An Effective and Decentralized Energy Transmission System for Developing Smart Villages

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Abstract

Over recent decades, village communities are facing numerous challenges. Some of those challenges have been addressed through the lenses of technological developments while some are still being addressed. One among them being unreliable Centralized Energy supply. Smart villages are adopting IoT solutions wherein they are using renewable resources like solar, wind, hydro and biomass as sources for clean energy production. However, the energy efficiency due to long-distance communication and the network life of smart grids are two of the major concerns in the context of implementing modern approaches in smart villages. The proposed system in this report helps in overcoming the inefficiency in energy transmission using Particle Swarm Optimization and Genetic algorithm in finding the best sensor node in a cluster of nodes to send the data and selecting the best and efficient route in between the sensor nodes and base station. Through this model, we can search for optimal solutions in less time.

Keywords · *Genetic Algorithm - MQTT Protocol - Particle Swarm Optimization - Renewable Energy - Smart Grid - Wireless Sensor Networks.*

1 Introduction

In many countries, villages face an ample number of challenges in the quality and standard of people's lives. The accessibility of resources is tough. There are many aspects where villages are facing issues and work can be done in developing villages by transforming them into smart and sustainable. One such issue is a huge gap in the distribution of power in village communities when compared to the urban regions. The major sources of electricity generation are non-renewable resources, which have created a great impact on the environment. According to the IEA report[1], the major sources of electricity production are coal and other carbon emission sources (approximately 75%). The trend in the adaptation of renewable resources is increasing over the years but there is a lot to accomplish. The major issue in centralized power distribution is a loss of power because it travels long distances.

To address this electric power distribution issue, villages could adopt decentralized power generation using renewable resources along with the Internet of Things for the development and maintenance of smart grids. A smart grid is a power unit or facility that has the same functionality as a conventional power grid with added bidirectional communication technology. It fills the existing gap between the electric power grid and consumer by taking inputs from the customer to improve efficiency by adding new renewable energy technology components like solar panels and windmills equipped with WSNs to help in sustaining the greenery in the environment.

Here the smart grid network consists of multiple consumers and power grids clubbed together as microgrids sharing a common terrain area sharing generated green energy resources based on necessity and requirement. Inculcating WSNs integrated with IoT technology will transform the village into a smart village consisting of communities satiating their own energy needs in a decentralized manner. In brief, the conventional power generation mechanisms which are non-renewable fuel-based working along with the renewable energy generation methods will act as a secondary source of energy to drive the smart grids in case of a potential power outage which happens frequently in remote villages where natural and geographical conditions such as rain and storms interfere with power distribution throughout the village. With the rise in electric vehicles and technology on-demand energy needs such as recharging an electric car or motorbike can be met utilizing the smart grid technology.

Advantages of making use of smart grid technologies in villages include reduction in cost and minimizing the loss of energy that occurs during the generation and transmission of power in the grids and to consumers. Disadvantages include maintenance and monitoring of sensors and devices constituting the WSNs which work in smart grids, along with a few other drawbacks in WSNs such as network security, power limitations and limited working range of the sensors and selection of optimal routing mechanism between nodes in a WSN. These can be overcome by the solution proposed in this report. In this report, we detail the use of a smart village energy model which uses the existing smart microgrid technology with a WSN which uses 3 methods which are Particle Swarm Optimization (PSO) technique which helps in solving the optimization problems, MQTT messaging transport protocol to enhance QOS and energy efficiency and the Genetic Algorithm (GA) for finding the energy-efficient and optimal route between sensor nodes.

The rest of this report is organized as follows. Section 2 summarizes the literature related to the optimization of wireless sensor networks and the articles mentioned have been cited and the works of respective authors are highlighted in this section. Section 3 is divided into three subsections and gives the details related to the background study conducted for this report. Section 3.1 explains the particle swarm optimization technique which deals with optimizing the problem in WSN and Section 3.2 details the genetic algorithm used for determining the power-efficient route for communication between sensors in the Wireless Sensor Networks (WSNs). Section 3.3 describes the popular MQTT protocol which is a message transport protocol used in IoT. Section 4 details the Experimental analysis performed to achieve results for the proposed method, work, and possible implementation. Section 5 contains the Conclusion.

2 Literature Review

The literature review is based on Effective and Decentralized Energy Transmission systems working on renewable energy sources and providing energy to houses in a village where access to electricity is meagre. IoT networks help villages to produce and consume power autonomously in a decentralized manner. The network used by the energy transmission system is power efficient due to the usage of metaheuristics and genetic algorithms. The wireless sensor networks (WSN) have drawn attention in both industries and research aspects in recent years and a significant amount of the recent research has been conducted in the optimization of wireless sensor networks to improve the overall performance of the Smart energy transmission system.

According to L. Yide[2], various applications and issues associated with the WSN in smart grids are discussed and it focuses on utilization, delivery and generation of power in the whole network constituting the smart grid. Multiple algorithms have been implemented concerning the localization of nodes, the formation of clusters and selection of cluster heads, optimal routing, network lifetime, energy constraints, data compression and aggregation, and self-organization, which are the current focus areas of research in the field of WSNs.
According to O. Gouda, A.B. Nassif, M.A. Talib, Q. Nasir[3], four types of metaheuristic optimization

techniques can be used for solving problems related to clustering, routing, coverage and node localization in WSNs. The SALP swarm algorithm or the Artificial Bee Colony (ABC) technique is similar to the PSO particle swarm optimization technique being used in this paper. For finding the optimal route in a WSN according to research conducted by W. Tianshu, Z. Gongxuan, Y. Xichen, V. Ahmadreza [4], genetic algorithm-based clustering and routing are proposed to improve the search efficiency of the optimal route considering load balancing in the network. In the results, cluster heads consumed the lowest average energy.

A. Yadav, S. Kumar, V. Singh[5], describes the network lifetime of a WSN when the PSO algorithm is implemented and compares it with other models such as LEACH and integration of LEACH-PSO to improve the effectiveness and efficiency of the algorithm compared to other algorithms for network optimization.

In this report, two meta-heuristic algorithms inspired by nature, particle swarm optimization and genetic algorithm along with MQTT are used to solve the optimization problem of WSN in smart grid applications. According to the characteristic of the Genetic Algorithm-based path, optimization is to obtain the shortest path connecting the cluster head node to the base station to realize cost-effective data transmission in a shorter processing time. This significantly reduces the power consumption of sensor nodes and improves the performance and lifetime of the network.

3 Background Study

3.1 Particle Swarm Optimization

The Particle Swarm Optimization (PSO)[6] algorithm is a metaheuristics population-based algorithm. It was proposed by James Kennedy and Russell Eberhart in 1995 and it is used in many fields. The algorithm mimics the navigation and foraging of schools of fishes or flock of birds. It is a popular method to solve optimization problems. It uses inertia, past experiences and social influence to find the best solutions or particles. A particle is a candidate solution and modifications are made by placing the particles around in the search space. Position and Velocity are continuously updated in each interaction if there is any improvement. Particles represent moving like a swarm to the solution in its visualization.

Based on the previous experience[7] of the particle and the groups' experience, the position of the particle will be updated. The update of the particle position in the search space will take place based on the following parameters.

- **x-vector**: Current position of the particles'.
- **P-best**: Individual particles' personal best position.
- **G-best**: Global best location found by the swarm

Every particle in the search space will try to move to its local best and the global best position thereby it tries to find the global optimum solution.

$$v_i = Wv_i + c_1 r_1 (P_{best,\, i} - x_i) + c_2 r_2 (g_{best} - x_i)$$
$$x_i = x_i + v_i$$

v_i= Velocity of i^{th} particle g_{best}= Global best

x_i= Position of i^{th} particle $r_1 \, and \, r_2$= Random numbers

$c_1 \, and \, c_2$=Acceleration Coefficient

$P_{best,\, i}$= Personal best of i^{th} particle

A smaller value for inertia weight, W, is useful for local search and a larger value for W facilitates the global search.

Acceleration Coefficients $c_1 > c_2$ facilities global search while $c_2 > c_1$ is helpful for local search. The search ends when either the maximum iterations are achieved or when the desired error criteria are attained.

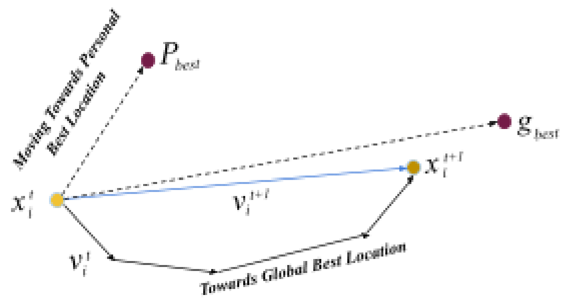

Figure 1. Particle Swarm Optimization

3.2 Genetic Algorithm

We cannot deny the point that successive generations are becoming increasingly better. Genetic algorithms[8] simulate/mimic the process of evolution. Evolution is an optimizing process and each generation is like an iteration in a genetic algorithm. GA is based on Darwin's theory of evolution. This strategy was proposed by Prof. John Holland in 1975. The central theme of this algorithm is robustness. GA can be used to generate solutions for problems for which we have no way to calculate a solution. They are a part of Evolutionary algorithms. They use natural selections to approximate solutions for a given problem. It is a slow gradual process that works by making changes to making slight and slow changes. The genetic Algorithm updates its solutions till it reaches the best optimal solution.

Five main phases are considered in a genetic algorithm[9].

3.2.1 Initializing population

First, we initialize the population which is the 0th generation in our scenario, each population has its various number genes(set of parameters) that are combined to form a solution which is called chromosomes. In general, we use binary values to represent a chromosome. Many chromosomes (solutions) for the given problem will form a population.

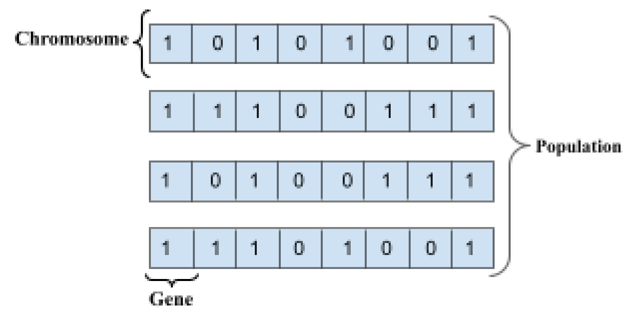

Figure 2. Understanding Structure of Population in GA

3.2.2 Fitness function

The fitness function will take a chromosome(a possible solution) as an input and produce output stating how to fit the chromosome to get selected for the next generation.

3.2.3 Selection

The main objective of this phase is to select the chromosomes that are the best fit for our solution. These selected chromosomes pass their genes to the next generation. The chromosomes with high fitness scores are considered as parents for the next generation and this process continues for each generation.

3.2.4 Crossover

It is used to vary the features of a chromosome by randomly selecting the chromosomes and the values are swapped to form their new offspring. There are various methods in finding the offspring through the crossover.

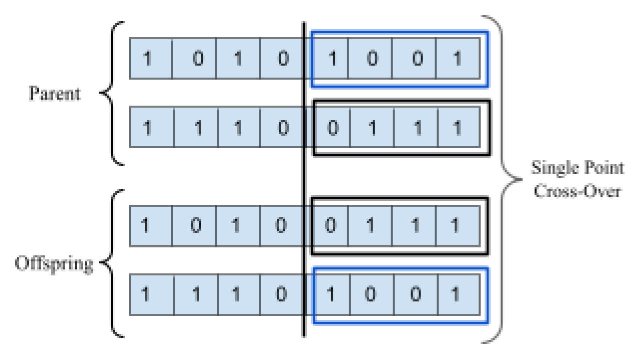

Figure 3. Example for Cross-Over in GA

3.2.5 Mutation

To maintain diversity between generations, mutation is used. In this phase, the values of the chromosomes are flipped. But only a few of them are probably mutating.

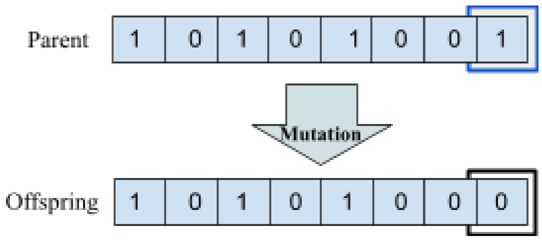

Figure 4. Example of Mutation in GA

3.3 MQTT Protocol

MQTT is a messaging transport protocol that will be applied on top of TCP/IP protocol. The MQTT is more suitable in the Internet of Things (IoT) environment because of its lightweight, simple and easy to implement with minimal code requirements. It is implemented as a publish/subscribe messaging system. There are two major actors in the implementation of the MQTT protocol[10]. One is the MQTT client and the other is the MQTT broker. The data transmitted through this protocol is filtered based on Topics. There can be multiple subtopics in a topic. The MQTT clients can be sensors in the IoT environment that will either publish the data on a particular topic to the MQTT broker or subscribe to the particular topic to the MQTT Broker so that when data is published in that particular topic the MQTT broker will transfer the message to that particular MQTT client.

Let us understand the MQTT client and broker in a particular scenario where there are multiple MQTT clients. One client is a temperature sensor that will sense the temperature every 5 seconds and publish the data to the MQTT broker on the topic “temp” and another MQTT client is a local database that is subscribed to the topic “temp”. When client1 publishes the data to the broker, the broker will send this message to the clients which are subscribed to that particular topic i.e, client2. There can be multiple MQTT brokers which can be connected through an MQTT Bridge.

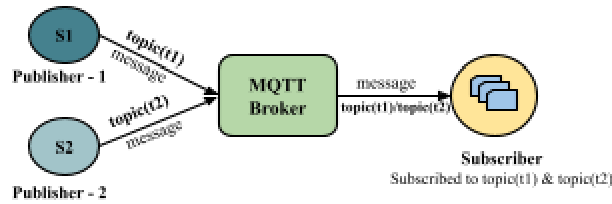

Figure 5. Sample Architecture of MQTT Protocol

The structure of the MQTT packet consists of the fixed header, variable header and payload. The fixed header of a minimum size of 2Bytes will be present in every MQTT packet which consists of the Control field(specifies the type of packet and flag) of 1 Byte and Packet length field of variable length between 1 to 4 Bytes. The next part is the Variable length header and then followed by the optional Payload.

The MQTT broker identifies the clients based on client id. To communicate with the broker the client initially sends the request message to identify itself by the broker and the connection approval is acknowledged to the client by a connack packet. The outstanding features of the MQTT protocol are scalability, as it can accommodate up to 1000 clients for one MQTT broker, reliability in the quality of service, energy-efficient and optimal utilization of bandwidth with minimal header size.

4 Proposed Model

The proposed model promotes the usage of clean energy in villages. Energy is produced within the village through natural resources and thus enabling a decentralized network within the village. In this model people in the village form communities by dividing into two groups. One is Prosumers and the other is Consumers. Prosumers are the group of people who own renewable energy generators. Consumers are those who rely on Prosumers for electricity. Prosumers can act as both producers and consumers i.e., the clean energy that is generated is utilized by prosumers priorly and the rest will be traded to the consumers.

The price at which energy is traded is influenced by various factors such as availability of resources, market demand, economic cost and pricing regulations underlined by the government.

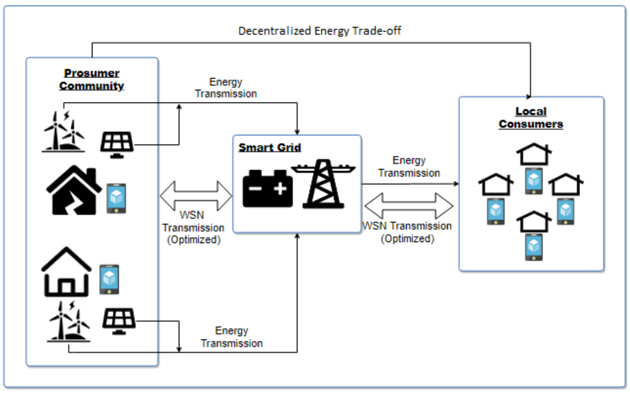

Figure 6. Architecture of Proposed Model

The renewable energy generators that are installed are equipped with various wireless sensors and controllers. These sensors track the data from the generating devices frequently and the controllers operate according to the sensed data. For example in the solar power plant, the solar panels are tilted based on the angle of sunlight that is sensed by the solar tracker to maximize the power generation. Therefore, many such sensors are set up on all the generating devices and communicate through Wireless Sensor Network(WSN). These sensors continuously sense their corresponding data and it is sent to a base station through WSN.

The smart grid acts as an energy market wherein prosumers and consumers can trade off the energy that is produced. The sensors on the generating devices have a limited energy supply. Since the sensors are supposed to monitor the energy system and collect the data frequently, the lifespan of the sensor may run out fastly. Hence the two main challenges in a WSN are maintaining the efficiency of the energy in sensors and improving the network life span.

As an initial step after installing many sensors and connecting them with WSN with a limited energy supply except for the base station. To resolve that, the sensor nodes form clusters. A particle Swarm Optimization algorithm is used to find the cluster head for each cluster. This Cluster head is comparatively energy adequate in the area of the cluster with other nodes as given in the figure below.

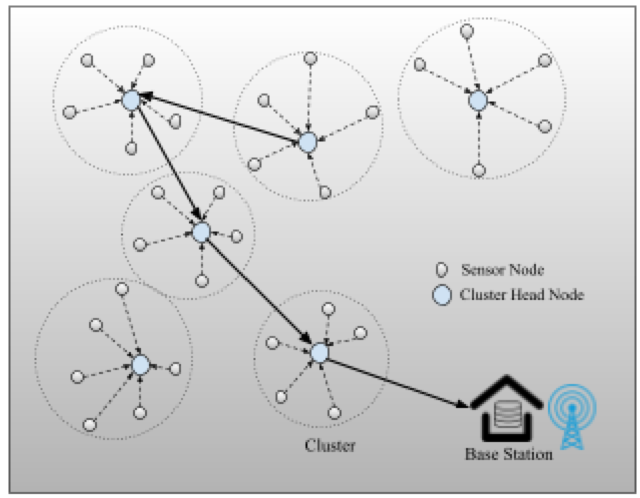

Figure 7. Working of PSO in the Proposed Model

The sensor nodes that are equipped with renewable energy-generating devices have a finite energy supply. When a sensor needs to send the information to the base station then it is very complex for a sensor node to transfer the packet to the base station. Hence using the PSO algorithm, the cluster nodes are assigned in each location, where the sensor nodes have to send the message to the cluster head which is near to the devices. These cluster heads are also clusters but they are selected based on three main qualities that are as follows:

1. The residual energy of a particular sensor node.
2. The total number of neighbours it has.
3. Its distance from the base station.

Based on the above three measures, a cluster head is selected by the PSO algorithm[11]. This cluster head will take the packets from the nearest sensor nodes and aggregate the message from each sensor node. The aggregated data is then sent to other cluster heads and it continues till it reaches the base station.

This helps in reducing the draining of energy during transmission.
The algorithm for Particle Swarm optimization is as follows:

Algorithm: Particle Swarm Optimization

Input: Initialize residual energy, particles and their position, velocity, and particle swarm parameters.
1. Find cost.
2. Identify Personal and Global best locations.
3. Update particle position, velocity and energy loss in each iteration.
4. Identify cluster heads as least cost.
5. Repeat steps 1 to 4 till all the other nodes in the cluster are dead.

After finding the cluster heads, to find the best route to transfer the data from sensor nodes to the base station, this is taken out by the Genetic Algorithm[12]. In a genetic algorithm, we provide the positions of cluster heads as inputs and all the possible routes are calculated in the initial generation. Each solution is considered as a chromosome and undergoes a fitness function. The fittest chromosome is then selected using the selection function and will be considered as parents for the next generation. Each chromosome contains gene values that are bit values (0 or 1).

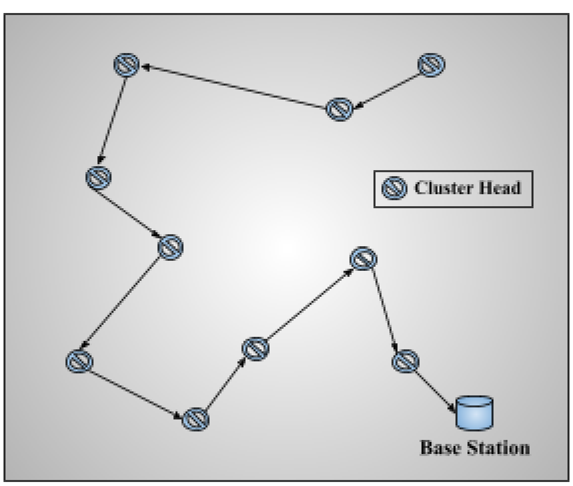

Figure 8. Shortest Path Using GA

From generation to generation, the optimal route will be calculated and produced through mutations and crossover functions in each iteration. Figure 8 shows the optimal path from cluster node 1 to the base station covering all the cluster nodes in between.

Algorithm: Genetic Algorithm

Input: Initialize the cluster heads, population size, and maximum iterations.
1. Calculate and evaluate the fitness for each chromosome of the population.
2. Selection of Best fit chromosomes as parents for the next generation.
3. Perform crossover on chromosomes.
4. perform mutation over chromosomes.
5. repeat steps 1 to 4 till the shortest path is identified or for maximum iterations.

We are proposing an extension to the approach in implementing efficient decentralized power distribution management using the MQTT protocol. MQTT is more efficient in managing a huge number of sensor nodes. In this architecture, we connect the wireless sensor nodes as MQTT clients to the MQTT broker and multiple MQTT Brokers are connected using a bridge. The proposed architecture is shown below figure.

The sensors reside at the required locations for sensing the features of the equipment[13]. This data is published as an MQTT message packet to the MQTT broker with a particular topic name. For instance, the temperature sensor that resides at the solar panel will sensor the temperature and send that to the MQTT broker on a topic name “temp”. The MQTT broker will send this message to the clients which are subscribed to the topic “temp”.

The MQTT brokers are positioned in such a way that the sensor nodes can communicate with optimal energy utilization. This can be implemented by particle swarm optimization technique where the clutter heads are referred to as the MQTT brokers. These cluster heads will communicate with each other in transferring the messages to clients connected to different MQTT brokers.

One of the MQTT clients is identified as the Database which subscribes to all the topics to receive the messages from every client and store them for processing and analysis. This database is located at the microgrid for accomplishing the requirement of an uninterrupted power supply. The consumer houses are equipped with smart metering systems which will communicate with the edge database to transmit the power consumption and pricing details of each customer. The data in the database is accessed by the prosumers and consumers through mobile applications where they receive information from the sensors and the base station according to their requirements in trading the energy among their communities.

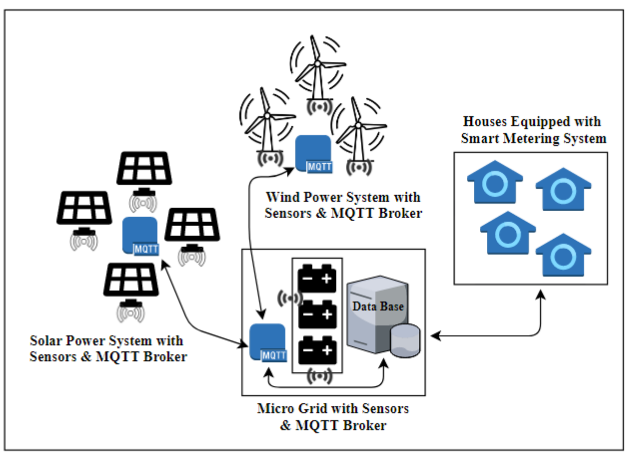

Figure 9. MQTT Architecture for Proposed Model

5 Experimental Results

In this section, we can see how the proposed model is implemented using the two stated algorithms.

Let us first see how the particle swarm algorithm works in the context of finding the best energy-efficient sensor node as cluster head. We implemented it in Python using a Jupyter notebook as IDE. The hardware configuration is MacBook Air with a 1.8 GHz dual-core Intel Core i5 processor with 8GB Memory.

Parameters taken are as follows:

- Nodes are randomly chosen.
- W = 45 (energy of the node)
- c1 = 3 (Personal acceleration coefficient)
- c2 = 3 (Social acceleration coefficient)
- target = 0
- n_iteration = 100(Number of max iteration)
- target_error = 0.00008
- n_particles = 15 (Total number of particles)

The corresponding result after implementation is as follow:

```
The cluster head is located at [ -7.753 , -7.746 ]
We got the cluster head in iteration number  100
The fitness candidate value is  2.299272556716869e-05
```

Figure 10. Location of Cluster Head Using PSO

With the above-given parameters, the location of the cluster node is calculated at [-7.75,-7.74] in the grid. Based on the location obtained we consider the sensor nodes in that position as cluster heads. The cluster heads should be self-sufficient with energy and should act as a sensor, superior node for that cluster and also they should be near to the base station.

After finding the cluster heads, the messages/data from the sensor nodes are to be transmitted to the base station. So for efficient transmission, we are finding the shortest path for the traversal among all the cluster heads to the base station. A genetic algorithm is used and its implementation for simulation is done in MATLAB. The hardware configuration is MacBook Air with a 1.8 GHz dual-core Intel Core i5 processor with 8GB Memory.

During the real implementation of the model, the nodes are taken in the positions that are produced from the above PSO algorithm. In the simulation, we implemented the Genetic algorithm which has taken random positions for cluster heads and finds the shortest and optimal route to the base station.

Parameters are as follows:

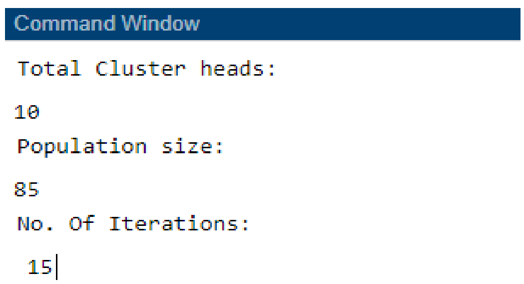

Figure 11. Initializing Values for GA

The nodes are randomly selected in a 3D grid as shown in the output below.

We have taken 10 nodes with a population size of 85. The number of Generations taken is 15

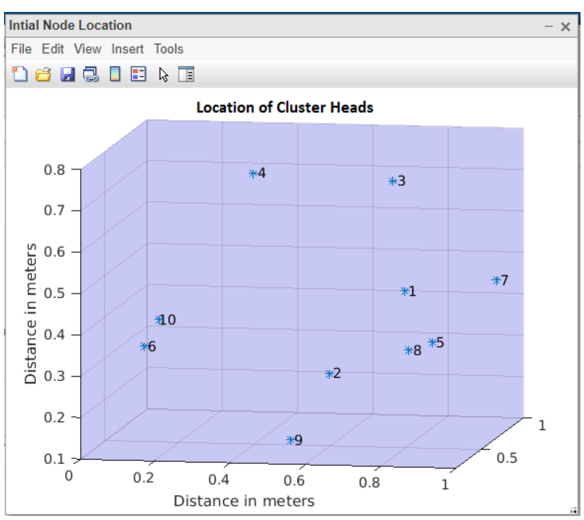

Figure 12. Random Location of Cluster Heads

In the implementation, we initially tried to find the best route from node1 to node10 using a simple genetic algorithm. In this algorithm, generations are produced based on the fittest chromosome being selected as the parent for its successive generations The resulting path is as shown below.

The length of the path using the Simple Genetic Algorithm is: 3.22 meters

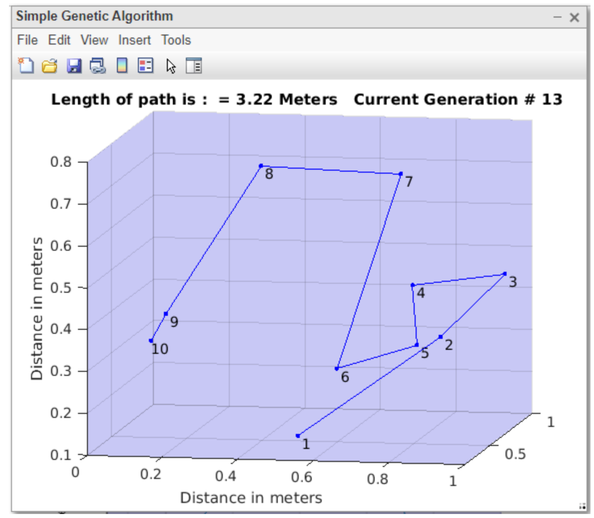

Figure 13. Shortest Path Using Simple GA

The simple GA is then modified and was named MGA (Modified Genetic Algorithm) and its performance was similar to SGA (Simple Genetic Algorithm). This algorithm uses Crossover and Mutation methods on the same population taken on SGA.

The length of the path using the Modified Genetic Algorithm is 3.06 meters

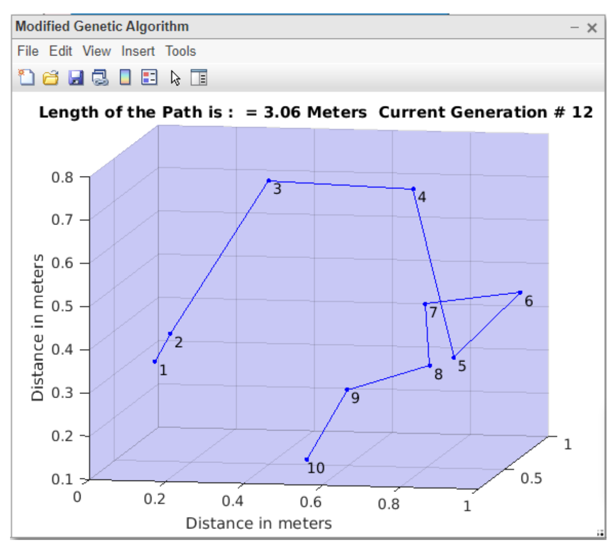

Figure 14. Shortest Path Using Modified GA

The performance of these two models can be seen in the figure below. The third plot in the below figure shows the change in the distance with respect to generations.

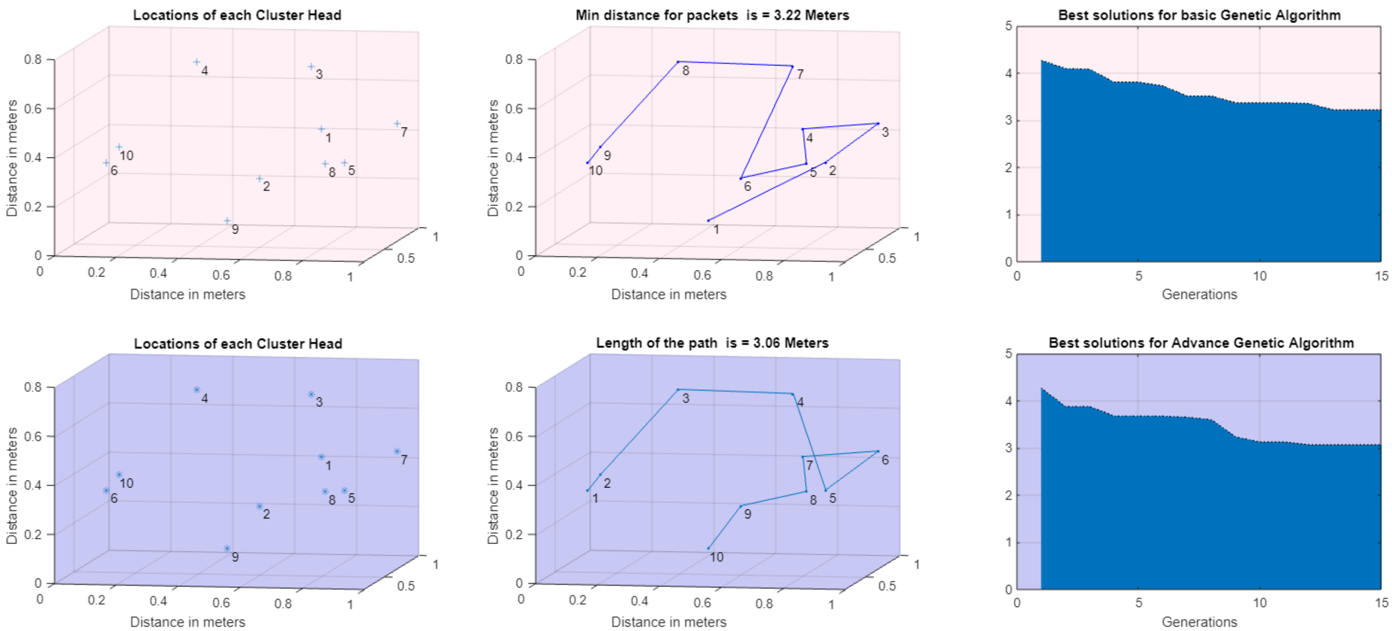

Figure 15. Results Showing Shortest Path and Plot showing distance Vs Generation Using Simple and Modified GA

6 Conclusion

In conclusion, this paper identifies the challenges faced by the village communities concerning centralized power distribution and proposes a model addressing the problems and implements a decentralized power production system using renewable resources, distributing and managing with the help of IoT. The main focus of solution architecture is the adaptation of state-of-the-art techniques in identifying Cluster head placements and finding the shortest path between these nodes in extending battery life with optimal bandwidth. An energy-efficient routing in wireless sensor networks is derived using a particle swarm algorithm which identifies potential cluster heads in communicating with sensor nodes in the cluster and with the other cluster heads in transferring messages. The shortest path among these cluster heads is derived using a bio-inspired optimization algorithm aka genetic algorithm. In extension to the simulated results, an efficient and effective protocol for the system is proposed.

MQTT protocol is efficient for IoT architecture because of its small header length, ease of implementation, efficient node failure management and publish/subscribe architecture.

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