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Energy Efficient Detection of Forest Fires Using Wireless Sensor Networks

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Abstract. Recent years have seen a considerable increase in the frequency of forest fires due to various factors that include climate changes, human activities which are essential for economic development. Uncontrolled human activities and abnormal natural conditions disturb the environmental conditions resulting in occurrence of forest fires frequently which lead to serious disasters, destroying a large portion of forest resources and destruction of human environment. Forests play a vital role in preserving the environment and natural human resources, which play a major role in maintaining ecological balance. Forest fires are catastrophic to the natural resources contained in the forests. It is hence imperative that forest fires are detected at the earliest. This paper describes the architecture of wireless sensor network and a scheme for data collection in real-time forest fire detection. Sensors have limited computational power and use low power batteries, which makes energy efficiency an extremely important factor for consideration. The performance of the approach of packet transmission at discrete time intervals vs continuous packet streaming is compared and is evaluated in terms of energy expenditure by simulation. The simulation results are good to encourage the environmentalists to adopt this technique in protection of forest.

Keywords: Wireless Sensor Network, Fire Detection, Network System, Network Node, Data Transmission.

1. Introduction

Over the years wireless sensor networks [1] have been proving that they make things simpler and more reliable and more importantly easy to implement and at comparatively lesser cost which have attracted many research efforts during the past few years and definitely, will keep attracting in the future years. Sensor networks , are mainly comprised of a large number of inexpensive and small sensor nodes and few sinks. These spatially distributed sensors monitor physical or environmental conditions like temperature , humidity, pressure and the collected data is passed onto a main controller. Sensor networks are used in many fields and have been deployed in a variety of applications ranging from monitoring a small room to large forests. The sensor networks are also used in many industrial and consumer applications in real time machine health monitoring, runway monitoring, coal mines, etc,. The importance of early detection of forest fires cannot be over emphasised: delays can lead to loss of acres of forest land and spread to nearby villages which may lead to loss of human life as well. Hence the prevention of these forest fires has become a global concern in forest fire prevention organizations and thus monitoring of forest fires is an important issue to consider.

Presently, forest fire prevention methods largely consist of patrols, observation from watch towers and satellite monitoring. Although the methods like patrols, watch towers are easy and feasible, they are not very effective as they require many financial and material resources with trained labour force. Many problems with fire protection personnel abound carelessness of workers, absence from the post, inability for real-time monitoring and the limited area coverage lead to turning these methods inefficient. The scope of application of satellite detection systems is also restricted by many factors such as, the resolution of its saturated pixel

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dots of images is low and satellite monitoring has long scan cycle which leads to the fact that the detection of forest fire cannot be forecasted until it has spread to a considerably large portion of the forest by which time the fire would have turned uncontrollable. Cloud layers may mask images during the scanning period and the real-time mathematical quantification of fire parameters is very difficult to achieve.

Considerable research has been done in the detection of forest fires. In [3] Zheping et al., propose a design for detection of forest fires using wireless sensor networks. It adopts low-power IC, enhances stability, credibility, and reduces volume. In [4] Breejan et. al., propose an autonomous forest fire detection principle based on temporal contrast differences with the natural background and spatial characteristics of the smoke plume. In [5] an analysis has been carried out on the dependence that certain magnitudes related with the pixels where there is fire present. Energy efficiency has not been considered as a primary factor for the above works. As wireless sensor networks deployed in hostile territory like fire- hazardous area, with minimal means of recharging the sensors, every effort has to be made to prolong the lifetime of the network by an energy efficient design.

Compared to the traditional methodologies, use of wireless sensor network makes the detection of forest fire is easier and make a quick assessment of a potential fire danger. This work proposes a simple but energy efficient wireless sensor network design for detection of forest fires. The aim is to detect and predict forest fire promptly and precisely in order to minimize the loss of forests, wild animals and people. Large number of sensor nodes are densely deployed in a forest environment to monitor and measure certain physical factors which contribute effectively in detection of forest fire like temperature, relative humidity, etc. The collected data is sent to the main controller of the monitoring center for analyzing. The analytical results will later be sent to forest department or any department which takes further actions to prevent the fire from spreading to other parts of the forest. In this paper it is proposed for the application of wireless sensor network technology as a monitoring system for forest fire.

The organization of the paper is as follows: Section II describes the parameters that result in forest fire, network model for forest fire detection is presented in section III, section IV deals with processing of collected data efficiently, simulation results in Section V and conclude this paper in section VI.

2. Parameters Causing Forest Fire

There are mainly three causes of forest fire, namely natural, intentional/deliberate and unintentional/accidental. Natural fires are those fires which cannot be averted as these occur naturally due to lightening, rolling of stones and rubbing of dry bamboos due to strong winds. Intentional/deliberate are those that are purposefully initiated for the better growth of fodder grass, and sometimes set by villagers to drive away the animals which destroy their crops. The unintentional/accidental fires are created due to the careless human activities like throwing of burning match sticks or cigarettes.

Availability of air, heat and fuel are the main parameters that initiate a fire in forest. The moisture content of the combustible material plays an important role in assessment and prediction of forest fire. The moisture content is related with relative humidity in the atmosphere, wind, temperature of the air and similar factors while relative humidity directly affects water evaporation. The physical properties of the combustible materials vary indirectly by air temperature. Hence, relative humidity and air temperature are regarded as the two major factors which affect the moisture content of the fuel.

3. Sensor Network Model For Forest Fire Detection

A wireless sensor network, is a group of specialized transducers and associated controller units which make up a system of wirless sensor nodes that autonomously monitor physical or environmental conditions (like temperature, humidity, pressure, vibration, etc, and send the collected information to a main controller for certain actions to be taken. This wireless sensor network is composed of many micro sensor nodes which have the ability to communicate and calculate. These sensor nodes can monitor, sense and collect information of different environments from various monitoring objects cooperatively.

A simple architecture of any sensor network comprises, a distribution of sensor nodes, gateway sensors and a controller which are described as follows:

3.1. Structure of sensor node

The sensor node [6] is a basic unit and platform of the wireless sensor network composed of a sensor module, a processing module, a wireless communication module and a power module. The processing module is responsible for controlling the operation of the whole sensor node, saving and managing the data collected by its own node and takes care of the binary information transmitted from other sensor nodes. The wireless communication module plays the role of communicating with other nodes, exchanging control information and receiving or transmitting data. The power module supplies power for the other three modules and drives the nodes, making it the vital factor for the effective operation of the network.

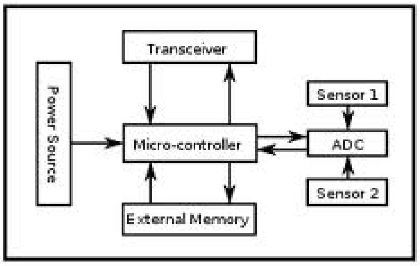

Fig. 1: Structure of sensor node

3.2. Gateway nodes

These are the nodes which are similar to the others nodes, which can not only sense the required parameters but also act as gates for routing the data collected from other nodes to the main controller.

3.3. Controller

This is the main unit where all the collected information is routed to. The physical parameter that is monitored and sensed is converted into digital form, and forwarded where the digital data collected is used in obtaining the actual information. Data Processing In Detecting Forest Fire

3.4. Network Topology

The entire forest area is divided into clusters each of 10kmX10km having a gateway point which is used to send signal to the main control center as presence of fire is detected. The snapshot shows two such clusters, with the gateway sensor node , the main control point , and other fixed sensor nodes of the clusters in Fig.2.

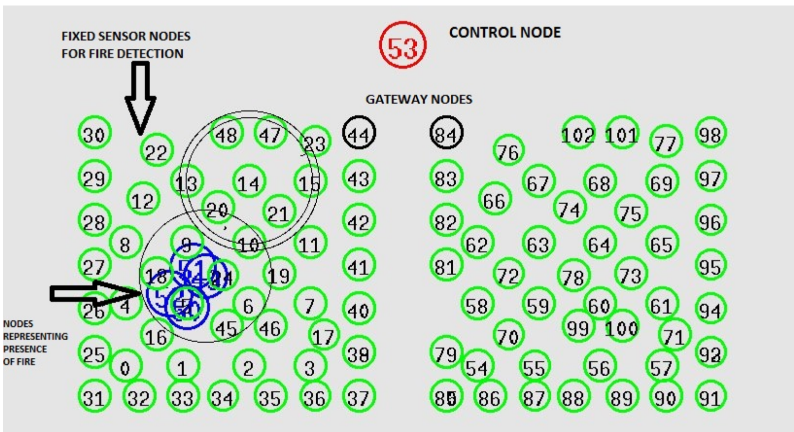

Fig. 2: Network topology

3.5. Network Protocols:

The communication links between the fixed sensors of the network and the Gateway node runs on the UDP protocol. Reason for this choice is that since the packets do not contain any information (other than their occurrence signifying the presence of a fire), certain amount of packet dropping can be tolerated. The link between the gateway node and the Control node on the other hand must be TCP as the packet loss would mean that the signal to indicate the presence of a fire is lost.

Table. 1: Practical sensors in use

Model	Protocol	TX Power	Range
XBee-802.15.4	802.15.4	1 mW	500 m
XBee-Zigbee	Zigbee-Pro	2 mW	500 m
XBee-868	RF	315 m W	40 km
XBee-900	RF	50 mW	10 km
XBee-XSC	RF	100 mW	24 km

4. Simulation And Results

NS2 Simulator [7] has been chosen in which the NAM and XGRAPH tools have been used to display the results of the simulation. Network Animator (NAM) is a Tcl/Tk based animation tool used for viewing network simulation traces and real world packet traces and creates NS-2 scripts through a graphical user interface that supports topology layout, packet level animation and various data inspection tools. The occurrence of fire is represented by the blue nodes and the method adopted is the detection mechanism of fire within the range of the fixed sensors wherein packets are transmitted to the access gateway point of the cluster to signify the detection of fire within the cluster. As there is a possibility of a false alarm, even with advanced sensors, a threshold time of 20 seconds is chosen for the packets received at the gateway node signifying the presence of fire over a period of time, it is considered sufficient to indicate the genuine presence of a fire within its cluster.

4.1. Performance of network in terms of energy efficiency

The performance of a WSN is evaluated using the Energy Model included in NS-2. The action to take on detection of the fire would be to continuously stream packets to the Gateway node over the threshold time period which is highly energy inefficient (since transmission and reception of packets consume energy) and an improvement would be to transmit a packet once every second as long as a fire is being detected over the period of 20 seconds. The nodes are kept idle for most part of the threshold interval, thus leading to an improvement of energy efficiency by a significant amount.

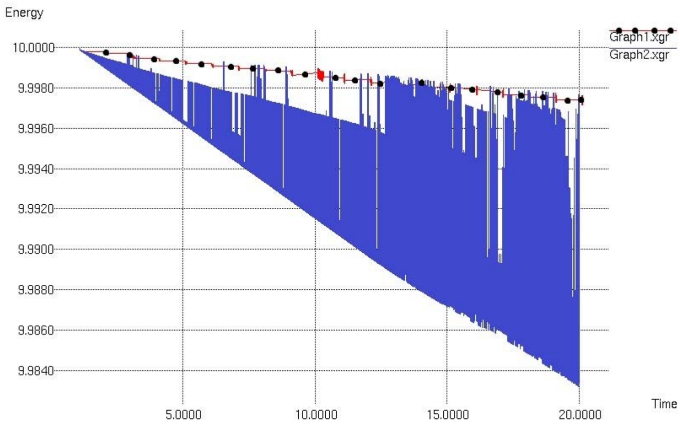

Fig. 3: Screenshot of XGRAPH for energy comparison

Twenty packets would be transmitted over the 20 second threshold period and the Received to Sent packet ratio measured for this network setup has been found to be around 0.9. A minimum of 15 packets received over the threshold period has been chosen to indicate the presence of a fire thereby the gateway node signals the Control centre and necessary steps can be taken.

The Clusters are numbered and stored in the Gateway node which includes the Cluster number within the packet signalling the Control Centre over the TCP link, thus determining the location of the fire. Performance evaluation is done on the presented network setup with the in-network processing implemented in ns-2.34 and the image indicates the energy consumption over the 20 second period comparing the level of improvement introduced by the modification in the detection scheme.

In Fig. 3, the graph shows the energy consumption for the nodes in the case where detection packets are continuously streamed to the gateway point. The dotted curve shows the energy consumption after introducing the proposed improvement to the network starting with an initial energy of 10 Joules. After 20 seconds, the energy of some nodes falls to around 9.9834 Joules, whereas after the improvement the lowest that the energy of any node falls to is around 9.9974 Joules .

4.2. Accelerated Lifetime Test

The performance of the two methods is measured, a case where the network continuously detects fire from the time the network starts to function to the time that nodes fail due to energy depletion is compared to this scheme by extending the readings measured over the 20 second period. The values used for comparison are: Initial Energy: 10 Joules (Chosen for convenience in representation of xgraph. Practical values are usually higher) TxPower: 1mW, RxPower: 1mW. Assuming these values, in the case of using a continuous stream of detection packets, energy depletion of a node would occur first in 3.34 hours. After the proposed improvement, energy depletion would occur in 21.36 hours, for the same values producing more than 6 fold increases in lifetime for the network.

5. Conclusion

Energy efficiency is one of the more important metrics while designing a wireless sensor network, especially when deployed in a difficult terrain like a forest fire-prone area where possibility for battery change or recharging are remote. The proposed scheme demonstrates through extensive simulation that the energy efficiency and therefore the lifetime of the network is much improved compared to the continuous packet streaming to the gateway method, without any perceptible loss in detection. By using the modification to the fire detection scheme as proposed in this paper, the energy efficiency can be further improved upon with an environment aware adaptive MAC protocols and selecting energy efficient sensors.

6. References

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