

# IoT: Smart Home using Zigbee Clustering Minimum Spanning Tree and Particle Swarm Optimization (MST-PSO)

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## Abstract

*In Smart home environment, appliances are monitored and controlled by sensor nodes. Zigbee Cluster Tree Network is widely used protocol for smart home environment. Minimum Energy consumption and minimum cost path are important issues in this type of networks. Among many solutions proposed by researchers clustering technique provides energy efficiency and less expensive. Clustering technique operates by dividing the network into many sections, each of which has a cluster head (CH). The tasks of cluster head are collection, aggregation and transmission of data to the base station. In this paper, we introduce a new approach for clustering namely Zigbee cluster tree networks based on Minimum Spanning Tree Particle Swarm Optimization (MST-PSO). It aims to extend network lifetime and reduce router dependency in Zigbee protocol. Simulation results show that the proposed method is more efficient compared to protocols such as Zigbee star and mesh topology in terms of network lifetime and energy consumption.*

**Keywords:** Zigbee, Clustering, Minimum Spanning Tree, Particle Swarm Optimization.

## 1. Introduction

Internet of Things (IoT) vision gives rise to development of innovative applications that integrates well in to familiar traditional digital technologies. IoT intends to communicate among devices autonomously without human intervention and generate integrated data. Innovative applications include smart home, smart transportation, smart healthcare, smart industry, etc. Initially smart home environment was focussed on efficient management of homes with smart devices. However, in recent years smart home environment is extended to smart lighting systems, smart home ambience. High end security systems, heating control systems, remotely controllable devices, smart device management, enhance energy consumption and so on.

Smart homes typically evoke the vision of The Jetsons' robot maid or refrigerators ordering milk from

Amazon, but they also offer possibilities for energy and cost savings, greater efficiency of home through automation as well as improved home security [1]. Smart homes have the potential to provide for consumers' growing expectations of convenience, sustainable living, low on expenditure, safety and security.

ZigBee is an open wireless standard designed to provide foundation for the Internet of Things (IoT) by enabling everyday objects to work together. ZigBee technology is used often to connect things because of its characteristics such as network resilience, interoperability and low power consumption. In ZigBee mesh connectivity, if an object is faulty or drained in energy the network connectivity will not be interrupted instead other objects will continue to communicate. Objects using Zigbee are interoperable, as the standard specifies how objects interoperate.

The outline of this paper is as follows. In section 2, related literature such as LEACH, CHEF and PSO-MV technique are discussed. Section 3 describes the overview of ZigBee and PSO which supports protocol stack and cluster tree network. Section 4 describes the experimental setup. Section 5 contains result and analysis. Section 6 concludes with and future challenges.

## 2. Related Work

**LEACH** [2] protocol is the oldest of the clustering algorithms in WSN. It is a hierarchical method in which the routing method uses a single step. Its main objective is to maximize network lifetime, and distribute energy consumption across all network nodes. Each node sends the received information to cluster heads and cluster heads in turn transmit the data to the base station. All data processing duties such as integration and collection is performed locally by cluster head (CH).

**CHEF**<sup>2</sup> protocol [3] cluster head selection mechanism uses fuzzy logic. CHEF algorithm obtains chance from two fuzzy set namely: residual energy of a node and total distance between a node with other nodes that are located at a radius. CHEF can overcome the defects of LEACH

The sensor node which has more residual energy has better chance of becoming cluster heads.

**PSO-MV<sup>7</sup>** protocol [4] as well is based on PSO method, and since energy consumption in cluster head is higher than other nodes, the purpose of the approach is energy balance. In the PSO-MV method, the 2 nodes are selected as cluster heads that is a node as main cluster heads(MCH) and other as (VCH).MCH is responsible for data collecting and transmission and VCH is responsible for inter-cluster communications or intra - cluster communications to base station (BS).

## 2.1 Proposed Work

**MST-PSO** cluster tree network is proposed to solve problem of energy consumption and path cost in smart home scenario. Although Zigbee cluster-tree topology has medium bandwidth MST finds the minimum distance between nodes and discover minimum spanning tree and PSO algorithm helps to select the cluster head (CH) based on node's residual energy. Cluster head is directly connected to coordinator. Hence CH gathers data from neighbour nodes and sends them to the coordinator.

## 3. Overview of the Zigbee Network and PSO

### 3.1 Zigbee Network

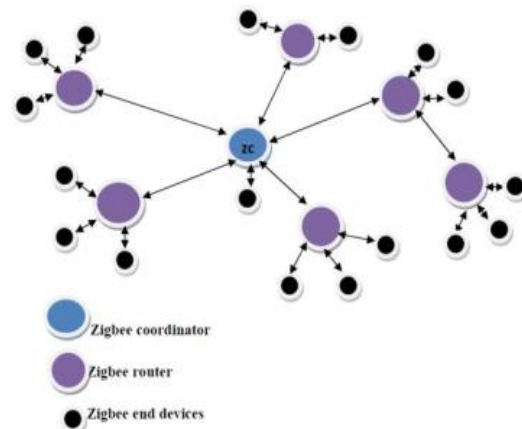
ZigBee is a standards technology that addresses the unique needs of remote monitoring and control sensor network applications [5]. The ZigBee standard was developed to address the following needs: Low cost, Secure, Reliable and self healing, Flexible and extendable, Low power consumption, Easy and inexpensive to deploy, Global with use of unlicensed radio bands, integrated intelligence for network set-up and message routing.

#### 3.1.1 Zigbee Devices

ZigBee networks include the following device types: Coordinators, Routers and End devices. Coordinator device controls the entire network Fig. (1). The coordinator stores information about the entire network which acts as the Trust Centre of the network. It also serves as repository for security keys purpose. Router devices focus on extending network coverage area. They dynamically allocate route that are with obstacles and provide backup routes in case of network congestion or device failure. Routers can interact with the coordinator, other routers and also support child devices. End Devices are also known as child device but child device is not always known as an end device. End devices can transmit receive a message, but cannot perform any routing operations. They must be connected to either the coordinator or a router, and do not support child devices [5].

### 3.1.2 Type of Networks

Zigbee supports star topology, cluster topology and mesh topology. Cluster tree based topology is effective for WSNs. But it has limitations such as routing and poor bandwidth utilization. In a tree structure, any link failure will suspend data delivery completely and the recovery operation will incur considerable overhead. The topology also prevents the use of many potential routing paths, which means, that a considerable amount of bandwidth cannot be utilized [5].



**Figure 1: Zigbee devices and network type**

As shown in figure 1, the end devices are directly connected to the router. End devices transfer the data to router and receive acknowledgement. Routers collect the data sent by end nodes and transfer the data to coordinator. Coordinator aggregates the data and sends it to the base station.

### 3.2 Particle Swarm Optimization (PSO)

PSO is originally attributed to Kennedy, Eberhart and Shi and was first intended for simulating social behaviour as a stylized representation of the movement of organisms in a bird flock or fish school [6]. The algorithm was simplified to perform optimization. An extensive survey of PSO applications is made by Poli. In computer science, Particle Swarm Optimization (PSO) is a computational method that optimizes a problem by iteratively trying to improve a candidate solution with regard to a given measure of quality. PSO optimizes a problem by having a population of candidate solutions, here dubbed particles, and moving these particles around in search-space according to simple mathematical formula over the particle's position and velocity. Each particle's movement is influenced by its local best known position and is also guided toward the best known positions in the search-space, which are updated as better positions are found by other particles. This is expected to move the swarm towards the best solutions.

$$v_{id}^{t+1} = w \cdot v_{id}^t + c_1 \cdot \psi_1 \cdot (p_{id}^t - x_{id}^t) + c_2 \cdot \psi_2 \cdot (p_{gd}^t - x_{id}^t)$$

$v_{id}^t$ : Component in dimension  $d$  of the  $i^{th}$  particle velocity in iteration  $t$ .

$x_{id}^t$ : Component in dimension  $d$  of the  $i^{th}$  particle position in iteration  $t$ .

$c_1, c_2$ : Constant weight factors.

$p_i$ : Best position achieved so long by particle  $i$ .

$p_g$ : Best position found by the neighbors of particle  $i$ .

$\psi_1, \psi_2$ : Random factors in the  $[0,1]$  interval.

$w$ : Inertia weight.

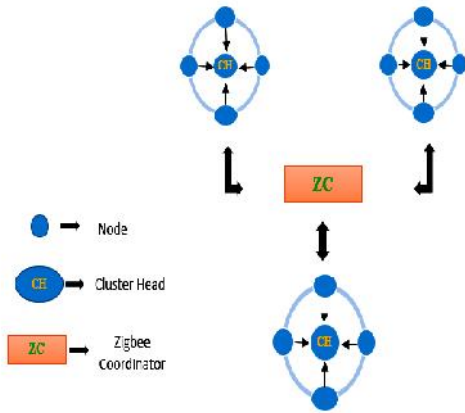


Figure 2: MST-PSO Zigbee devices and network

In Fig 2, modified Zigbee cluster tree network is shown, where routers are removed from the network. The cluster head (CH) in MST-PSO work as router to gather information from cluster and then send to coordinator. Selection of Cluster head from end nodes will be change periodically.

## 4. Experimental Setup

This section discusses proposed methodology for Zigbee cluster tree network. It contains MST using Prim's algorithm, and PSO algorithm with flowchart.

### 4.1 Minimum Spanning Tree

MST method is used to find minimum distance between nodes in the Zigbee network. MST contain Kruskal's algorithm and Prim's algorithm[7] to form spanning tree. Here we use Prim's algorithm to find minimum distance between each nodes.

#### 4.1.1 Prim's Algorithm

In Prim's algorithm is explained below. At the initialization phase a tree with a single vertex is chosen arbitrarily from the graph. Grow the tree by one edge: of the edges that connect the tree to vertices not yet in the tree, find the minimum-weight edge, and transfer it to the tree. Repeat until all vertices are in the tree. The result is explained in Figure 3.

#### Algorithm: 1 Prim's algorithm

```

T = a spanning tree containing a single node s;
E = set of edges adjacent to v;
while T does not contain all the nodes {
    remove an edge (v, w) of lowest cost from E
    if w is already in T then discard edge (v, w)
    else {
        add edge (v, w) and node w to T
        add to E the edges adjacent to w
    }
}

```

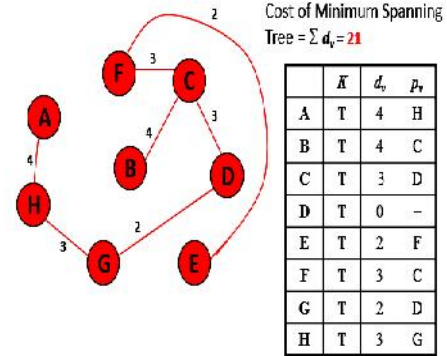


Figure 3: Prim's MST

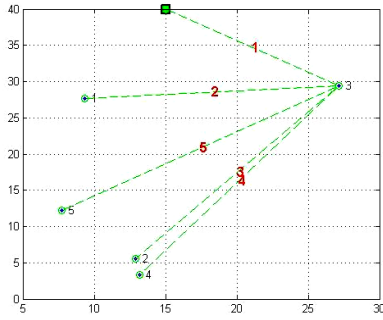
In Figure 3, using prim's algorithm to find minimum spanning tree:(1)Start with any nodes here start from D.(2)updated distance of adjacent nodes, unselected nodes. (3)Select node with minimum distance G.(4)Repeat step 2 until all vertices are in tree.

### 4.2. Cluster Setup

In clustering phase, the particles are generated randomly. Then the best points are selected as the cluster heads and other nodes which are located near each cluster head becomes member of the cluster head and then fitness function is calculated for every cluster head [8]. If the fitness function is better than global best it is substituted. This process is done for 1000 generation. Then each node prepares a control message that contains identity and value of its residual energy and sends it directly to the base station as in Figure.(4).The base station which receives the information performs clustering operation.

### Algorithm 2: Cluster head selection

Initialize a population of particles with random values positions and velocities from D dimensions in the search space  
While Termination condition not reached  
  For Each particle i  
    Adapt velocity of the particle using Equation 1  
    Update the position of the particle using Equation 1  
    Evaluate the fitness  $f(X_i)$   
    If  $f(X_i) < f(P_i)$   
       $P_i = X_i$   
    EndIf  
    If  $f(X_i) < f(P_g)$   
       $P_g = X_i$   
    End If  
  End For  
End While



**Figure 4: Cluster Head Selection**

As shown in Figure 4, node 3 is selected as Cluster head(CH), other nodes in network transfer the data to CH.

### 4.3 Data Transmission Phase

Once Cluster formation and cluster heads election of each cluster is over, data transmission phase begins wherein data is sent to cluster head from the neighbour nodes. Data can be transmitted by the normal node to corresponding cluster heads. In this phase, each normal node is connected to the nearest cluster head. Each node sends its data at allocated interval to cluster head in the form of data message. The cluster head aggregates and transmit data towards Zigbee coordinator.

## 5. Results and Analysis

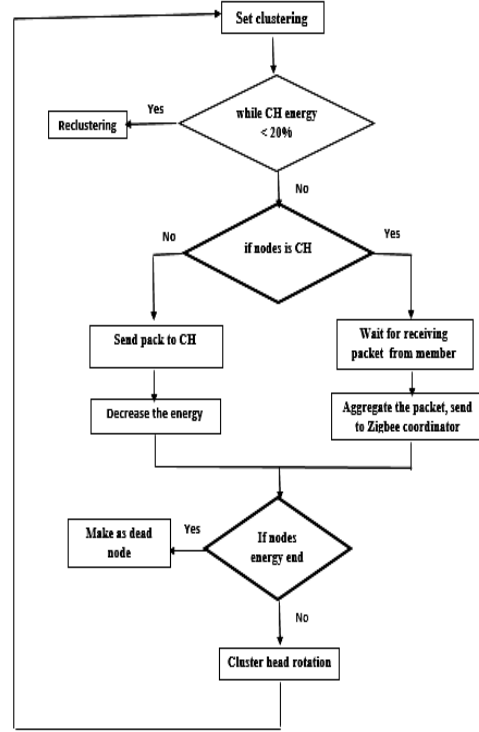
The Simulation using MAT-Lab IDE, analyses of old zigbee cluster tree network and their energy efficiency

### 5.1 Energy Efficiency

Energy efficiency of the proposed MST-PSO zigbee cluster tree network is calculated by formula 2. Here,  $n$  is a total number of nodes,  $m$  is total number of routers,  $l$  is

a total number of Coordinators,  $ed$  is end devices energy,  $rd$  is router energy,  $cd$  is coordinator energy

In old zigbee cluster tree network the energy taken by network calculated as follows:



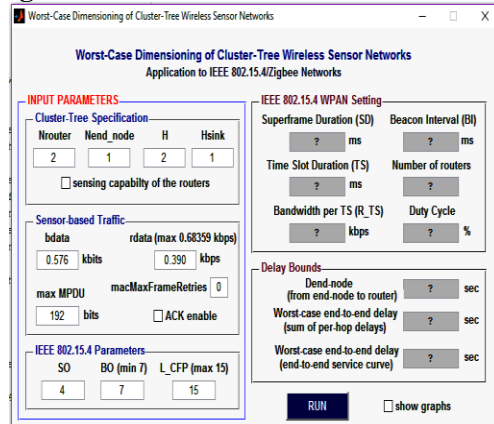
**Figure 5: Data transmission in MST-PSO**

$$e = \sum_{i=1}^n ed + \sum_{j=1}^m rd + \sum_{k=1}^l cd \quad (2)$$

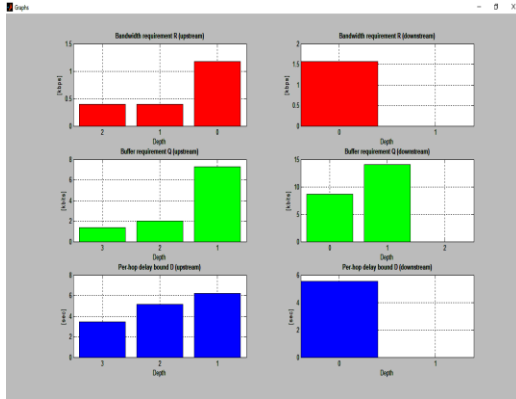
In MST-PSO zigbee cluster tree network the energy calculated as:

$$e = \sum_{i=1}^n ed \quad (3)$$

### 5.2 Zigbee old Cluster Tree model



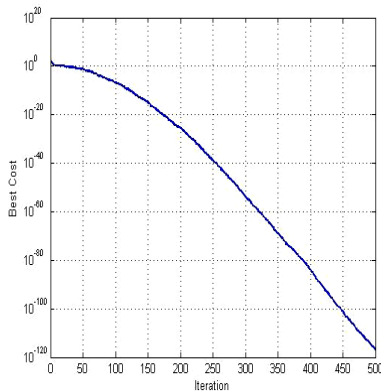
**Figure 6: Zigbee cluster tree network dimensioning**  
Worst-Case dimensioning of zigbee cluster tree network is shown in figure 6.



**Figure 7: Zigbee cluster tree network dimensioning in Graph format**

Figure 7 represents the Worst-Case dimensioning of zigbee cluster tree network in graph format.

### 5.3 MST- Partical Swarm Optimization in Zigbee



**Figure 8: MST-PSO for 500 iteration**

Figure 8 shows MST-PSO algorithm output for 500 iteration with their best cost.

## 6. Conclusion and Future Challenge

In old zigbee cluster tree network the increase in number of routers will increase power consumption. For improving efficiency of network a new approach of network arrangement is proposed and implemented that is also known as a MST-PSO zigbee cluster tree organization. The performance of the network is assessed by energy efficiency, packet transmission ratio and path cost. After implementing MST-PSO cluster tree network, we conclude that in our proposed network, power consumption is low even when the number of nodes increases. Comparing to the old network, efficient packet transmission rate and low path cost are also achieved. However, our proposed work consumes higher implementation time compared to the old network. According to the results the newly arranged network performs well than old network. Future enhancement of

proposed system is that the end devices itself select the cluster head instead of base station.

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