J. Basic. Appl. Sci. Res., 3(2)195-201, 2013

ISSN 2090-4304
Journal of Basic and Applied Scientific Research
www.textroad.com

Investigating Multi-Topological ZigBee Based Wireless Sensor Network in Precision Agriculture

M. Hussnain, M. Sharjeel, S. R. Chaudhry, S. A. Hussain, I. Raza and J. S. Mirza

Communication Network Research Center (CNRC), Department of Computer Science
COMSATS Institute of Information Technology, Lahore, Pakistan

ABSTRACT

Wireless Sensor Networks (WSNs) have attracted researchers and developers in the last decade because of its small size, minimum power consumption and lightweight, having the ability to monitor, measure and communicate over wireless channel in various fields of our daily life. This paper evaluates WSNs applications in agriculture, comparing different IEEE802.15.4/ZigBee topologies (Tree, Mesh and Grid) for the enhanced and precision agriculture. Multiple network scenarios are simulated to study the performance of WSNs topologies in terms of throughput, network load and end-to-end delay. Simulation results show that the WSNs have better throughput and network usage when tree topology is used. WSNs with tree topology show an increase of 11% and 57% in throughput as compare to Mesh and Grid topologies respectively. Tree topology also has 35% and 80% more network load than Mesh and Grid topologies respectively. However, the end-to-end delay of ZigBee based Tree topology has 1% and 2 % more delay than Mesh and Grid respectively, which is negligible in the proposed study.

KEYWORDS: Wireless Sensor Networks, Precision Agriculture, Grid Topology, Mesh Topology and Tree Topology.

INTRODUCTION

WSNs have many applications such as nuclear reactor control, security, tactical surveillance, habitat monitoring, and precision agriculture cooperatively relaying data through the network to the main location [1]. They are used for sharing, storing, and collecting sensed data. WSNs topology is built of nodes from many to several hundred nodes or even more and each node is connected to one or sometime several sensors. WSNs topology can vary from very simple star network to an advance multi-hop wireless mesh network [2, 3].

WSNs applications in agriculture can increase the crop production developing information systems and is known as Precision Agriculture [4, 5, 6]. Wireless sensor network is a major technology that drives the development of precision agriculture. The use of WSNs for precision agriculture leads to many research issues such as selection of technology, topologies and routing keeping different performance parameters in consideration. Considering the requirement of precision agriculture, the selection of topology has been a major factor for the better performance of WSNs.

In Europe, Low Frequency Array (LOFAR)-Agro [7] investigates the precision agriculture that focuses on as consequence crop protection management system. This involves monitoring soil, crop and climate conditions in a field, generalizing the results and providing a Decision Support System (DSS) for treatments or taking differential action such as real time variation of fertilizer or pesticide application.

The benefits, which arise from the application of precision agriculture technique, come from the precision in the irrigation quantity, the use of chemurgy only in the appropriate field areas, the control in the quantities of the fertilizer, the exact definition of the semination and crop. More over the use of appropriate quality of seed depending on the field conditions, water control, the optimum quantity of seed semination and spending less money on agriculture scientists and consulting firms are factors that WSN has a direct impact. In addition with WSN the advantages are:

a. Ability to observe for long periods of time crop state.
b. Direct, exact briefing of the field state and ability to interfere in case of an emergency.
c. Distant decision-making.
d. Analytical information storage in order to create a case record of the field crop.
e. Friendly Graphical User Interface with the monitoring system.
f. Potential to make exact evaluation of new crop methods and techniques.

The motive of this paper is to the design and evaluates a WSN topology for precision agriculture. Agriculture land is divided into different regions and each region is covered with multiple sensors using WSN topologies i.e. Grid, Mesh and Tree.

***Corresponding Author:** I. Raza, Communication Network Research Center (CNRC), Department of Computer Science, COMSATS Institute of Information Technology, Lahore, Pakistan. Email: iraza@ciitlahore.edu.pk

Different network performance parameters such as network delay, throughput and load are observed, analyzed and discussed selecting best topology for precision agriculture.

This paper is organized into following sections. Section 2 describes the related work. Section 3 explains the ZigBee network. Simulation and performance analysis is presented in section 4. Section 5 concludes the paper.

1. RELATED WORK

In the past few years, new trends have appeared in the agricultural sector. Precision agriculture concentrates on providing the means for monitoring, determining and managing agricultural practices. It covers a wide range of agricultural involves from daily herd management through horticulture to field crop production.

Authors in [8] simulate different topologies such as Grid, Mesh and Tree using OPNET modeler. Simulation results conclude that end-to-end delay of the tree topology is higher for more than 50% than Grid and Mesh. The throughput is higher in tree topology and lower in Mesh topology. In [9] authors compare the different ZigBee topologies against the network load. Authors' proposed topology that presents less network load in comparison to ZigBee based Grid topology.

WSN based automatic monitoring in precision agriculture is proposed in [10]. The performance of Grid topology with different arrangement of sensor nodes is compared. In the first arrangement, the sensor nodes are placed at the corner of grid and in the second arrangement, the nodes are placed at random positions. Grid topology with nodes at the corner provides better throughput in comparison to grid topology where nodes are placed at random.

In [16], the authors proposed an integrated WSN based system for crop monitoring, Video surveillance and process cultivation control. This network implies an innovative redeployment of precision agriculture using IEEE 802.15.4 cost effective technology. Their approach has been developed to conduct all these functions not only in a single crop but also in deployments considering scattered crops separated several kilometers from the farmer's cooperative premises.

[17] Utilized sensor network to monitor air temperature, humidity, soil moisture and temperature that helped them in analyzing the current state of art nursery. They further suggested that such network may help in finding the plant disease using multiple topologies.

Many topologies for WSNs have been developed but most of them do not take into consideration the limited resources for the sensor nodes. This is a main drawback in most topologies where they should choose the sensing place based on the supposition. More over the use of appropriate topology depending on the field conditions, water control, the optimum quantity of topology and spending less money on agriculture scientists and consulting firms are factors that WSN has a direct impact.

2. ZIGBEE NETWORK

ZigBee is a wireless standard that is aimed at remote control ends sensing applications, which is suitable for difficult radio environments and in isolated locations. ZigBee has three different types of device support: ZigBee coordinator, ZigBee router and ZigBee end device [11- 13].

ZigBee coordinator (ZC) is at the top in mesh topology and there should be one in each network. It initiates the network formation, select frequency to be used by the network and allow devices to connect. ZigBee router (ZR) allows nodes or ZigBee end devices to connect with ZC. ZigBee end devices (ZED) report sensor states. Table 1 shows basic ZigBee specifications.

Table-1 Standard ZigBee Specifications [8,9]

Parameters	ZigBee Value
Transmission Range	1-100 (m)
Battery life	>1 year
Throughput	20-250 (kb/sec)
Complexity	Simple
Cost	3-5($)
Data type	Small packets
Slave enumeration latency	64,000
Node per master	30 ms
Radio	DSSS

ZigBee is established by the ZigBee Alliance [15] that is supported by more than 70 member companies. It adds network, security and application software to the IEEE 802.15.4 standard. Owing to its low power consumption and simple networking configuration, ZigBee is considered the most promising technology for wireless sensors.

a. ZigBee *Network Topologies*

IEEE 802.15.4/ZigBee support different topologies such as Tree, Mesh and Grid.

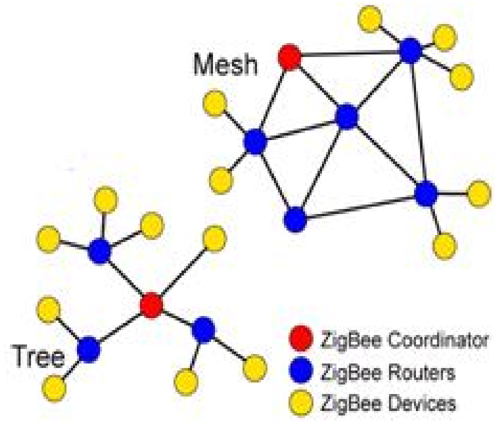

Figure 1: ZigBee Network Topologies [8]

b. Tree Topology

Figure 1 devices connects with the ZigBee coordinator. For every router connected, there is a possibility for connection of more child nodes to shows a tree topology based network having a coordinator that initializes the network, and is at the top of the tree. Routers and end each router. Child nodes cannot relay messages therefore they do not have the ability to expand.

ZigBee tree topology [8] allows different levels of nodes with the coordinator being at the highest level. If messages are to be passed to other nodes in the same network, the source node must pass the messages to its parent, which is the node higher up by one level of the source node, and the message is continually relayed higher up in the tree until it is passed back down to the destination node. Because the number of potential paths a message can take is only one, this type of topology is not the most reliable topology. If a router fails, then all of the children are cut off from communicating with the rest of the network.

c. Mesh Topology

Most flexible topology is the Mesh topology. A message can go through multiple paths from source to destinations. If a particular router fails, then ZigBee's self-healing mechanism will allow the network to search for an alternate path for the message to be passed [14]. Each router is connected to each other and a coordinator is attached with all routers as shown in figure 1.

d. Grid Topology

In this type of network all ZED are connected with ZC in a grid shape as shown in Figure 4. This topology deployed without ZR as mention in Table 2.

3. Simulation and Performance Analysis

In this research work, three topologies for precision agriculture are simulated. The topologies presented here contain one ZC, three ZR and six ZEDs deployed in area of 1000 meters in the simulation environment as shown in Table 2.

Table 2 Proposed Specifications for ZigBee Topologies

Topology	ZC	ZR	ZED	Area
Tree	1	3	6	1000
Mesh	1	3	6	1000
Grid	1	0	6	1000

In all topologies ZigBee coordinator's MAC layer results are taken which are available in Table 2. ZEDs are associated with sensor nodes, which get parameters like soil temperature, moisture and humidity. Simulations are performed with Tree, Mesh and Grid topologies deployed within the area of 1000 meters as shown in Figures 2, 3 and 4.

a. Simulation environment

Multiple scenarios have been simulated for WSNs topologies. All the simulated scenarios are depicted in Figures 2, 3 and 4 in the simulation environment.

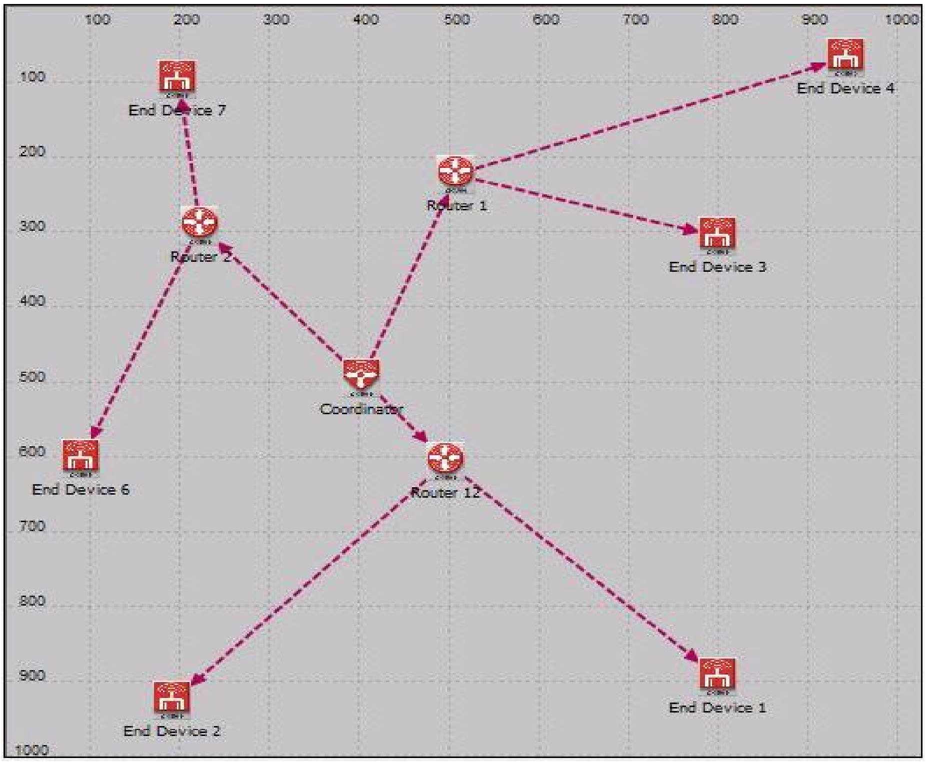

Figure 2 presents a tree topology having one ZC, three ZR and six ZEDs in an area of 1000 meters.

Figure 3 shows Mesh topology according to parameters given in table1.

Figure 4 shows the Grid arrangement having only one ZC working as sink for six ZEDs. In Grid there is no need to add ZR. ZED can directly communicate with ZC.

b. Simulation Results

Simulation results are based on a set of performance meters such as end-to-end MAC delay, throughput and network load for comparing different topologies.

a. ***Throughput*:** In specified time, the data quantity transmitted correctly to the destination or total number of messages is received per second at destination. The throughput of the network is the sum of the throughputs of all the destinations.

b. ***Delay:*** Delay is the total time to send a message from source to destination. For any destination, if **n** packets have arrived, delay can be calculated using Eq (1). Where $\mathbf{d_i}$ is the delay of the $\mathbf{i^{th}}$ packet. Network delay is calculated by taking the average of all the destinations [9].

$$Delay = \sum_{i=1}^{n} \frac{di}{n} \qquad (1)$$

c. ***Load:*** Number of packets that can be sent by the network at one time.

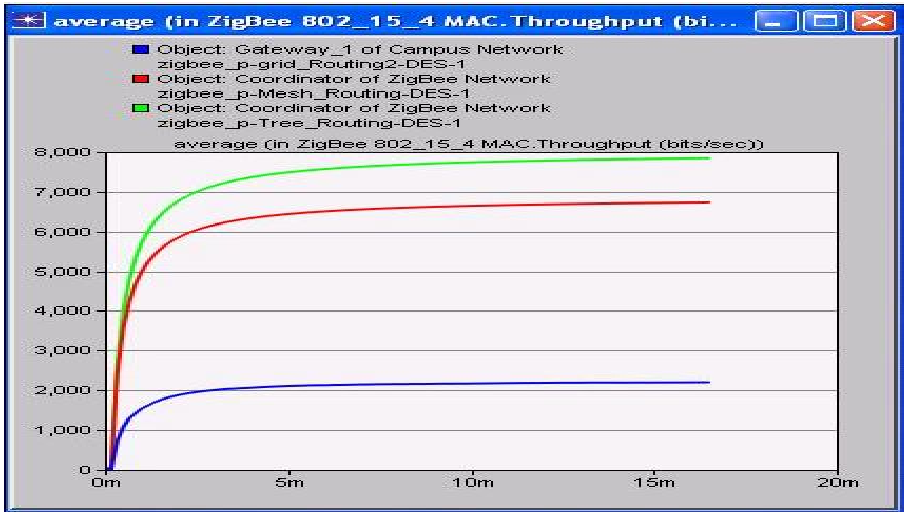

Figure 5: Average Network Throughput

Figure 5 shows average MAC throughput, of different topologies.. Tree topology yields maximum throughput 7900 (bits/sec) as compared to Mesh and Grid. Tree topology has better throughput because it communicates on the basis of ZC and ZR, which are more efficient as compared to the end devices.

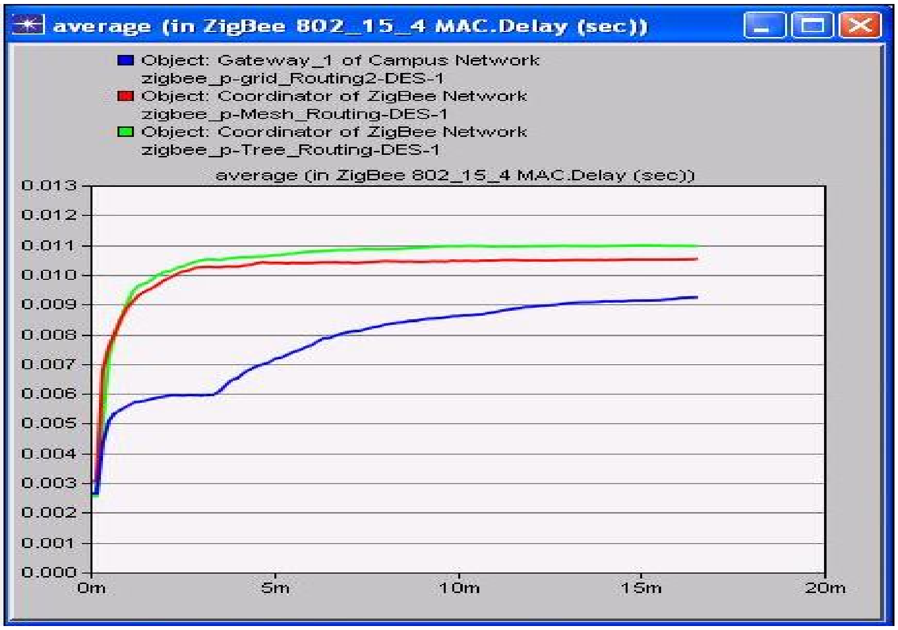

Figure 6: Average Network Delay

Figure 6 shows that average MAC delay of Tree topology is 1% more than and 2% more than Grid topology. This marginal increase of delay in tree topology is due to the involvement of ZC and ZR for relaying the data to the sink node. Mesh topology is giving 0.010 sec and Grid is providing 0.009 sec. MAC delay.

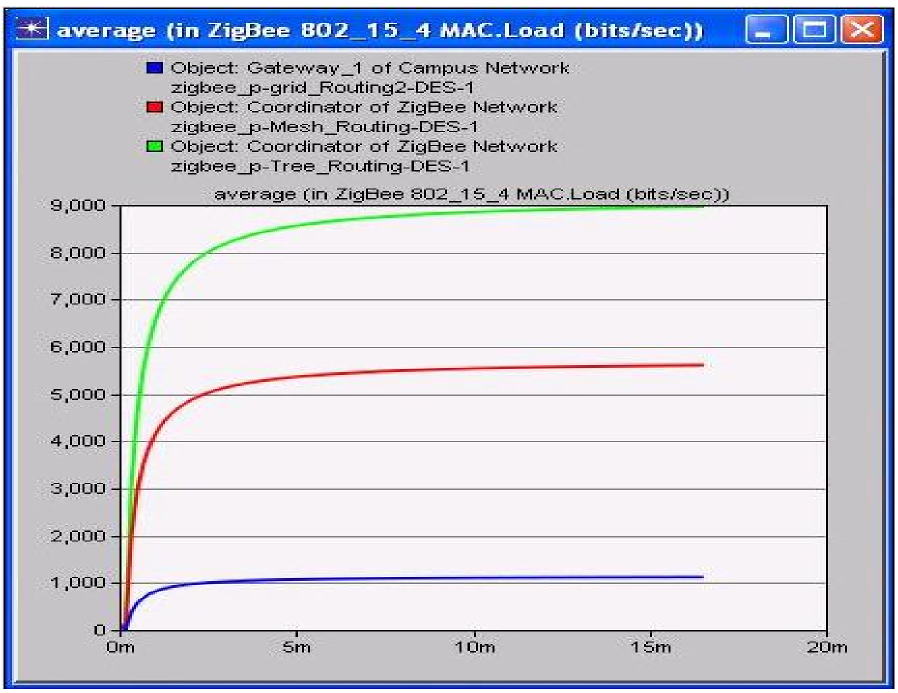

Figure 7: Average Network Load

Figure 7 shows average MAC load in bits/sec from three topologies and it can be easily seen that tree is providing maximum 9,000 (bits/sec). Mesh is giving maximum 5,500 and Grid is providing 1,000 (bits/sec). Tree topology increases the network utilization due to involvement of multiple ZCs and ZRs.

Table 3 Topology Simulations Result

Topology	Delay (sec)	Load (bits/sec)	Throughput (bits/sec)
Tree	0.0025-0.011	0-9,000	0-79,00
Mesh	0.003-0.010	0-55,00	0-68,00
Grid	0.0025-0.009	0-1,000	0-22,00

Table 3 summaries the results of Tree, Mesh and Grid topologies. WSN in Tree topology is providing better network utilization and throughput.

4. Conclusion

This paper studies and compares different topologies for deploying WSNs in precision agriculture. Each topology is deployed in the area of 1000 meters. Tree and Mesh is deployed with 10 (one ZC, three ZR and six ZED) nodes and Grid is deployed with 7 (one ZC and six ZED) nodes because there is no need to add ZR in Grid topology. Tree topology is providing efficient results as compared to Mesh and Grid. From the simulation results, it can be concluded that Network throughput and utilization is highest in Tree and lowest in Grid. Tree yields 11% more network throughput than Mesh and 57% more than Grid. Tree also has 35% more network utilization as compared to Mesh and 80% more than Grid. End-to-end delay for Tree is 1% higher than Mesh and 2% higher than Grid. WSNs expansion with Tree topology is easy due to its network structure. If any sensor is damaged, it can be replaced without affecting the other sensors. Therefore, ZigBee Tree topology is more appropriate if deployed in an agriculture land for precision agriculture. The future work aims at dynamic topology adoption for agriculture land to improve and adequately switch for the most suited topology for better crop production results.

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