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LIFETIME MAXIMIZATION OF WIRELESS SENSOR NETWORKS IN A WIND TURBINE

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Abstract:

Wind turbines are installed in remote places and operated continuously which demands continuous condition monitoring systems for effective utilization. The condition monitoring of wind turbine is using machine learning approach is an established area. While the initial cost of the wind turbines are higher, the additional cost introduced by the condition monitoring system makes the situation worse. The fault diagnosis technique is employed using wireless sensor networks (WSN) wherein one sensor node is attached to every wind turbine in which the fault diagnosis is done. A sink node receives the signals from all the wind turbines and all the operations are carried out in the sink node. A major issue in WSN is that the battery of the sensor nodes will reduce gradually with time, as the location of the sensor nodes are very far from the sink node in many wind turbine plants. The effective operation of the WSN based fault diagnosis system is greatly dependent on number of wind turbines per base station of the wireless sensor network. In the present work, the machine learning technique is used for the extracted vibration signals from the wind turbine bearing. The wind turbine plant is equipped with the wireless sensor network and found that when the base station is in the middle of the wind turbine plant, three wind turbines has to be kept for one base station. The simulation is done using Matlab©.

Keywords: Fault diagnosis; Wind Turbines; Wireless sensor networks; Life time maximization, LEACH.

1. Introduction

For an illustration of an outdoor setup which is influenced by environmental changes a wind turbine plant is considered. As any downtime of the wind turbine will greatly increase its maintenance and service cost. Hence proper prevention measures should be taken to avoid any major fault in wind turbine. In wind mills, the human intervention cannot be done very frequently as they are located in remote locations. Such systems are expected to operate continuously throughout the year. Any damage or fault occurs in any components in wind turbine will affect the continuous operation. Hence, continuous monitoring of such systems is a critical task (Fausto Pedro García Márquez, et al., 2012). Wind turbines are normally installed in clusters (in a group of few) owned by an organization or an individual. Installing fault diagnostic system in each wind turbine individually incurs more cost. The cost can be reduced by using wireless sensor networks. The vibration signals acquired from the wind turbine can be used and the well-established machine learning approach can be applied to arrive at the diagnostic information and the signals can be passed to the base station. One base station can be used to handle a cluster of a few wind turbines. If the data communication is very frequent or the computational effort required to do the diagnosis is very high, then the battery life will be shortened. On contrary, if the diagnostic information does not require much computational effort or the information passed to the base station is very small, then the battery lifetime can be extended. In this context, the lifetime maximization becomes an important task.

Every wind turbine present in the field is fixed with a sensor node and the sensor nodes extracts the vibration signals and sends this to the base station. The vibration signal from the sensor node is extracted using an accelerometer from the wind turbines present in the field and the extracted signal is transmitted from the sensor nodes to the base station which acts as a central control point. During the transmission of signals the energy of the sensor nodes is used as it uses a radio to transmit signals. In a power generation wind turbine, the total quantity of the energy produced depends on the effective performance of the wind turbines.

A condition monitoring system uses wireless sensor network for diagnosing the faults with self-healing ability for offshore wind turbines. The self-healing capacity of the system will overall increase the maintenance ability. The sensing distance of the sensor nodes are varied so that the system can be repaired itself. The system is simulated for self-healing strategy for a blind monitoring area and found that the number of redundant nodes and energy consumed are reduced (Zhixin et al., 2016).

Reducing the operation and maintenance costs of wind turbines is of most important as the requirement of wind energy is more in recent days. Then the wind turbine will become reliable and cost effective. The different classifications of wind turbine condition monitoring methods and techniques with its trends and future challenges are reviewed (Pierre, et al., 2014).

Different methods for fault diagnosis and its related algorithms are reviewed. The wind energy fault diagnosis and condition monitoring are surveyed. Variety of faults that might occur and their symptoms in wind turbines are also reviewed. The blade, gearbox, generator, braking system, and rotor are the primary parts where there could be faults coming and their performance monitoring strategies are proposed. The information is also gathered which will help future researchers to improve the ability and accuracy of wind turbine condition monitoring techniques (Seyed, et al., 2016).

From the vibration the faults can be detected using a two-stage neural network. Followed by the test bed, wireless sensors for sending the vibration signals and a novel two-stage neural network is designed to classify the bearing faults. Generalized Hebbian Algorithm (GHA) uses first stage neural network. A supervised learning vector quantization network (SLVQ) uses a self-organizing map technique to differentiate various fault modes (Ballal, et al., 2009).

Ankit Beniwal, et al., (2016) proposed a method for the long Life of the Wireless Sensor Network using Leach protocol. The protocol is designed to minimize the energy dissipation of the network so that the lifetime can also be increased. The optimal planning of sensors' states is done to sensors so that it gives maximum lifetime. Also, the sensors can be turned on, turned off; cluster head can be promoted so that different power consumption level can be assigned to different states. Also using LEACH protocol, full area coverage and sensor connectivity to cluster heads can be achieved.

A bat monitoring and deterrent system based on wireless sensor and actor networks is proposed to monitor the environment of wind farms. The system is capable of capturing data and it can be transferred through GPRS to a server located far away and the received data is stored. A reactive system-built triggers a reaction to detect an event which creates faults (João Carneiro, et al., 2008). Using LEACH for Wireless Sensor network, the position of the base station is kept in the middle and the cluster combination of wind turbines is varied to four different sizes and the optimum size is decided where in the wireless sensor network lifetime is maximized.

2. Cluster sizes and their field dimension: The transmission and reception of the vibration signals is done by the radio of the wireless unit and it consumes more battery. The central control point cannot be very far from the wind turbines. Hence, four different set of wind turbines known as clusters are taken and the energy patterns are found (Mallika, et al., 2017). The cluster size of the wind turbines and their field dimension is given in the Table 1.

Table 1: Cluster sizes & field dimensions

S. No	Cluster Size of wind	Field Dimension	Base Station Location(m)
1	3	200×200	(100,100)
2	5	400×200	(200,100)
3	7	600×200	(300,100)
4	9	800×200	(400,100)

3. Optimal number of sensor node per base station: The number of sensor node present in a group is varied and the energy patterns are simulated for different combination of wind turbines. The Table 2 shows the parameters used for simulation of WSN using LEACH protocol for different cluster of wind turbines. In Table 1, the field dimensions, the base station location and the wind turbine locations are chosen for a 1.3 MW wind turbine in which radius of the blade is 30 m and it can be kept at a minimum of 3 to 10 times of its diameter.

The best cluster combination of wind turbines is found by Wireless Sensor Networks simulation using LEACH Protocol. The energy consumption patterns are found (Archana, et al., 2016).

Table 2: Simulation parameters for WSN using LEACH protocol

S.No.	Parameter	Value
1.	Cluster Size	3, 5, 7, 9
2.	Plant area	(200 × 200) m, (400 × 200) m, (600 × 200) m, (800 × 200) m,
3.	No. of base station	1
4.	Initial energy of nodes	0.5 J

5.	Energy for transferring a bit (ETX)	5×10^{-8} J
6.	Energy for receiving a bit (ERX)	5×10^{-8} J
7.	Free space energy (EFS)	1×10^{-11} J
8.	Multipath Energy (MPE)	1.3×10^{-15} J
9.	Data Aggregate Energy (DAE)	5×10^{-9} J
10.	Routing Protocol	LEACH
11.	Maximum Number of Rounds	10000
12.	Control packet length (Bytes)	200
13.	Packet length (Bytes)	4500

3.1 Three wind Turbines: Three wind turbines are considered as a cluster with one base station. The wind turbines are kept in a square of 200 × 200 m^2. The base station is kept at the middle of the wind turbine plant at 100, 100m and denoted using circle symbol. The wind turbines are denoted using star symbol. As wind is the primary source of energy, the wind turbines have to be kept in the middle of the two wind turbines in the previous row. It is because the first-row wind turbines should not hide the wind for the second-row wind turbines. The distance between two wind turbines is 180m. A sensor node is installed in each of three wind turbines and from the sensor nodes the extracted vibrations signals are sent to the base station for fault diagnosis.

3.2 Five wind Turbines: There are five wind turbines considered and one base station is kept for the five wind turbines. The wind turbines are kept in a field of 400 × 200 m^2. The base station is kept at the middle of the wind turbine plant at 200, 100m.

3.3 Seven wind Turbines: There are seven wind turbines considered and one base station is kept for the seven wind turbines. The wind turbines are kept in a field of 600×200 m^2. The base station is kept at the middle of the wind turbine plant at 300, 100m and denoted using circle symbol. The wind turbines are denoted using star symbol. Seven sensors are placed in all the seven wind turbines and from the sensor nodes the extracted vibrations signals are sent to the base station for fault diagnosis. The Table 3 gives the locations of all the seven wind turbines.

3.4 Nine wind Turbines: There are nine wind turbines considered and one base station is kept for the nine wind turbines. The wind turbines are kept in a field of 800 × 200 m^2. The base station is kept at the middle of the wind turbine plant at 800, 400m and denoted using circle symbol. The wind turbines are denoted using star symbol. Nine sensors are placed in all the nine wind turbines and from the sensor nodes the extracted vibrations signals are sent to the base station for fault diagnosis. The location specification of the wind turbine clusters is given in Table 3.

Table 3: Location of individual wind turbines

Wind Turbine number	Location for three wind turbines (m)	Location for five wind turbines (m)	Location for seven wind turbines (m)	Location for nine wind turbines (m)
1	(10,190)	(20,190)	(30,190)	(40,190)
2	(190,190)	(200,190)	(210,190)	(220,190)
3	(100,10)	(380,190)	(390,190)	(400,190)
4		(110,10)	(570,190)	(580,190)
5		(290,10)	(120,10)	(760,190)
6			(310,10)	(130,10)
7			(490,10)	(310,10)
8				(490,10)
9				(670,10)

4. RESULTS AND DISCUSSION

The WSN is simulated for four different cluster sizes of the wind turbines three, five, seven and nine wind turbines. The simulation result shows the sum of energy of nodes, number of packets sent to base station and number of dead nodes. The results and discussion for the energy results are given in sections 4.1 - 4.4 and the best cluster size is found.

4.1 Simulation result of three wind turbine cluster

Figure 1 shows the energy results of three wind turbine cluster. One can note the number of packets sent to base station goes upto 2000 with 3689 rounds. The first node dies when the number of rounds is 2768 and the second dies at 3689 rounds. As there is no hopping when two nodes are died in three cluster scenario, the third node does not die till 10000 rounds, which is set as maximum limit for rounds in the simulation. The sum of energies is 1.5 J as the initial energy of the nodes was set at 0.5 J. As data getting transmitted from sensor node to base station, the energy of the battery gets consumed as a result the sum of energies also gets reduced. The third part of Figure 1 shows the energy dissipation pattern of the whole sensor network. When the number of dead nodes is two, the sum of the energies is less than 0.5 J. The WSN is considered to be effective as long as at least half of the sensor nodes are alive. The WSN is effective till the second node dies for this case.

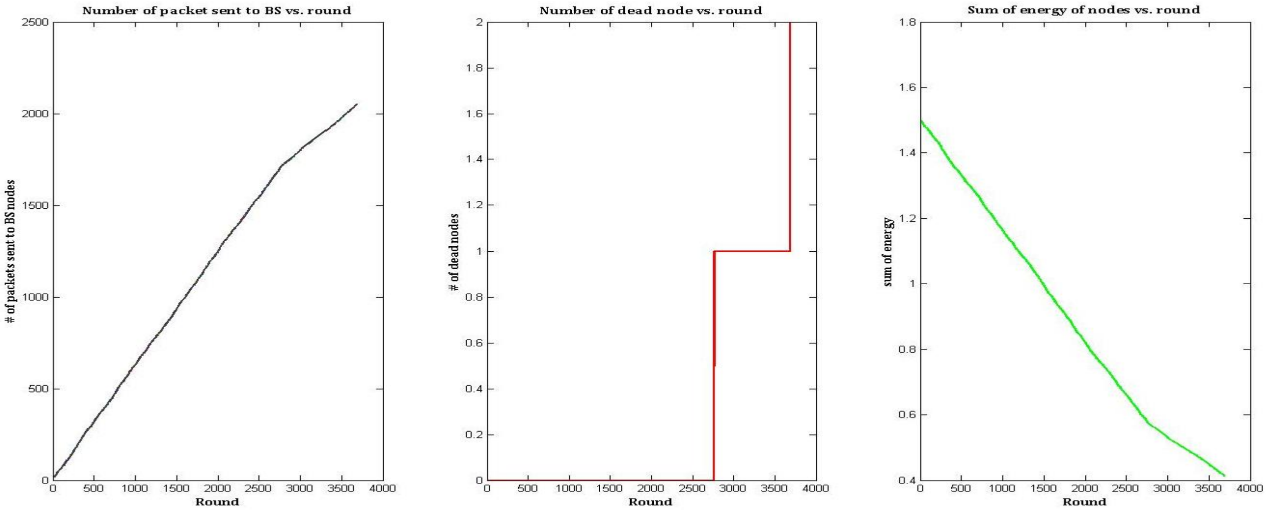

Figure 1: Simulation result of three wind turbine clusters

4.2 Simulation result of five wind turbine cluster: The Figure 2 shows the energy results for five wind turbine cluster. The WSN is considered to be effective until the third node dies in this case. Then the number of packets transmitted to base station is about 2600 in 2769 rounds. And the sum of energies when third node dies is around 0.5 J.

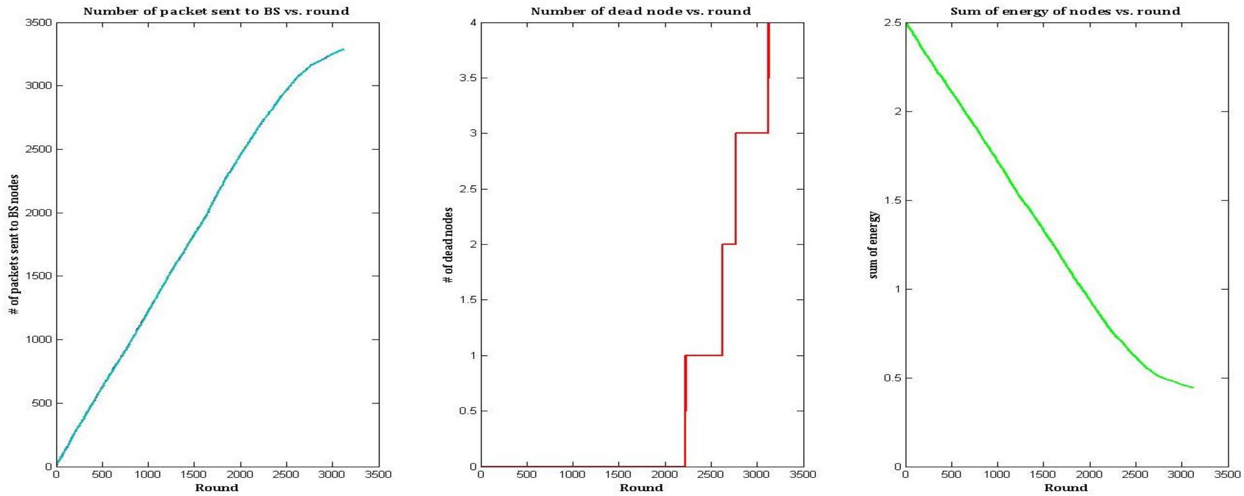

Figure 2: Simulation results of five wind turbine clusters

4.3 Simulation result of seven wind turbine cluster: The energy results of seven wind turbine cluster are given in the Figure 3. In above cases the WSN is considered to be effective if half of the nodes are alive. In this seven-wind turbine cluster, if four nodes are dead then the network is considered to be in effective. The fourth node dies in 2474 rounds and it sends around 3000 packets before it dies. The Sum of energy is little above 0.5 J in 2474 round.

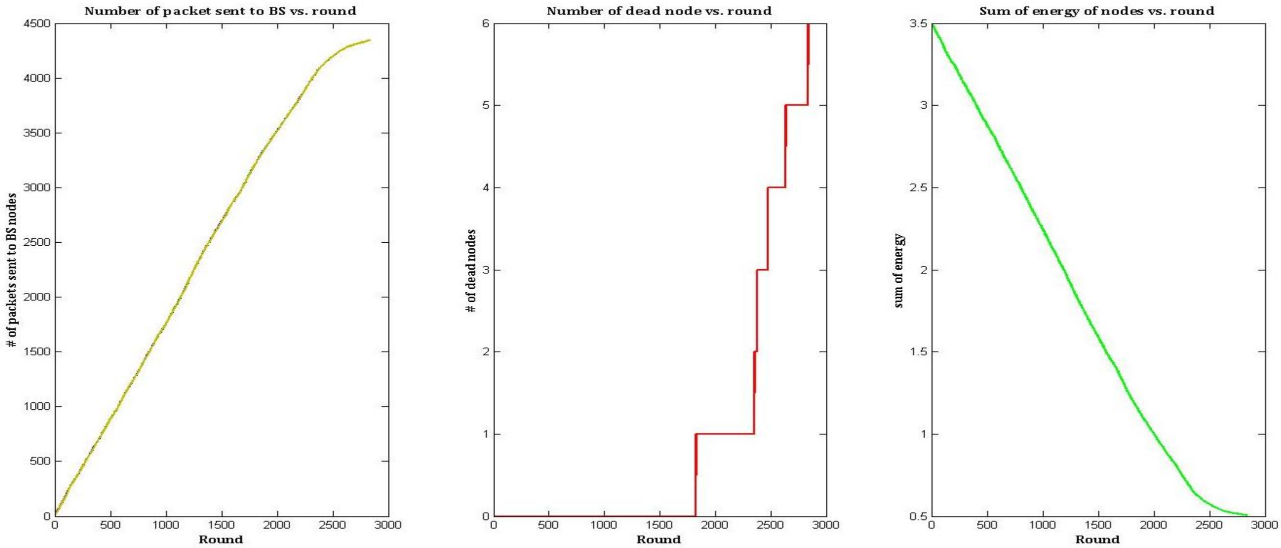

Figure 3: Simulation results of seven wind turbine clusters

4.4 Simulation result of nine wind turbine cluster: The Figure 4 shows the WSN simulation results of nine wind turbine cluster. When five nodes die, the network is considered to be ineffective. The fifth node dies in 2166 rounds. Around 3900 packets are sent before the fifth node dies. Also the sum of energy when it dies is around 0.9 J.

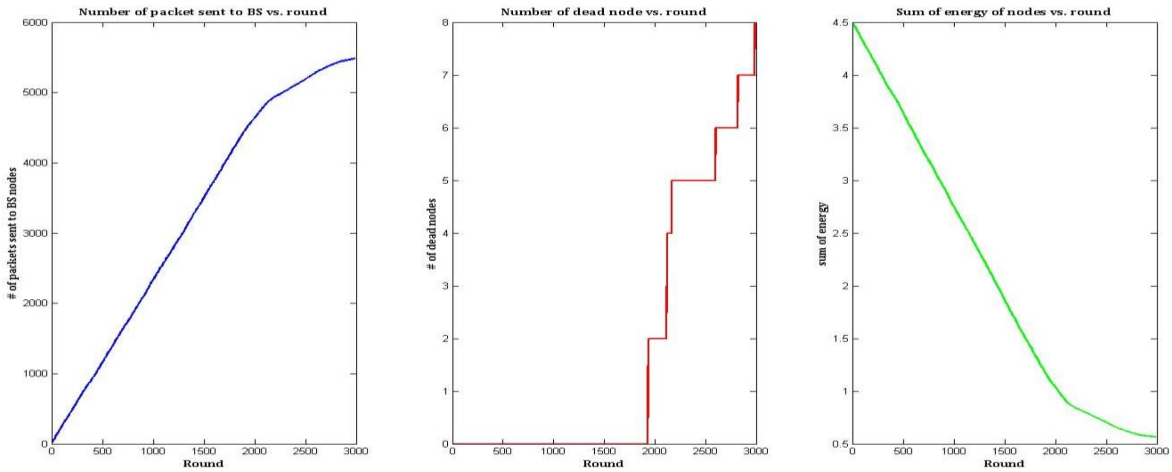

Figure 4: Simulation results of nine wind turbine clusters

5. Conclusion

The proposed method is to find the cluster size for one base station for an wind turbine, an outdoor system which gives maximum lifetime for the wireless sensor network. Different sizes of wind turbines are considered and out of four cluster sizes, the best case needs to be suggested. The criterion for selecting the best case is the cluster which sends more amounts of data and survives for more rounds. In three turbine case the number of packets transmitted is 2000 and the number of packets transmitted per turbine comes to 667 packets. Similarly for five wind turbine case and seven wind turbine case it comes to 500 packets. For nine winds turbine case the number of packets transmitted is 4000 and it leads to 445 per wind turbine. From the above discussion it is clear that three wind turbine cluster is suitable for maximizing the lifetime of the WSN. The result is also reassured by the number of rounds (3689) which is the highest number of round for the effective wireless sensor network.

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