energy aware ant colony algorithm (EAACA) was used to select the closest path from the source node to sink node for fast communication with limited use of energy in WSN. In case of off node, the EAACA routing protocol shifts to the next hop node, taking into account the distance of the sink node. During this process, the residual energy of next hop node and average energy of the path is considered. By balancing the energy consumption of the nodes in WSN, the network lifetime is increased. Lee *et al* (2014) in their research work used a model for applications in streaming real-time in controlling congestion and hence energy consumption. A control technique to achieve the needed smoothness of the transmission rate should be TCP friendly. Moreover, in wireless networks, TCP-friendly congestion control should be based on differentiation of packet losses due to congestion and wireless link error to improve network utilization. The authors employed a TCP-friendly congestion control algorithm based on explicit congestion notification over the wireless networks. They assumed that the outgoing link of the BTS is the bottleneck link, where electronic communication network (ECN) is implemented. Their assumption that the BTS implements ECN is realistic because ECN has gained popularity since it was first introduced in the early 1990s. The control algorithm for a non-TCP flow consists of three states, that is, initial state, operation state, and back-off state. At the initial state, a sender begins by transmitting at a slow rate but increases its transmission rate exponentially fast. At the operation state, the sender adjusts the transmission rate using the ECN mechanism. At the back-off state, the current transmission rate holds until the sender receives an acknowledge (ACK) packet. Simulation result showed that the algorithm utilized the link bandwidth efficiently, providing smoothness of the transmission rate. The research work was centered on congestion management but did not cover network security issues. Sunita1 and Khanna (2018) analyzed energy-efficient and QoS multipath routing (EQMR) in which drop packets and end-to-end delay is concluded using two pass algorithms. The sequence is that the model will examine the drop packets and thereafter attack the packet loss. This model equally minimizes the dropping packets by diminishing the end –to- end delay in the network. Simulation results showed that technique was effective.

None of the algorithms incorporated error correction scheme which will ensure corrupted message/packets are not transmitted and that will in turn minimize consumed energy and wastage. Consequently, response time will improve so as to achieve better performance. In this work error correction scheme will be incorporated in the new algorithm.

2.0 EXPERIMENTAL MEASUREMENT

In this work, a wireless sensor network of seven nodes including one sink node was set up so as to characterize the network and obtain practical values based on a conventional (non-hierarchical) routing algorithm. The equipment used for the drive test are Tektronix PS280 DC power supplies, prototyping boards and measurement equipment which included fluke 8050A digital multi-meters, Hewlett Packard 54600A oscilloscopes, Agilent, 89600 vector signal analyzer and spectrum analyzer, a laptop/personal computer (PC), and flash memory. All nodes were powered with recently recharged batteries for measuring network lifetime in a direct way. The initial voltage of each node was measured using a voltmeter, and then all nodes were started simultaneously and located in their positions. Nodes started to send the counter through the network. Packets finally reached the sink, which is another node attached to the base for information management (MIB510) module, AC powered and directly connected to a PC using a serial port. The sink sent all packets received to the PC and they were stored in plain text files, along with the date and time when they were received. The sink could only receive packets. Its radio was “On” always and as such only received packets, showed the counter last three digits in its LEDs and sent the messages to the serial port. The network was left running this way until the sink stopped receiving packets from some of the nodes. That was the visible signal of the death of those nodes. Then, information of the files was analyzed, to know exactly when the first and last packets from each node were received. Subtracting the date and time, it was possible to calculate the time each node was transmitting (alive). The moment when the first node was dead was considered the lifetime of the network. The location and connectivity pattern of the six nodes and one sink used in this network experimental set up is shown in figure 1.

Nodes 0 (sink), 1, 3 and 12 are located in the wireless laboratory. The rest are located as follows: node 2 in room 1, node 13 in room 2, node 20 in room 3. Nodes 1, 3, 12 and the sink node are in direct communication. Nodes 2, 13 and 20 should reach the sink through some of the other nodes. Table 1 shows the distances measured between the nodes and the sink. The sink receives all messages and sends them to a computer, using a serial port. All packets received are registered with the date and time they were received. The nodes were programmed to transmit

in the 903MHz band at the maximum power, 5dBm, using binary frequency shift keying (FSK) with Manchester coding at 19.2 kbps. The experiments employed the default media access control (MAC) protocol.

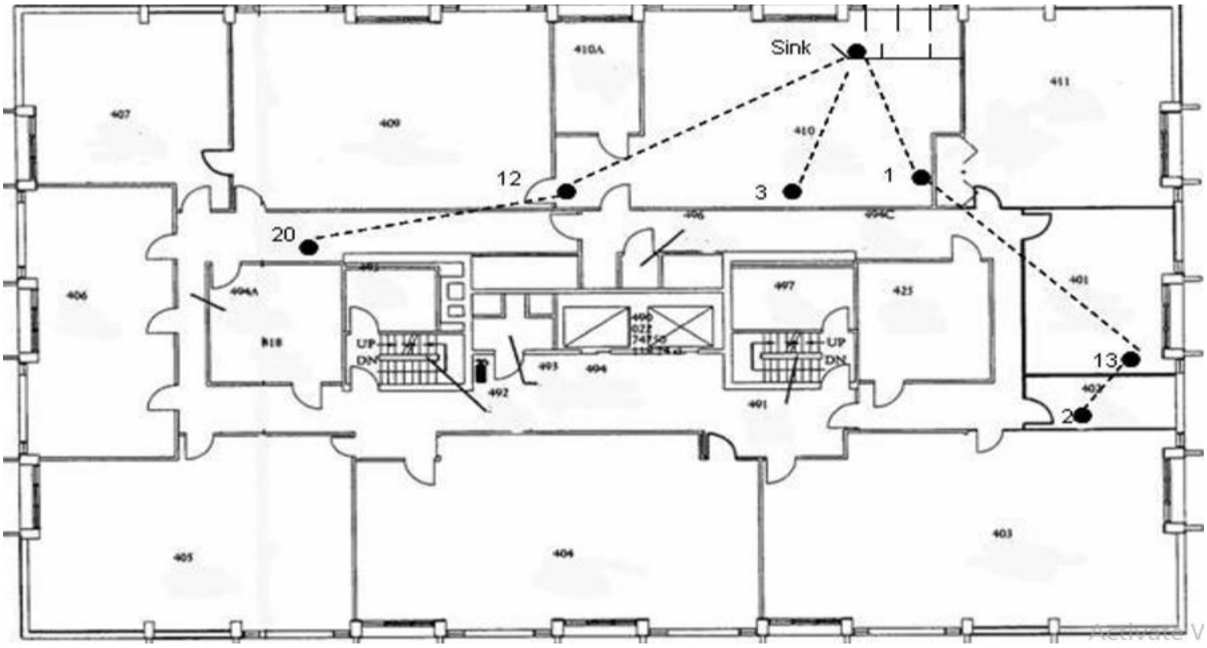

Figure 1: Node Location and Connectivity of the Network

Table 1: Distances Measured Between the Nodes and the Sink Node

Node	Distance (m)
1	5.32
2	15.22
3	4.19
20	16.31
12	16.31
13	13.44

3.0 ENERGY REQUIREMENTS OF WSN

This research used a radio model for a shorter distance such as single-hop transmission, direct data transfer from sensor node to a cluster-head, the utilized energy by a transmit amplifier is proportional to d^2, where d is distance. However, for a longer distance transmission, such as multi-hop transmission between a node and the sink, the energy consumed is proportional to d^4. Using the given radio model, the energy consumed to transmit l-bit message for a longer distance, d, is given by (Hamza and Alhayani, 2018):

$$ET = Ee + EL\ d^4 \qquad (1)$$

Where ET is energy consumed to transmit, Ee is energy utilized by the electronics circuit to send or receive the signal, EL is energy utilized by the amplifier for a long-distance transmission, and d^4 is long distance. In the same way, the energy consumed to transmit l-bit message for a short distance is given by (Hamza and Alhayani, 2018):

$$ET = Ee + ES\, d^2 \qquad (2)$$

Where ET is energy used to transmit, Ee is energy used by the electronics circuit to send or

receive the signal, Es is energy used by the amplifier for distance transmission, and d^2 is short distance. Moreover, the energy consumed to receive l-bit message is given by (Hamza and Alhayani, 2018):

$$ER = Ee + EB \qquad (3)$$

Where ER is energy consumed to receive, Ee is energy consumed in the electronic circuit to send or receive the signal, and EBF is Energy consumed for beam forming. Beam forming approach reduces energy consumption. Equations (1) to (3) are the energy requirements for WSN.

4.0 ENERGY-EFFICIENT ROUTING ALGORITHM FOR LONG DISTANCE INFRASTRUCTURE MONITORING

This is the new algorithm that was developed to improve energy consumption in WSN. It is a clustering algorithm that maximizes efficient utilization of energy in the whole network. The design of the algorithm will put more emphasis on minimizing the energy being used in long-distance transmission that can be applicable to small, medium and large-scale networks which can be single hop or multiple hop in configuration.

4.1 Multi-Hop Energy-Efficient Distance Routing Algorithm

Dividing the network into multiple clusters guarantees energy saving as the cluster head node collects and aggregates information from its neighbours and delivers the summary to the base transceiver station through a collection of hops that are optimum in number, to avoid redundant transmissions and hence save communication costs. However, if a sensor node is close to the BTS, it can forward information straight to it and thus also save energy. Figure 2 is the diagram of the developed routing algorithm.

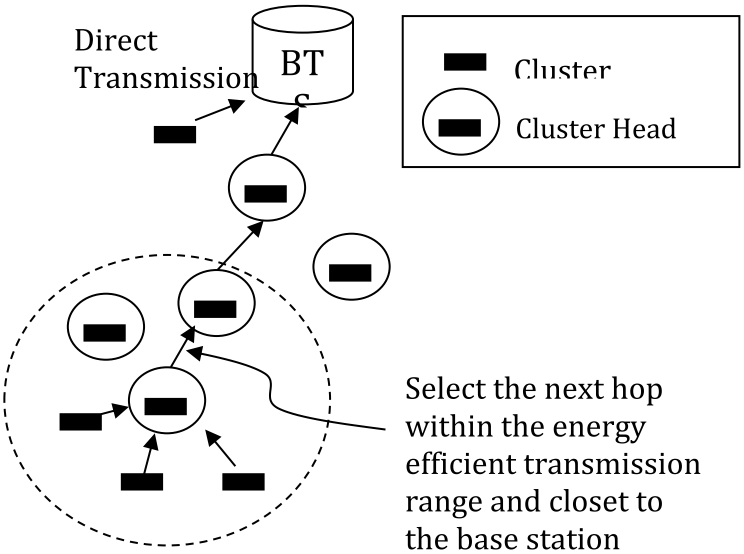

Figure 2: Multiple Hop Transmission with Energy-Efficient Distance

Cluster heads will wait for a fixed period of time or for a certain message size to accumulate before starting a transmission. If the distance to the BTS is shorter than other clusters, nodes (clusters) will send data to BTS directly otherwise it will extract the cluster head information from the database. It selects the next target cluster heads within its energy efficient transmission range and also closest to the BTS. It then estimates the energy used for data transmission of both cluster heads. If the remaining energy is enough for both cluster heads, it will send the data and update the cluster heads with the energy that may be remaining.

4.2 Simulation of the Developed Energy Efficient Routing Algorithm for Long Distance Infrastructure Monitoring

Extensive simulations of the developed energy efficient scheme were carried out in MATLAB. A heterogeneous WSN of 100 sensor nodes deployed randomly between [0,0] and [100,100] in a square area with field dimensions of 100*100m considered. The simulation parameters are depicted in table 2.

Table 2: Simulation Parameters

Parameter	**Value**
RF Power	–25 dBm~0 dBm
Power Supply	0.1 V~3.6 V – (AA or AAA battery)
Range	~150 m (outdoor), 20~30 m (indoor)
Numerical Value of Sensor Nodes, n	10
Number of Clusters	5
Number of cluster Heads	5
Network Field Dimensions	100 x 100m
Sink Location	50, 150
Number of Packets sent	50
Maximum Transmission Rounds	400

4.2.1 Cluster Head Competition Phase

After updating the information table, each node chooses node residual energy (NE), node degree (ND), and neighbour nodes' energy (average residual) (NNE) to be the input variables and each of it is converted into fuzzy linguistic variables (FLVs). Equations are formed with their fuzzy sets as listed.

A1(NE) = {X1 = "low",X2 = "medium",X3 = "high"}
A2(ND) = {X1 = "short", X2 = "long"}
A3(NNE) = {X1 = "weak",X2 = "normal",X3 = "strong"} (4)

As can be seen in equation (4), the FLV for node residual energy has the membership degree division as: "low", "medium" and "high", the fuzzy linguistic variable for node degree has the membership degree division as: "short", and "long", and the fuzzy linguistic variable for neighbour nodes' average residual energy has the membership degree division as: "weak", "normal" and "strong".

The fuzzy inference system (FIS) does the conversion of the original crisp values to the fuzzy vocabulary variables accordingly. Furthermore, the IF-THEN rules can be developed in line with the principle of Takagi, Sugeno and Kang (TSK, 2013) deductive system. Table 3 depicts the IF-THEN rules table of algorithm. NE represents residual energy, ND represents node distance, and NNE represents neighbour nodes' average residual energy.

The node energy (NE) is classified into three levels of low, medium and high as shown in equation (4) and each level is a range of values as presented below.

(0.1 – 0.4) = Low (1), (>= 0.4 < 0.7) = Medium (2), (>= 0.7 = High (3)

Table 3: **IF-THEN Rules**

SN	**NE**	CH	ND	NNE	Result	Node
1	Low	Low	Short	Weak	Check other cluster heads	All nodes
2	Medium	High	Short	Weak	Transmit	1
3	High	High	Short	Weak	Transmit	1
4	Low	Low	Long	Strong	Transmit	2
5	Low	Medium	Long	Strong	Transmit	2
6	Medium	Medium	Long	normal	Transmit	1
7	Medium	Medium	Long	Strong	Transmit	2

The FIS does the conversion of the original crisp input variables into corresponding FLVs based on the input membership functions mentioned above. In the fuzzy logic field, the most widely used technique to develop the algorithm for human beings' thinking is to make instantiation of linguistic expressions, such as the well-known IF concept, THEN conclusion, where the concept is the decision condition described by the FLVs the fuzzy set of input variables, and the conclusion is regarded as the fuzzy output variable. The IF-THEN rule-based knowledge representation is based on natural language representations and algorithms. That is to say that the fuzzy system will compute the value of the output variables in line with the rules which capture the experts' knowledge of the evaluation systems

The performance improvement of the developed WSN provides a data routing platform needed by the wireless sensor gate-way networks (WSGNs). The software employed for the simulation of the developed algorithm is a MATLAB/Simulink simulation tool that is of high-level technical computing language with an interactive environment for algorithm development, data visualization, data analysis, and numerical computation. After configuring the network and commencing simulation, it was left running until the sink stopped receiving signal packets from certain nodes. That was the visible evidence that those nodes are dead, and in this set up the death was observed to occur after 330 rounds of transmissions.

5. ANALYSIS AND DISCUSSION OF RESULTS

The performance of the conventional and developed algorithms were evaluated based on parameters such as packet delivery ratio, energy saving capability and configuration structure.

5.1 Packet Delivery Ratio

The nodes transmit packets/data to the sink and any moment the first node is dead (stopped transmitting) is considered the lifetime or transmission rounds of the network. Table 4 depicts transmission rounds visa vis packet delivery out of 50 sent packets for the conventional routing algorithm

Table 4: Transmission Rounds versus Packet Delivery for Conventional Algorithm

Transmission Rounds	Number of Packets Delivered
10	5
20	10
50	15
100	20
150	35
200	40
250	43
300	45
350	49
400	50

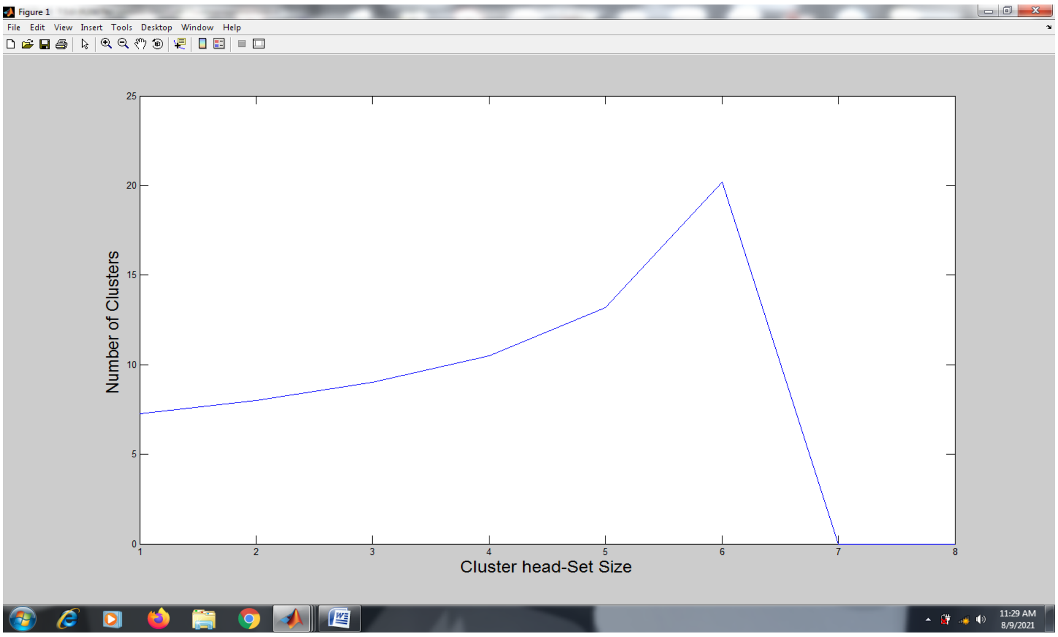

Figure 3: Transmission Rounds versus Packet Delivery for Conventional Algorithm

The network was left running this way until some of the nodes stopped transmitting packets to the sink. Figure 3 shows that after 120 rounds of transmissions for the conventional model, the sink node didn’t receive any packets further from all the nodes and it was observed that the first node to die delivered 32 packets out of 50 packets sent. This means that the conventional (non-hierarchical) model has functional capacity that lasted 120 rounds delivering 32 packets out of 50 packets sent during lifetime test-running (table 4) which translates to 30% of energy savings. When the network was tested based on the developed algorithm the functional capacity lasted 330 rounds delivering 48 packets out of 50 packets sent which translate to 82.5% of energy savings. This implies that the developed algorithm has higher packet delivery ratio than the convention algorithm. Packets delivery ratio is calculated as the total numerical value of packets received successfully at the final destination over total numerical value of packets sent. Figure 4 showed the variation in the packet’s delivery ratio when cluster-based routing technique (developed model) was compared to the conventional model. A percentage value of 96% as packet delivery ratio was achieved with the developed model and 64% with the existing (conventional) model.

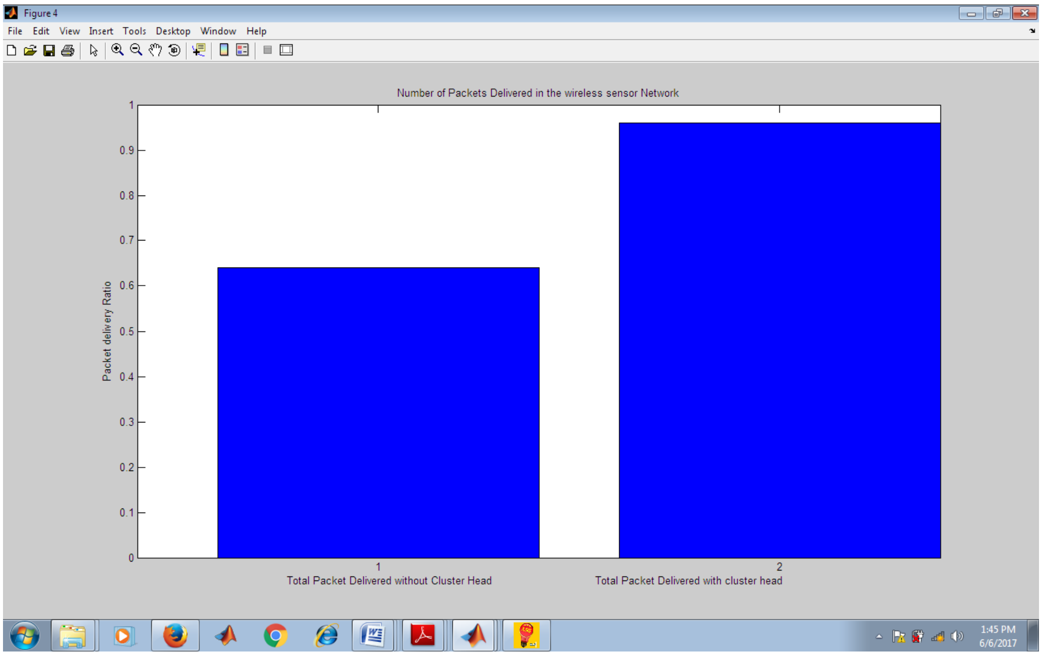

Figure 4: Packet Delivery Ratio of the Conventional WSN and the Developed Model

5.2 Multi-Hop Energy-Efficient Distance Routing Algorithm

To save energy, a technique is adopted in which the network is split into clusters which are multiple in arrangement and the cluster head node is positioned to collect and aggregate information from its neighbours and deliver the summary through optimum collection of hops to the base transceiver station to avoid redundant transmissions, and this also saves communication costs. However, if a sensor node is close to the BTS, it can forward information to the BTS directly and thus also save energy. Clusters are grouped with a cluster head selected according to cluster head-set size. Table 5 represents the cluster head-set size in relation to the number of clusters. Figure 5 is a graphical representation of table 5.

Table 5: Cluster Head-Set Size Versus Number of Clusters

Cluster head-Set Size	Number of Clusters
1	7.2666
2	7.9959
3	9.0006
4	10.5134
5	13.1875
6	20.1902
7	0.0000 +34.4240i
8	0.0000 +15.5401i

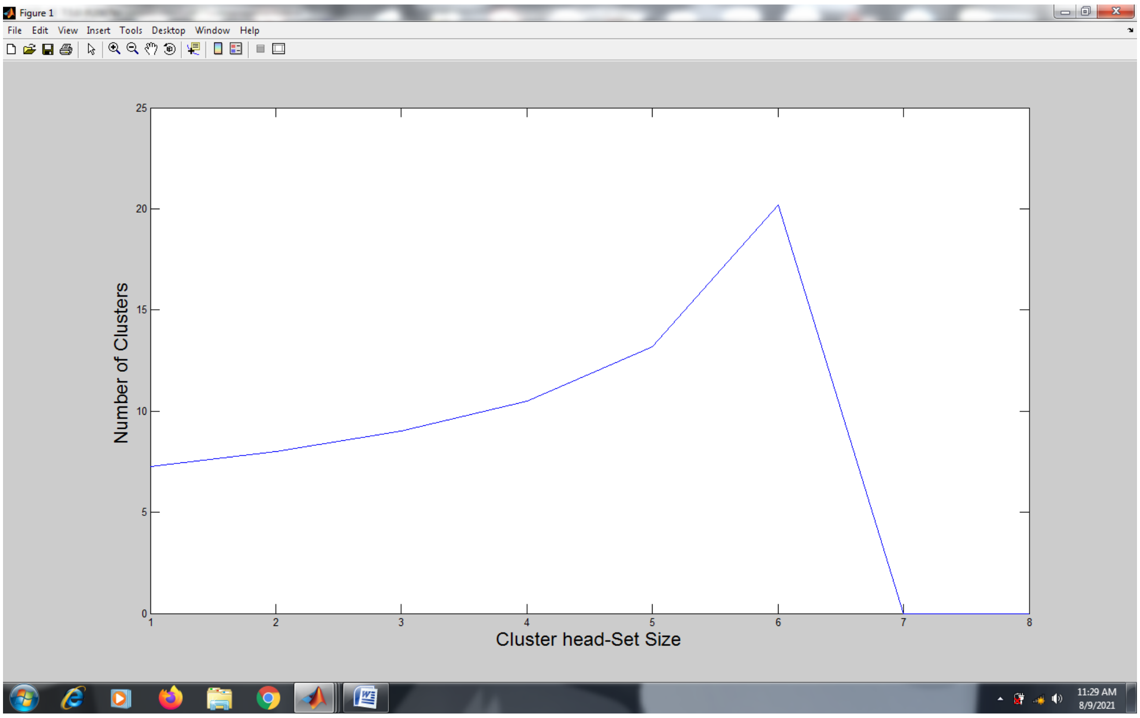

Figure 5: Cluster Head-Set Size Versus Number of Clusters

The results were analyzed for the developed cluster-based routing technique. Figure 5 shows the optimum number of clusters when considering cluster head-set size. From the graph, the maximum number of clusters is approximately 20 and its corresponding cluster head-set size is 6. As the graph shows, the cluster number decreases as the cluster head-set size number exceeds 6. The minimum number of clusters is approximately 7 and its corresponding cluster head-set size is 1. Therefore, as the number of clusters increases the cluster head-set size also increases. As a result, bigger number of clusters can manage bigger cluster head set size whiles smaller number of clusters can manage smaller cluster head-set size. The reason for this observation is that, in the WSN, if a cluster head-set size is not carefully chosen for its respective number of clusters, during data transmission much burden is put on the cluster head-set nodes and could result to packet drop.

5.3: Distance of Clusters to BTS

The distance of nodes to the BTS would determine whether cluster formation will arise with ultimate grouping of cluster head-set sizes. This will result in finding the optimal number of cluster head-set sizes to minimize power consumption in the network (Kim and Cobb, 2011). Figure 6 shows the variation of the number of clusters with respect to the distance of nodes from a BTS while figure 6 depicts same in graphical form.

Table 6: Distance versus Number of Clusters

Distance	No of Clusters				
	Cluster head size 1	Cluster head size 2	Cluster head size 3	Cluster head size 4	Cluster head size 5
150	7.2666	7.9959	9.0006	10.5134	13.1875
160	6.3214	6.7841	7.3659	8.1288	9.1914
170	5.5584	5.8652	6.2291	6.6703	7.2210
180	4.9312	5.1416	5.3815	5.6584	5.9830
190	4.4078	4.5561	4.7206	4.9041	5.1110
200	3.9657	4.0727	4.1889	4.3156	4.4545
210	3.5884	3.6671	3.7512	3.8414	3.9383
220	3.2634	3.3223	3.3844	3.4502	3.5200
230	2.9814	3.0260	3.0728	3.1218	3.1731
240	2.7348	2.7692	2.8049	2.8420	2.8806

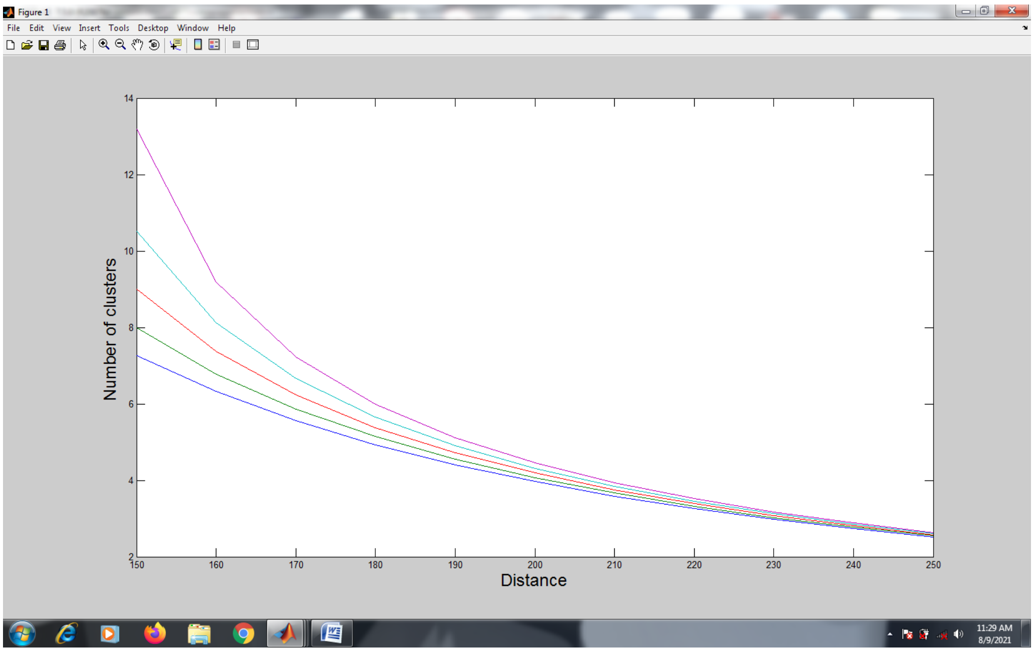

Figure 6: Distance versus Number of Clusters

Figure 6 shows the variation in number of clusters with respect to distance from the base transceiver station (BTS) for various number of cluster head-set sizes. In the graph, the number of clusters increases with decrease in distance between the clusters and the BTS. This variation is the same for the various cluster head-set sizes (that is from cluster head set size 1 to cluster head set size 5). This implies that the cluster head-set size does not vary with respect to distance but rather the number of clusters.

5.4 Power Consumption in Relation to Number of Clusters on the Network

A key aspect of WSN is to minimize the power consumed by the nodes, especially when the haul is long, necessitating the formation of clusters because the nodes will require cluster heads through which the nodes will deliver the packets to the BTS. The more the grouping to increase the cluster head-set size, the less the energy consumed and the better for the network with improved lifetime. Table 7 is a display of the variation in power consumption in WSN with respect to cluster head-et size and figure 7 displays same as graph.

Table 7: Power Consumption with Respect to Number of Clusters on the Network

Number of Clusters	**Energy Consumption (J)** cluster head-set size is 1	**Energy Consumption (J)** cluster head-set size is 3
1	5.2391	1.7462
2	2.4620	0.8205
3	1.6072	0.5356
4	1.1931	0.3976
5	0.9490	0.3162
6	0.7881	0.2626
7	0.6741	0.2246
8	0.5891	0.1962
9	0.5233	0.1743
10	0.4709	0.1569
11	0.4282	0.1426
12	0.3927	0.1308
13	0.3628	0.1208
14	0.3372	0.1123
15	0.3151	0.1049
16	0.2958	0.0985
17	0.2788	0.0928
18	0.2637	0.0878
19	0.2503	0.0833
20	0.2382	0.0793

Figures 7a and 7b illustrate the energy consumption when considering number of clusters in relation to various cluster head-set sizes. From figure 7a the energy consumption reduces with increase in cluster numbers. The optimum variation in the energy consumption ranges between 0 (Joules) and 6 (Joules) when the cluster head-set size is 1. From figure 7b the utilized power decrease with increase in as cluster numbers. The optimum variation in the energy consumption ranges between 0 (Joules) and 1.8 (Joules) when the cluster head-set size is 3. Therefore, comparing the two graphs, the power utilised in figure 7b is comparatively lower when cluster head-set size is 3 as compared to figure 7a when cluster head-set size is 1. Utilised power in figure 7b is approximately three times less when cluster head-set size is 3 as compared to figure 7a, when cluster head-set size is 1.

As a result, the bigger the cluster head-set size the less the consumed power during transmission and vice versa. This concept of reducing consumed energy guarantees prolonged network lifetime and hence allows more transmissions to be accommodated in the network.

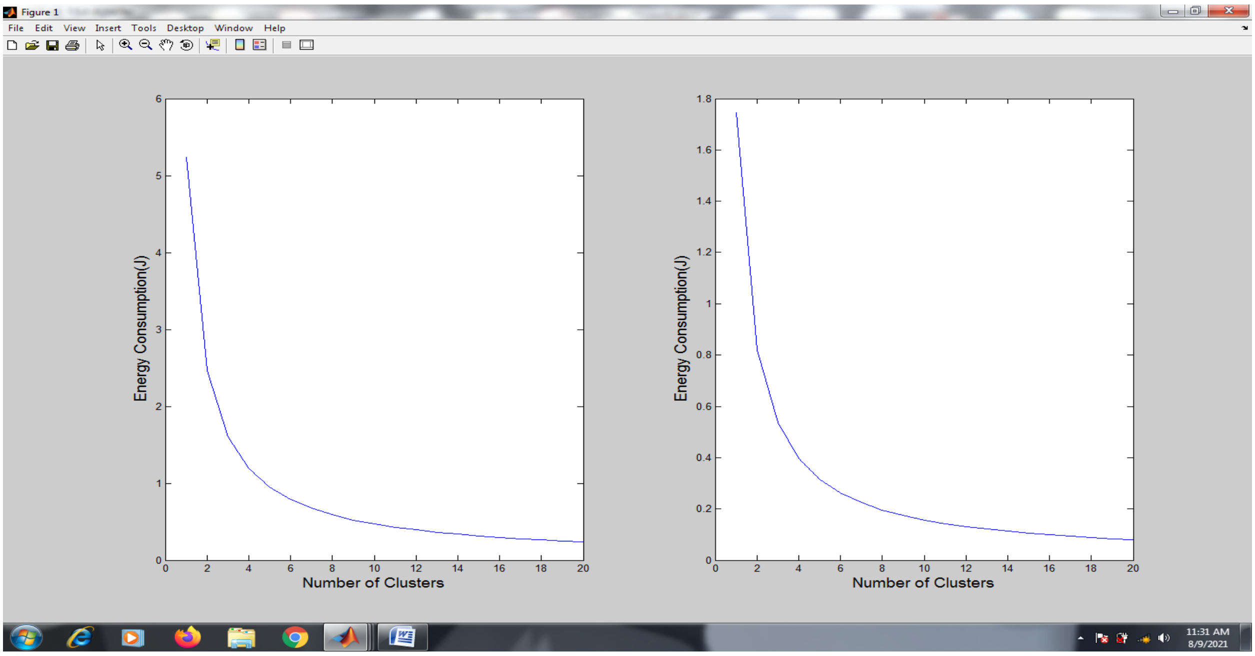

Figure 7: Energy Consumption Verses Number of Clusters in a WSN

6.0 CONCLUSION

The lifetime of nodes during transmission sessions for the conventional WSN in this work is 120 rounds, which translates to 30% energy savings while for the developed model, it is 330 rounds and translates to 82.5% energy savings. Data delivery ratio for both models shows that 32 packets were received in the conventional network out of 50 packets sent, representing 64% packet delivery ratio against the developed model that sent 50 packets and 48 packets received, translating to 96% packet delivery ratio. This work shows that the optimum number of clusters in relation to cluster head-set is approximately 20 when the cluster head-set size is 6. Cluster formation in WSN becomes necessary and crucial in long distance transmission of data where the nodes may not be able to transmit directly to the BTS. The optimum variation in the energy consumption ranges in this work from 0.0 Joules to 1.8 Joules when the cluster head-set size is 3, unlike when the cluster head-set size is 1 where consumption ranges from 0Joules to 6Joules. It follows that energy consumption reduces as the clusters increase. The development of detection and correction model for long distance WSN infrastructure monitoring is a quality contribution in this work.

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