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Fault Tolerant Sensor Node Placement for IoT based Large Scale Automated Greenhouse System

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Abstract: Greenhouse method of agriculture overcomes various issues of traditional agriculture and provides good crop yield in farming. When the maintenance of greenhouse plants is automated, it helps the farmers in monitoring the soil, water and lighting required for higher crop yield, with low cost and saving man power and time. Internet of Things (IoT) makes the different components involved in this monitoring process to talk to each other, and coordinate and disseminate the observed data to reach the sink node and direct instructions to the actuator components to perform appropriate actions. The lifetime of the network is directly proportional to the energy of the nodes in the automated system. So as to improve the network lifetime, location of sensors and the distance between the relay nodes should be taken into consideration. This paper demonstrates the work of an automated greenhouse system based on IoT for sensing soil moisture, light, temperature and humidity. For improving the lifetime of this system, especially when the system is deployed in a large scale greenhouse, the complexity involved are discussed and the solution based on node placement is provided to efficiently improve the network lifetime. We provide solution for fault tolerant node placement using Menger's Theorem. Simulation of the proposed model has been carried out and the results suggest the better model of sensor node placement in a green house system. The simulation results prove that the model we proposed provides reliable transmission and better throughput compared to the existing approach.

Keywords: Greenhouse, IoT, Sensors, Lifetime of Network, Fault Tolerance

1. INTRODUCTION

To overcome the crisis of conventional agriculture, it is necessary to build and consolidate models for agricultural sector that is market-oriented and eco-friendly. The models have to respond to the demands of modern agricultural practices which the society places upon it. The importance of technological innovations in the field of agriculture has an influence on the quantity of raw materials required, their composition, their usage and applications and their nature to the environment [1]. Intensification of agriculture threatens the soil and water, and raises challenges for sustainable agriculture. Contamination and overuse of these resources also affects the production process and the quality of soil. As only 10.6 percent of the world's land is tillable, to meet the future food requirement of the world population, measures has to be taken for the proper use of soil and water conservation. Integrated knowledge of engineering and basic agriculture will suit best for soil and water conservation [2]. Knowledge on the type of soil required for crop varieties will help in mapping of the crop and soil accordingly for its use. For maintaining better crop yield throughout, soil erosion caused by water and by wind has to be controlled. This soil erosion leads to the loss of soil, macro, micro and organic soil nutrients and fine soil particles.

Like soil protection, water conservation is also very important. Proper or efficient irrigation is another factor for increasing crop yield. But irrigation is limited by the availability and supply of water resource. Inspite of conveyance and regulation, evaporation and seepage losses, water should be supplied to the farm in adequate. Hence we need to develop practices that stubbornly reduce unnecessary wastage of water in storage, transmission and application processes. A major and critical issue commonly challenges the crop production is the deficiency of soil moisture. Dryness of soil spoils the plant growth and in turn the harvest. There are generally three means for preservation of soil moisture: increasing infiltration, reducing evaporation and preventing unwanted plant growth. Greenhouse way of farming helps a part in the intensification of agriculture for efficient utilization of resources, saving farms from

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climate changes, minimizing cost on production but maximizing returns and so on. A well designed and well maintained greenhouse system effectively protects the crops from erosion damages. Greenhouse method of agriculture overcomes various issues of traditional agriculture and provides good crop yield in farming. When the maintenance of greenhouse plants is automated, it helps the farmers in monitoring soil, water and lighting required for higher crop yield, with low cost and saving man power and time.

IoT technically supports the greenhouse components to talk to each other, coordinate and report the status of the greenhouse and utilize the resources efficiently for attaining the goal of sustainable agriculture. The sole portion of this automated system is the wireless sensor network. The sensor network here is made up of large number of low cost sensor devices that are self organized through the wireless technology, generally a Zigbee communication based on IEEE 802.15.4. Other communication technologies, to list out are HSCSD(High Speed Circuit Switched Data), GSM (Global System for Mobile Communication), Sig-Fox, LoRaWAN, Low-Power WiFi, One-Net, WirelessHART and so on. The data required to be monitored in the agricultural process is about the climate, soil, crop, food storage, transportation and livestock. IoT is used in agriculture for precision monitoring, irrigation scheduling, and optimization of plant growth, livestock monitoring, farm area border monitoring and production process monitoring.

In this paper, we have developed and automated a greenhouse system that monitors soil moisture, aeration, temperature and light intensity inside a greenhouse. The goal for the work is to develop a reduced human intervention system for greenhouse automation that is cost efficient with the life time of the network. With very few sensors if we could achieve our target, then, what would be the efficiency of monitoring a large scale greenhouse system is our main research work of this paper. We have developed a model for placing the sensor components in the greenhouse efficiently to reduce the cost but to improve the coverage of the large greenhouse farm. As the size of the greenhouse increases, the number of sensor nodes required to cover the entire area's monitoring parameter increases, which may increase the cost of the network. Most of the work done so far is concerned with general wireless sensor networks. But greenhouse comes with criteria like count of sensors to be deployed in the specified area, line of sight disturbance in communication, position of placing the sensors from the floor, improving the life time of the network which avoid maintenance cost for the farmer and delay constraints to avoid wastage of resources.

The paper has been organized as follows. Section 2 provides the study of research work related to fault tolerance in routing. Section 3 describes the greenhouse automated system we developed. Section 4 demonstrates the node placement model we proposed. Section 5 gives the simulation parameters and results of simulation. Section 6 concludes the paper.

2. Related Study

The main focus of fault tolerant routing in a network is to provide efficient communication in spite of weak and victim nodes in a network. In [3], the authors have proposed a delay constrained relay node placement algorithm for wireless sensor networks. The knowledge of subtree and mergence based algorithm is used to reduce the number of relay nodes required for data dissemination. An optimal node placement strategy was proposed in [4] using mathematical modeling of the sensor network as a non-linear problem. A modified genetic algorithm based relay node placement in wireless sensor networks was proposed to minimize the total number of relay nodes used in the sensor network and to provide maximum connectivity between sensor nodes and relay nodes [5].

A network model of linear wireless multimedia sensor network was made [6]. Considering the initial energy and the power consumption and distance between the nodes, a node placement approach was proposed. Using an ant based routing approach, placement of the sink node in single hop and multi hop sensor networks is proposed in [7]. For two tired sensor networks, using approximation algorithm, a fault tolerant node placement approach was proposed in [8]. Reference [9] has proposed an approach to move the sink node where ever and when ever needed based on energy constraints. Using a multi-objective territorial predator scent marking algorithm, a node placement approach for sensor networks was proposed by Abidin et.al. in [10]. A study on routing of data packets through multiple paths in an efficient way helped to identify the advantages and disadvantages of having redundant paths between a source and a sink node. When multiple paths are identified for achieving a fault tolerant data network, it is also required to select an interference and congestion free path [11, 12, 13, 14] and an assured connectivity available path [15].

The authors of [16] have proposed a bio-inspired particle multi-swarm optimization routing algorithm to construct k-disjoint paths. A self healing routing scheme to provide reliability has been proposed in [17]. This work mainly concentrates in developing two algorithms for low memory components. In contrast, the authors of [18] have proposed a multi particle swarm immune cooperative algorithm for reliable routing in WSNs with more number

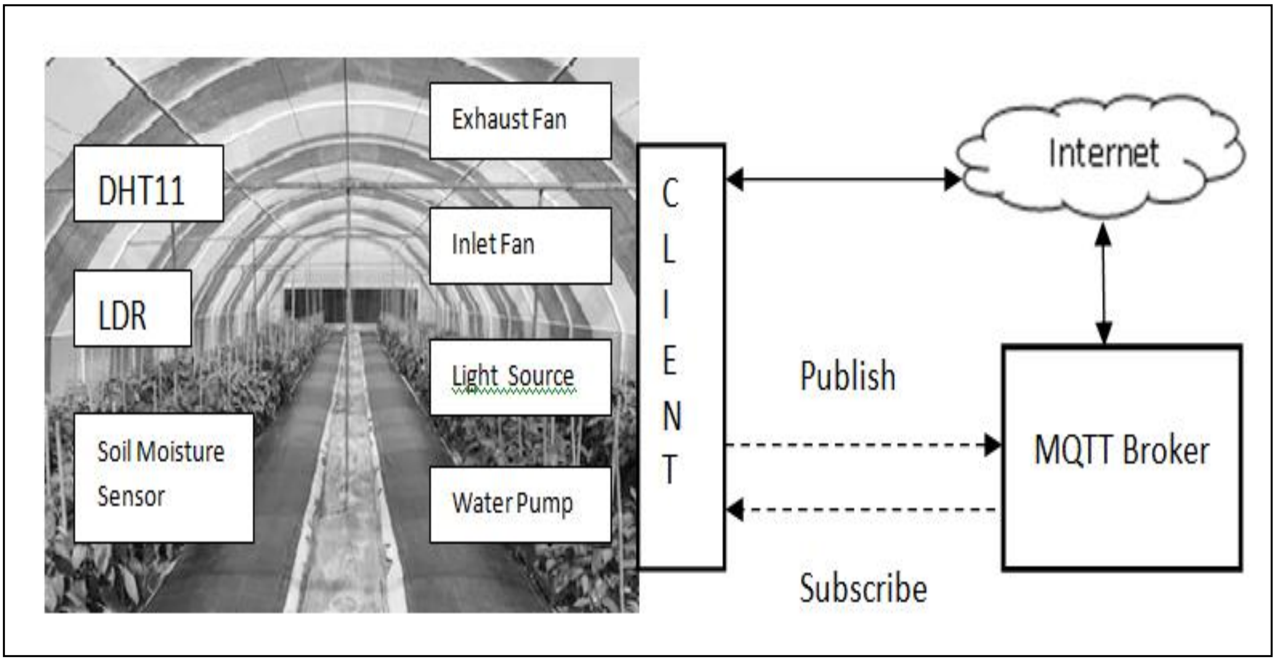

Figure 1. System Framework of the Automated Greenhouse System.

of resource rich nodes. Protocols to be followed in case of node failure have been proposed as a failure resilient routing approach in [19].

Even though a lot of work has been performed to provide reliability in a network, the constraints like cost efficiency, delay requirement, QoS requirement, number of a nodes required for a specific application, structure and topology of the network varies in case of greenhouse automated systems. This is the motivation of our work to build a fault tolerant node placement in a large scale greenhouse system.

3. System Architecture

A. Impementation of Automated Greenhouse System

Sensor network as it is defined to work for a specific purpose, here too is designed to sense the environment and report to the administrator to perform actuating process in the monitored area of greenhouse. The goal of this design of greenhouse monitoring system is to monitor the soil moisture, temperature, humidity and lighting inside the greenhouse, with cost constraint and power efficiency. The sensing and actuating devices are shown in Figure 1. The environmental monitoring sensors used in our work are DHT11, Light Dependent Resistor(LDR), and soil moisture sensor.

The DHT11 is used for monitoring the temperature and humidity. The goodness of DHT11 is its connection ease, good quality, low cost, anti-interference ability and accurate calibration. LDR is used for sensing the light intensity inside the greenhouse. If the light intensity increases, the resistance of the LDR will decrease. The soil moisture sensor is used to measure the water content of the soil, which is usually reported in percentage.The end devices are the exhaust fan, inlet fan, artificial light source and water pump. To maintain proper airflow inside the greenhouse we use exhaust and inlet fans. The water pump is switched ON or OFF based on the soil moisture content.

The Message Queuing Telemetry Transport(MQTT) protocol used is especially for supporting device to device connectivity. It is a light weight protocol that is more suitable in designing resource constrained applications. MQTT is an ideal protocol for the implementation of IoT applications, as it attempts to ensure reliability while minimizing the requirement of network bandwidth and resource requirements.

The monitored physical event is characterized by k variables. These may represent the current state of the system. Each state is modeled as a random process in discrete time. Based on the subscribed pattern of data by the MQTT broker, the client maintained in the greenhouse publishes the data generated from the sensors by transmitting it over the communication link. This transmission facility is modeled by a conditional distribution. The published data is received by the MQTT broker installed in the base station. Thus the MQTT broker receives the required data of interest and not the actually raw data sensed. This communication may be well pictured as a sequence of random vectors of sensed data S[n], in general term as:

$$\{ S[n] \}_{n \geq 0} = \{ (M[n], T[n], H[n], R[n]) \}_{n \geq 0} \quad (1)$$

'n' represents the time index. The Eqn. (1) represents the sequence of independent and identically distributed random vectors, representing the soil moisture sensor reading M[n], temperature reading T[n], humidity H[n] and resistance from LDR R[n]. This state of the system, is from the observation of the sensors on the monitored environment based on the conditional probability distribution, $p(\{s_l[n]\}_{n\geq 0})$. Where s_l represents the observation or realization random variables from the state space. The 'l' here represents the four monitored variables, each as soil moisture, temperature, humidity and resistance respectively. The overall goal in transmission is to maintain the cost generally, and specifically the power below the constraint factor.

B. Greenhouse Monitoring Sensors

The greenhouse is automated for monitoring the state of the immediate environment through multiple sensors. These sensors usually come with limited communication facility, power, memory and computational resources. But in a wireless sensor network these sensors are mentioned to act smart to perform transmission, reception forwarding, sensing and actuating.

If there are too many sensors in the network, cost, in terms of device and communication may shoot up in deploying and maintaining the automation process. If the sensors are too less, the farmers may not be able to provide consistent support required for the crops. Hence we demonstrate in this paper about achieving the desired accuracy of measurement by identifying the number of sensors to measure the state of the immediate environment and proper placement of these sensors.

Greenhouses based on the area it covers, can be categorized to three models: small sized, medium sized and large sized [20]. Small sized green houses are approximately of size 100sqm, and can accommodate two sensor nodes and a sink node. Medium sized greenhouses are of size 1000sqm with eight sensors and one sink node. Large sized greenhouses of size approximately 4500sqm can be set up with 72 sensor nodes and one sink node.

As the sensors could only measure the immediate environment, it becomes necessary to have a sufficient volume of sensors to cover the greenhouse, for a consistent care. In order to maintain optimal cost and better coverage, sensor nodes placement knowledge becomes must. For an in depth understanding of the IoT communication in greenhouse, we view the architecture from various dimensions to cover the issues and concerns that helps us to have an efficient and reliable greenhouse system.

4. NETWORK MODELING

A. Definition 1

Let S = (N, L) is a digraph representing the greenhouse network, with a set of sensor nodes represented by a vertex set 'N' and the communication links represented by an edge set 'L'. A link 'l' of 'L' is denoted by 'uv' that indicates 't' the tail vertex, which is the transmitting node and 'h' the head vertex, which is a forwarding or a receiving node. This says that 'l' joins 't' to 'h', 'l' is incident with 't' and 'h', 'l' is incident from 't' and 'l' is incident to 'h', or 't' is adjacent to 'h' and 'h' is adjacent from 't'. If for any pair of nodes in the network,'t' and 'h' both 'th' and 'ht' are links of S, we say we have a symmetric pair of link and denote it by (th).

For any $h \in N$, the number of links adjacent to 'h' is the in-degree of 'h' and the number of links adjacent from 'h' is the out-degree of 'h'. These can be denoted by $d^-(h)$ and $d^+(h)$ respectively. From this we can define the total degree, or the degree of 'h' is $d(h) = d^-(h) + d^+(h)$. This can be represented by the definition

$$N^+(h) = \{ t \in N \mid ht \in L\} \quad (3)$$

$$N^-(h) = \{ t \in N \mid th \in L\} \quad (4)$$

The in degree and out degree of a node 'h' that belongs to the set N, is thus given by equations (3) & (4). A node with $d^+ = d^- = 0$ is said to be disconnected and isolated as there is no link adjacent to or from that node. For a node $t \in N$, and if $d^+(t) > 0$ and $d^-(t) = 0$, then 't' behaves as a transmitter only node. A node $t \in N$, and if $d^+(t) = 0$ and $d^-(t) > 0$, then it behaves as a receive only node.

Statement and Proof1

Statement: At any time t_0, if the network graph S is changed to its converse S', the path, most aptly the shortest path in reverse direction will be the same.

Proof: If a sensor node 'n_1' is in the range of 'n_0', then the link 'l' is true with n_0n_1 and n_1n_0. This shows that, if the multihop or a shortest path from a transmitter node 't' to a sink node 'h' or a shortest path from a sink node 'h' and the receiver node 't', which is in reverse is the same at time t_0.

The greenhouse automated system should provide reliable data transmission. This assurance can be ensured by maintaining the event transmission connected, even when some nodes fail. Having too many redundant nodes is expensive. And so it is required to achieve this goal of reliable transmission with fewer sensor nodes itself. Through the following discussions, we have provided a sensor node placement approach that provides reliable data transmission.

B. Definition 2

A cut vertex of a graph 'S' representing a sensor network, is defined, as a vertex, that if removed, increases the number of components of the graph by more than one. Hence the vertex connectivity of the network: k(S-t) > k(S). A greenhouse network is connected if there is a path between every sensor node and the sink node. Our goal is to maintain a connected graph called as a non separable graph or a biconnected graph. Through the following statement and proof, we learn the effect of cut vertex in a greenhouse network.

Statement and Proof 2

Statement: For a connected graph 'S', the following statements are equivalent.

(i) 'n' is a cut vertex

(ii) N – {n} produces a vertex subset that can be partitioned as N_0 U N_1 such that for any node t ϵ N_0 and any node h ϵ N_1, every t-h path passes through n.

(iii) There exist nodes t,h ϵ N-{n} such that every t-h path in S passes through n.

Proof:

(a) (i) => (ii) since the node n is a cut vertex in the graph, S-n disconnects or separates the graph. Connectivity of a disconnected graph = 0.

Let S_1, S_2…S_k be the components of S-n. Let N_0=N(S) and N_1= N(S_i) $\forall$i = 2 to k. Let t ϵ N_0 and h$\epsilon$$N_1$. Specifically, let h ϵ V (S_i) (i$\neq$ 1). If there is a t-h path 'p' in S not passing through n, then the path 'p' connects 't' and 'h' in S – n also. Thus $S_i \cup S_i$ is a single component in S-n. Thus every t–h path in S passes through 'n', and N_0 and N_1 satisfy the condition (ii).

(b) Proof of the above condition leads to the proof of (iii).

(c) Since every t–h path in 'S' passes through 'n', there is no t–h path in S-n. Thus 't' and 'h' belongs to different components of S-n. That is S-n is disconnected and 'n' is a cut vertex of 'S'.

Statement and Proof 3

Statement: If there is no cut vertex in a connected graph, such graph is called a block or a clique. The maximality of blocks says, two blocks in a graph share utmost one vertex.

Proof by contradiction: Let us consider that the above said statement is not true. Let us assume the graph 'S' consists of two blocks 'S_0' and 'S_1'. If 'S_0' and 'S_1' share two vertices, then let us consider 'a' be any vertex in the vertex set of the union of the two blocks N($S_0 \cup$ S_1). Now, we can assure there cannot be a cut vertex, as removing one vertex will still leave a path through another vertex. This says $S_0 \cap$ S_1 – {a} $\neq \emptyset$. ($S_0 \cup$ S_1) – {x} still is connected. Therefore $S_0 \cup S_1$ is a subgraph without any cut vertex.

The assurance of a clique network to provide connectivity, provides hope for the data delivery between nodes in the network. The sensor network will be even more efficient if it is fault tolerant. Hence we provide a solution for a fault tolerant network using the measure of connectivity, given by the Menger's theorem [21, 22].

Statement and Proof 4

*Statement:*If 'u' and 'v' are two nodes of a graph 'S', then the minimum number of vertex cut required to make an uv separable network is the maximum number of disjoint paths between 'u' and 'v'.

Proof:

Let us use proof by induction on the number of sensor nodes when removed from the greenhouse will separate the network. Let the greenhouse has only two sensors – x,y., i.e n=2. Then they are directly connected and there is no cut node to separate these two nodes. Therefore we can say the cut vertex between x and y given as κ(x,y) =0. For the same two node model, the edge cut λ(x,y)=0. So the theorem holds for sensor nodes n=2. With this let us also assume for the number of sensor nodes n>2 also the theorem holds. Then we have to prove that the graph connectivity 'k' is equal to the minimum cut κ_S(x,y). This will leave us 'k' disjoint paths between the two sensors x and y in the greenhouse network.

Let 'C' be a separating set or vertex cut of the sensor network, where C $\subseteq$ N(S), (N => set of sensor nodes, S=> network graph) such that S-C has more than one component. This S is a k-connected network if every C has atleast k nodes. This says κ (S)≤n(S)-1 for all S. S has a minimum x-y cut C such that C-(N(x) $\cup$ N(y)) $\neq \emptyset$. Let V_1 be the set of nodes on x, C-paths and let V_2 be the set of vertices on C,y-paths. Then we say C=$V_1 \cap V_2$. As C is a minimal x,y cut, every node of C lies on a path from x to y. Hence C $\subseteq$ $V_1 \cap V_2$. Suppose C $\neq$$V_1 \cap V_2$. There exists a node v $\in$($V_1 \cap V_2$)-C. The portion from x to v of some x,C-path followed by the portion from v to y of some C,y-path generates a path from x to y that avoids the x,y – cut C. But this is not possible. Therefore we can say C=$V_1 \cap V_2$.

Now, let us say $V_1 \cap$ (N(y)-C) = $\emptyset$. Suppose that there is a sensor node v $\in$$V_1 \cap$ (N(y)-C). The portion from x to v of some x,C-path followed by (v,y) generates a path from node x to node y that avoids the x,y-cut C. This is also not possible. Thus, $V_1 \cap$ (N(y)-C) = $\emptyset$. Similarly $V_2 \cap$ (N(x)-C) = $\emptyset$.

Then, we merge the network nodes in 2 different ways H_1 & H_2 such that H_1 is formed by adding to the induced subgraph S[V_1] a node y' with each link from C.

H_2 is formed by adding to the induced subgraph $S[V_2]$ a node x' with each link to C.

Every path from x to y in S that starts with an x,C-path is contained in H_1. Thus every x, y'-cut in H_1 is an x,y cut in S. Hence $\kappa_{H1}(x,y')=k$. Similarly $\kappa_{H2}(x',y)=k$. As $V_1\cap (N(y)-C) = \emptyset$ and $V_2\cap (N(x)-C) = \emptyset$, both H_1 and H_2 have fewer nodes than S. Since $C=V_1\cap V_2$, deleting y' from the k-paths in H_1 and deleting x' from H_2 generates the desired x,C-paths and the C,y-paths in S. Combining these paths, we obtain k pair wise internally disjoint paths from x to y in S.

Proof by illustration:

Let us consider a network with 7 sensor nodes as shown in figure 2. Set of sensor nodes $S = \{N_1, N_2, N_3, N_4, N_5, N_6, N_7\}$. Let node N_1 be the source node and Node N_7 is the sink node. The different paths between N_1 and N_7 are

$$p_1=\{N_1,N_2,N_4,N_7\}$$
$$p_2=\{N_1,N_2,N_5,N_4,N_7\}$$
$$p_3=\{N_1,N_2,N_5,N_6,N_7\}$$
$$p_4=\{N_1,N_3,N_6,N_7\}$$
$$p_5=\{N_1,N_3,N_5,N_4,N_7\}$$
$$p_6=\{N_1,N_3,N_5,N_6,N_7\}$$

The minimum number of vertex cut for N_1-N_7 is 2, which is also the maximum number of disjoint sets, in this graph.

5. Simulation Experiments and Results

Sensor node placement based on the 3 models of greenhouse, representing different dimensions of area was simulated for vertical, horizontal and random placements. Then for a large scale greenhouse, placement of sensor nodes was identified using Menger's theorem and the simulation was also performed. Simulation was performed with the network simulator tool NS 2.35. The parameters measured are throughput, instant throughput, residual energy of all nodes and the packet delivery ratio. Table I shows the network parameters set for the simulation. MAC type is 802.11. Transmission range is 15m. Interference range is 30m. Bandwidth is 11Mb. Packet size is 1500 bytes. Data packets are generated at a constant rate.

TABLE I. Network Simulation Parameters

Paramenter	***Value***
Small Sized Network: Area	100sqm
Medium Sized Network: Area	1000sqm
Large Sized Network: Area	5000sqm
Small Sized Network: No. of Sensors	3
Medium Sized Network: No. of Sensors	9
Large Sized Network: No. of Sensors	80
Radio Propagation Model	Two Ray Ground
Queue Type	Drop Tail/PriQueue
Antenna Type	Omni Antenna
Initial Energy	10Joules

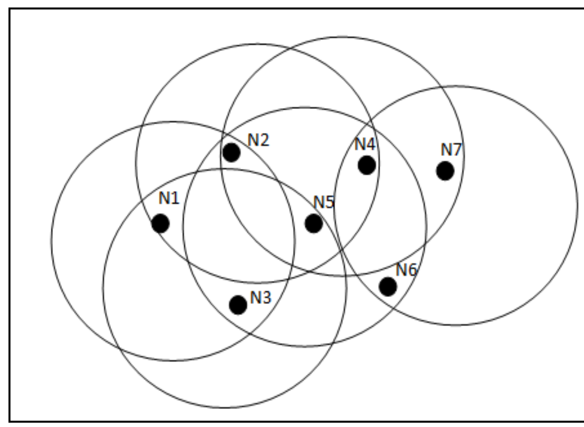

Figure 2. An illustration for Sensor node placement with k=2

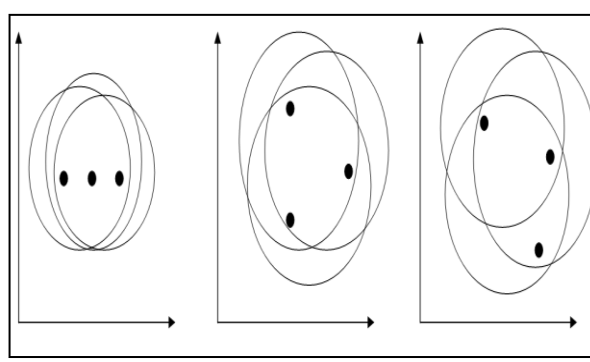

Figure 3. An illustration of a small sized sensor network with 3 nodes covering the entire area

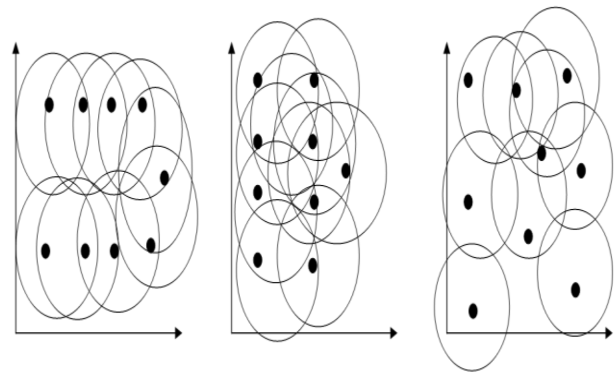

Figure 4. An illustration of a medium sized sensor network with 3 nodes covering the entire area

A. Parameters Measured

Residual Energy: The network lifetime is defined as the time until the network is considered non-functional. The expected network lifetime depends on the power consumption of all sensors in the greenhouse, the sensor's rate of data sensing from the immediate environment and the total energy left out without usage when the network dies [23]. It is proved that by reducing the measured energy used and utilizing the expected remaining energy, the network lifetime can be prolonged.

Throughput: Throughput gives the measure of data delivered successfully in comparison with the available communication facility. The sensor network expects good throughput, for it is an assurance of the sensed data transmission utilizing the available bandwidth.

Instant Throughput: Instant throughput is measured in discrete time events. In greenhouse various sensors sense and send data to the sink node at discrete event of time. Hence at these various time events, the throughput is measured and made available as instant throughput. This measurement can be used to analyze the nature of data in transit and the routing protocol can be improved to efficiently utilize the network capacity.

Packet Delivery Ratio (PDR): PDR is a measure of the packets sent and received. If the sensed data is all transmitted to the sink node, the sink node can give back the feedback on time. PDR measurement helps to check whether the expected decisions are taken.

B. Small Sized Greenhouse

For small scale greenhouse, measure of these parameters showed almost similar response for the horizontal, vertical or random placement of nodes, but still there was a slight betterment in the response ofhorizontal placement of nodes, towards the sink node. The arrangement of small sized networks is shown in the figure 3.

C. Medium Sized Greenhouse

The next moderate sized greenhouse is approximately with area covering 1000sqm, with dimension 50mx20m. 8 homogeneous sensors can be sufficiently placed in this area. The more number of sensors deployed will sense redundant data and the quantity of data in transit will create more network traffic. This will also reduce the battery power of the sensors, as they have to listen to the data in transit and forward the same, even though these sensors have nothing to do with the redundant data. The nodes were placed in horizontal, vertical and random directions towards the sink node, and the performance parameters were monitored. The arrangement of sensor nodes is given in figure 4. It was found that the packet delivery ratio and throughput was better for horizontal and vertical placements. But the residual energy of the nodes near the sink node was depleting more than other nodes. This problem called as hot-spot problem in wireless sensor networks, reduces the lifetime of the wireless networks, as the lifetime of a network longs only till the network is functional. Due to hot-spot problem, if the nodes near the sink node die soon, then the other sensors cannot communicate to the sink node. This problem can be resolved by Menger's theorem, by increasing the strength of connectivity of the network. As the strength of connectivity factor denoted as k, is increased the numberof disjoint paths also will be to a limit, which helps to build fault tolerant networks.

D. Large Scale Greenhouse

The size of the large scale greenhouse is around 5000sqm. With this large scale, the complexity of data collection and the challenge to improve the network lifetime increases. The constraint here is cost and ease of maintenance. Hence the simulation was performed to measure the residual energy to learn the battery strength of the active sensor nodes and the data reachability parameters.

Residual Energy:

The residual energy of the nodes is measured for the greenhouse with random placement of nodes represented as Random Node Placement (RNP) and our approach Menger's Theorem based Node Placement (MNP). The residual energy of the nodes based on MNP is found to be higher than that of the RNP approach. Graph obtained through simulation of sensor nodes in a greenhouse setup is shown in figure 5.

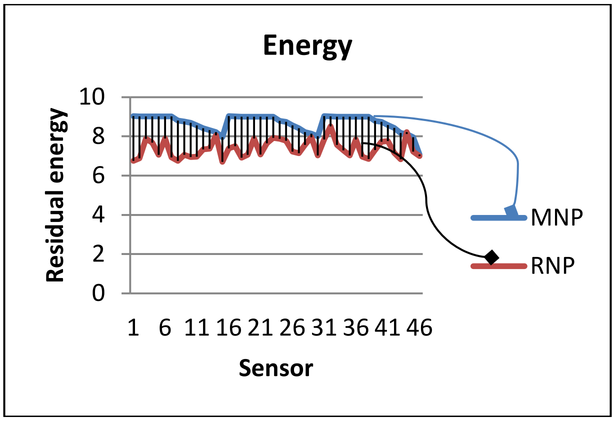

Figure 5. Residual Energy

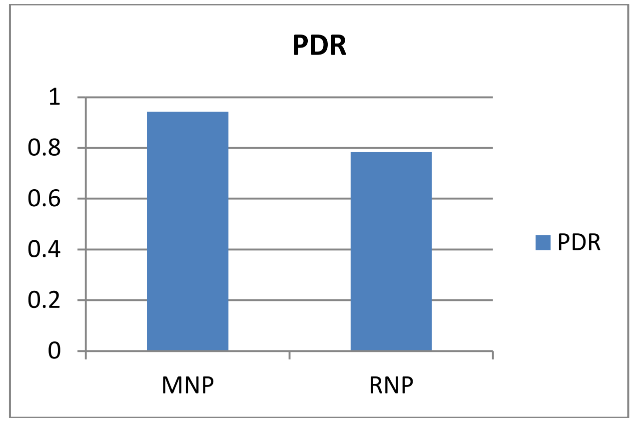

Figure 7. Packet Delivery Ratio

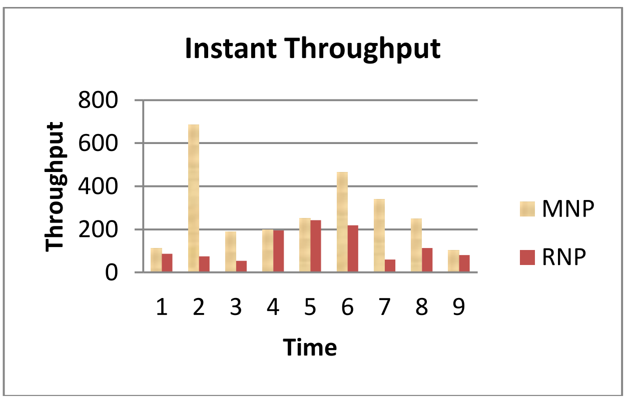

Figure 6. Instant Throughput

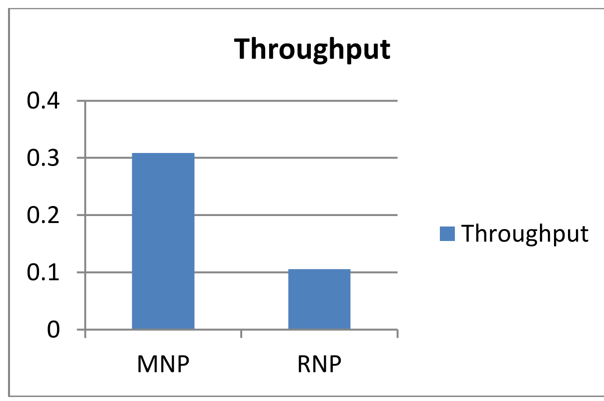

Figure 8. Throughput

Instant Throughput:

Instant throughput gives the successful data transfer at any given time. The series of data transfer from the start of the simulation to the end was monitored and the instant throughput was measured. Figure 6 shows the instant throughput of the network at discrete time events.

Packet Delivery Ratio:

Packet Delivery Ratio(PDR) gives the total number of packets sent from the sensors to the total number of packets successfully received by the sink node. Figure 7 shows the PDR achieved for the two schemes- MNP and RNP. PDR of MNP was found higher than the RNP.

Throughput:

Throughput gives the rate of successful data delivery, and here we measure it in kbps. Throughput in kbps is plotted for the RNP and MNP. Average throughput of MNP is higher than the throughput measured for RNP. Figure 8 shows the graph of this plot.

6. Conclusion

Agriculture is finding technological improvements in various facets. One such area is the greenhouse monitoring systems. Plenty of sensors are required for the monitoring activity. IoT especially plays a main role for the heterogeneous applications. Heterogeneous monitoring activities even more increase the complexity in large scale green house systems. Hence a node placement algorithm helps in positioning the sensors in right place to improve the lifetime of the sensor network involved in the sensing and actuating process. In this paper we discussed various, related mathematical parameters when the network is modeled as a graph. Using mathematical modeling and various proofs, and finally through the Menger's algorithm on connectivity of a network, a node placement algorithm is proposed. The proposed approach is also simulated using a network simulator tool and the performance parameters are measured and analyzed for the betterment of the proposed approach.

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