Eff cient Protection of Palms from RPW Larvae using Wireless Sensor Networks

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***Abstract*—Red Palm Weevil (Rhynchophorus ferrugineus) is one of the most serious pests of coconut (Cocos nucifera L.) palms. It is known to attack 20 palm species worldwide. Due to the concealed nature of feeding RPW, infestation is detected during the last stages and farmers become aware of the problem only when the tree is about to die. The acoustic activity of RPW *larvae* (inside an offshoot and base of leaves) consists of chewing, crawling, emission and quick oscillating sounds. In this paper, acoustic techniques are used to detect hidden *larvae* infestations of coconut palm trees in the early stages that are recorded using wireless sensor network establishing ad-hoc network. The fundamental frequency of the acoustic activity generated by the RPW *larvae* also contains environmental noise which is captured by the wireless sensors (nodes) fixed to the palms and transmitted to the server through access points covering number of palms arranged in the form of hexagon for processing using MatLab tools. This method is inexpensive when compared to the existing methods for the detection of RPW larvae. The simulation results are encouraging in establishing the detection of *larvae* (grubs) inside the palm, thus enabling the farmer to takeup the control measures before the damage reaches the economic threshold.**

Keywords: *Acoustic activity, Ad-hoc Network(MANET), Fundamental Frequency, Larvae.*

I. Introduction

Female Red Palm Weevils bore into a palm tree to form a hole into which they lay eggs. Each female may lay an average of 250 eggs which take about three days to hatch. ***Larvae*** emerge and tunnel toward the interior of the palm, inhibiting the palms ability to transport water and nutrients upward to the crown. RPW ***larvae*** bore deep into palm crowns, trunks and offshoots, generally concealed from visual inspection until the palms are nearly dead. Adults live for two to three months, during which time they feed on palms, mate multiple times and lay eggs. Adult Weevils are attracted to dying or damaged palms and can also attack undamaged host trees. Symptoms of the weevil and the larval entry holes are often diff cult to detect because the entry sites can be covered with offshoots and tree f bres [1]. Careful inspection of infested palms may show holes in the crown or trunk possibly along with oozing brown liquid and chewed f bres.

Fig. 1. Weevil Grub inside the Cocoon

The acoustic activity of uninfected offshoots consists of a couple of distinct sounds: sharp quick click sounds or long continuous sounds that resemble paper being crushed [2]. To control and eradicate the red palm weevil, it is fundamental to detect the infested trees before they constitute new focus of dispersion of the pest. Unfortunately, the ***larvae*** that cause the damages to the palms live inside the stems and at the base of the leaves. Since, visible methods are not enough to detect the ***larvae*** which is the major cause of destruction and as they are present inside the trunk of the palms, acoustic detection method is a better option. The sounds emerging from a tree do not directly indicate the presence of ***larvae*** but sound produced by heavy infestations indicates the severe damage to palm tissue has already occurred [3]. The noise received is a mixture of ***larvae*** chewing sound and the environmental noise conditions. To detect the presence of ***larvae*** in the palms at an early stage, advanced sensors and sound processing tools are established in the coconut grove to detect and avoid disaster through wireless sensor networks.

Fig. 2. Weevil Damage to Coconut Trunk

In this paper, a network is established using wireless sensor nodes with each sensor(microphone) attached to a transmitter. Each block of the wireless sensor network(WSN) and the transmitter are explained in brief and the process is elaborated with a f ow chart. The Filter Designer and SPtool used for bandpass f lter and the parameters of WSN are also touched upon in the later sections.

II. Existing Methods of RPWs Detection

Attempts have been made to automatically identify and classify singing insects based on a speaker recognition paradigm [2]. The sensitive automatic detection systems utilized state-of-the-art speaker recognition methods. However, they were not found applicable to the palm agro system. Some methods used microphone and sound amplif ers for the recording the sound of the RPW directly without any atmospheric noise which used an isolated atmosphere to record the sound from the palm [2]. However this method cannot be practically implemented in coconut farms because of the heavy rustling noises of the trees. Bucket trap methods were also used to capture RPW, but this system could only capture the RPW which live on the offshoot of the palms but the ***larvae*** which are present inside the tree trunk could not be detected [4]. Chemical insecticides proved to be ineff cient due to the cryptic feeding habits of this insect inside the palm tree trunk [5].

Another method of eradicating red palm weevil is Microwave Irradiation. It uses microwave energy for irradiation of RPW adults and ***larvae*** using dipole antenna. This apparatus is quite bulky or practical purposes. The dipole antenna in this setup is loaded to a relatively high absorbing material (tree trunk) in its forward direction, thus totally altering the radiation pattern of the antenna, with the majority of the antenna power ref ecting backward. Thus, the microwave power reaching the weevil ***larvae*** through the tree trunk is very small compared to the incident power.

III. Proposed Method of Detection of the Red Palm Weevil larvae using Wireless sensor Networks.

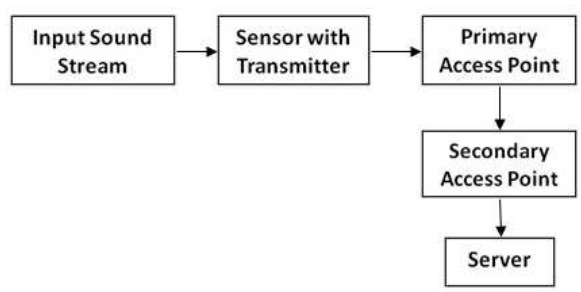

Fig. 3. Block diagram

The sensors along with communication module containing a transceiver attached to the trees are latched to the network of the access points nearby. Each access point receives the information from the eight palms in the vicinity of its radio range. The received information is routed to the server via the secondary access point that is wire connected to the server. The main server processes the received information to analyse the current scenario on the palm tree.

IJCSI International Journal of Computer Science Issues, Vol. 10, Issue 3, No 2, May 2013
ISSN (Print): 1694-0814 | ISSN (Online): 1694-0784
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A. *Transmitter*

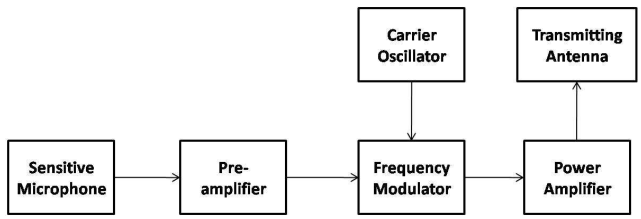

Fig. 4. Transmitter

The input sound signal is converted into equivalent electrical current/voltage by a microphone (transducer). The microphone output is amplif ed by a microphone pre-amplif er and frequency modulated (to travel longer distances). A Class C power amplif er is used to amplify the modulated signal and this amplif ed signal is radiated through the transmitting antenna using simplex mode of transmission.

1) Microphone: The sensitive transducer element of a microphone is called its element or capsule. A wireless microphone contains a radio transmitter. It transmits the audio as a radio rather than via a cable. It sends its signal using a small FM radio transmitter to a nearby receiver connected to the sound system, but can also use infra-red waves if the transmitter and receiver are within sight of each other.
An electret microphone is a type of capacitor microphone with a permanent charge in an electret material. An electret is a ferroelectric material that has been permanently electrically charged or polarized. A static charge is embedded in an electret by alignment of the static charges in the material, much the way a magnet is made by aligning the magnetic domains in a piece of iron. Due to their good performance and ease of manufacture, hence low cost, the vast majority of microphones made today are electret microphones. These often contain an integrated pre-amplif er.
An omnidirectional (or non directional) microphone's response is generally considered to be a perfect sphere in three dimensions. The smallest diameter microphone gives the best omnidirectional characteristics at high frequencies. Being pressure-sensitive they can also have a very f at low-frequency response down to 20Hz or below. Pressure-sensitive microphones also respond much less to wind noise and plosives than directional (velocity sensitive) microphones [6].

2) Preamplifier: A microphone pre-amplif er is a sound engineering device that prepares a microphone signal to be processed by other equipment. Microphone signals are normally too weak to be transmitted to units such as modulators and recording devices. Pre amplif ers increase a microphone signal to line-level (i.e. the level of signal strength required by such devices) by providing stable gain while preventing induced noise that would otherwise distort the signal.
The output voltage on a dynamic microphone may be very low, typically in the 0 to 100 microvolt range. A microphone pre-amplif er increases that level by up to 70 dB, to approximately 0 to 10 volts. A pre-amplif er might load the microphone with low impedance, forcing the microphone to work harder thus changing its output sound quality [7].

3) Frequency Modulator: In the modulation process, a varying current is produced when sound waves strike a microphone, the microphone output is then fed into the modulator circuit where the audio and carrier waves are combined. In the FM process, the alternating current (AC) from the microphone modulates the carrier wave by changing carrier waves frequency.
Indirect FM employs a varicap diode to impose a phase shift (which is voltage-controlled) in a tuned circuit that is fed with a plain carrier, termed phase modulation. The modulated signal from a phase-modulated stage can be understood with an FM receiver, but for good audio quality, the audio is applied to the phase modulation stage. The amount of modulation is referred to as the deviation, being the amount that the frequency of the carrier instantaneously deviates from the centre carrier frequency.

4) Power Amplifier: Class-C amplif ers are the most eff cient with a conduction range of about 120° and are non-linear in nature. They can only be used for non-AM modes, such as FM, CW, or RTTY. The semiconductor or vacuum tube conducts through less than half the RF cycle. The increase in eff ciency can allow a given vacuum tube to deliver more RF power than it could do so in class A or AB [8].

5) Antenna: The Folded dipole antenna is commonly used for the FM band. The tips of the antenna are folded back until they almost meet at the feed point, such that the antenna comprises one entire wavelength. This arrangement has a greater bandwidth than a standard half-wave dipole. If the conductor has a constant radius and cross-section, at resonance the input impedance is four times that of a half-wave dipole. Dipoles are generally more eff cient than whip antennas (quarter-wave monopoles). The total radiated power and the radiation resistance are twice that of a quarter-wave monopole [9].

B. *Radio repeater*

A radio repeater is a combination of a radio receiver and a radio transmitter that receives a weak or low-level signal and retransmits it at a higher level or higher power, so that the signal can cover longer distances without degradation.
The most basic repeater consists of an FM receiver on one frequency and an FM transmitter on another frequency usually in the same radio band, connected together so that when the receiver picks up a signal, the transmitter is keyed and rebroadcasts whatever is heard.

The simplex repeater uses a single transceiver and a short-duration voice recorder, which records whatever the receiver picks up for a set length of time (usually 30 seconds or less), then plays back the recording over the transmitter on the same frequency. A common name for a simplex repeater is ”parrot” repeater.

IV. Process

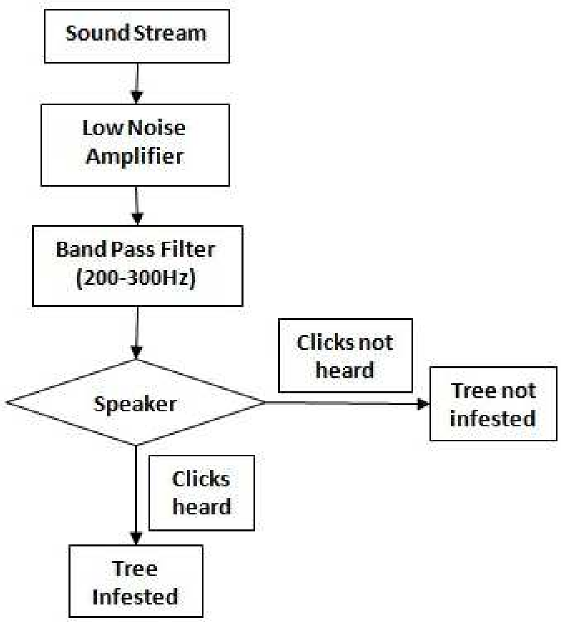

Fig. 5. Flowchart

Each tree is attached with the sensor apparatus. The sound stream is obtained from the tree through the microphone which acts as the node. As the first step of the recording process, a simple electronic device with considerable amplification but without any filtering was used. The recorded sound signals are continuously transmitted to the nearest access point (Repeater) from which it is sent to the server. The sounds were recorded and a MATLAB program was used to calculate the fundamental frequency of the sound. The Fundamental Frequency was found to be in the range of 200 to 300Hz which is taken as the pass band of the Band pass filter. The sound is amplified by a Low Noise amplifier. The recorded sound stream is imported to the Band Pass filter and we listen to the output of the Band Pass filter, which consists of only the clicks through speaker. If the clicks are heard, the tree is said to be infested, else the tree is not infested.
The above process is continued for all the trees in the plantation.

A. Decimation

Decimation is a technique for reducing the number of samples in a discrete-time signal. It is a two-step process: Low-pass anti-aliasing filter and Down sampling.
The frequency of the recorded sound can be down sampled by eliminating every other sample without changing the sampling rate. This will result in aliasing if the sound contains overtones whose frequency will exceed half the sampling rate. Decimation aliasing can be avoided by eliminating those overtones with a low pass filter before down sampling. The pass band frequency of the sound of the Red Palm weevil is between 200-300Hz. Hence, the sampling frequency of 11025Hz is sufficient. Therefore, an anti-aliasing filter is not required and the recorded sound can be directly down sampled by any factor to the required frequency. The original sound signal and the decimated signal are shown in Fig. 6 and 7 respectively.

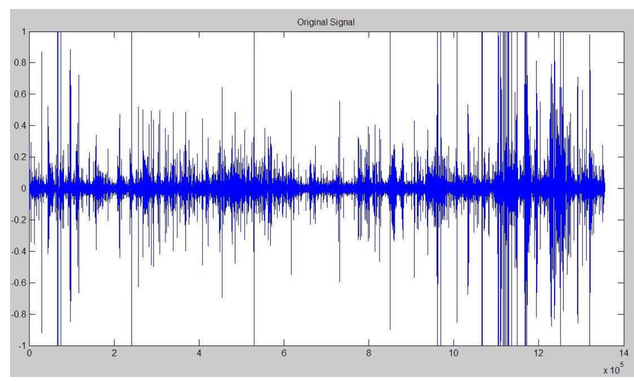

Fig. 6. Before decimation

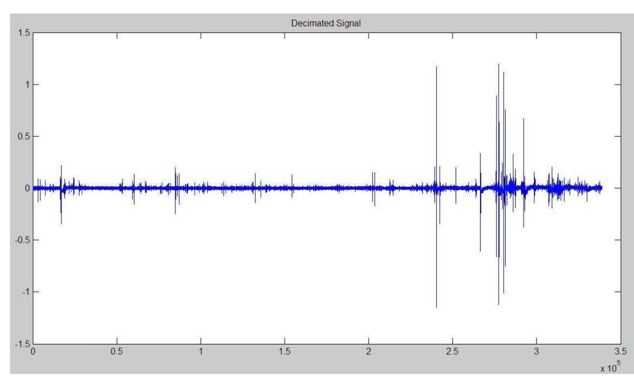

Fig. 7. After decimation

B. Filter Design

A Butterworth IIR filter is used to have a flat frequency response in the pass band. The Butterworth filter of order N, also called the maximally flat filter, is an approximation of the ideal filter, which the first 2N-1 derivatives of its magnitude squared are zero. As a result, the frequency response of this filter decreases monotonically with frequency. The decrease

IJCSI International Journal of Computer Science Issues, Vol. 10, Issue 3, No 2, May 2013
ISSN (Print): 1694-0814 | ISSN (Online): 1694-0784
www.IJCSI.org

is very slow in the pass band and quick in the stop band. In a design problem where no ripple is acceptable in pass band and stop band, Butterworth filter is a good choice. Both the signals can be visualized using the Signal Browser window in SPTool.
The Signal Browser is used to display and analyse signals listed in the Signals list box in SPTool. The Signal Browser can: Analyse and compare vector or array (matrix) signals, Zoom in on portions of signal data, Measure a variety of characteristics of signal data, Compare multiple signals, Play portions of signal data on audio hardware, Print signal plots.
The Magnitude and Phase response of the filter are shown in Fig. 8 and 9 respectively.

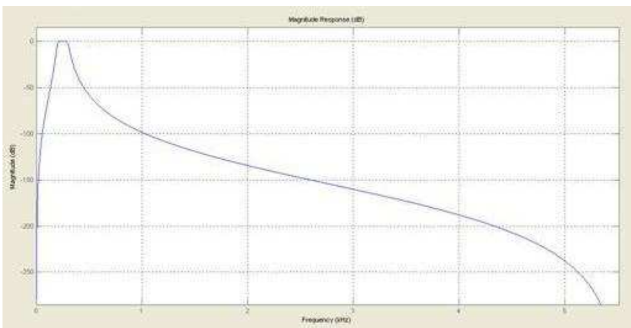

Fig. 8. Magnitude Response

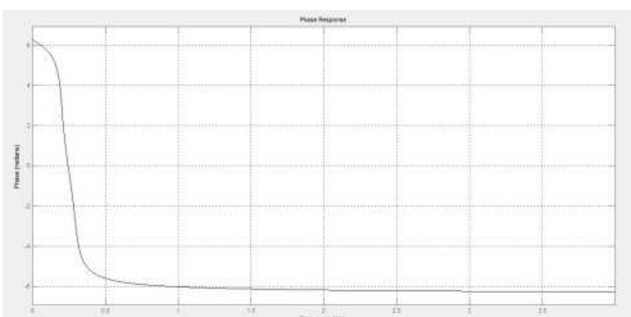

Fig. 9. Phase Response

C. Signal Processing Tool

SPTool is a graphical user interface (GUI) for analysing and manipulating digital signals, filters, and spectra (Fig. 10). SPTool is an interactive GUI for digital signal processing that can be used to Analyse signals, Design filters, Analyse (view) filters, Filter signals and Analyse signal spectra.
These tasks are accomplished using four GUIs that can be accessed from within SPTool: The Signal Browser is used to analyse signals. Portions of signals can be played using the computer's audio hardware. The Filter Designer is for designing or editing FIR and IIR digital filters. Most of the Signal Processing Toolbox filter design methods available at the command line are also available in the Filter Designer. Additionally, a filter can be designed by using the Pole/Zero Editor to graphically place poles and zeros on the z-plane. The Filter Viewer is for analysing filter characteristics and the Spectrum Viewer is used for spectral analysis while Signal Processing Toolbox provides spectral estimation methods to estimate the power spectral density of a signal.
Signals, filters, or spectra can be brought from the MATLAB workspace into the SPTool workspace using the Import item under the File menu. Signals, filters, or spectra that you create in (or import into) the SPTool workspace exist as MATLAB structures.

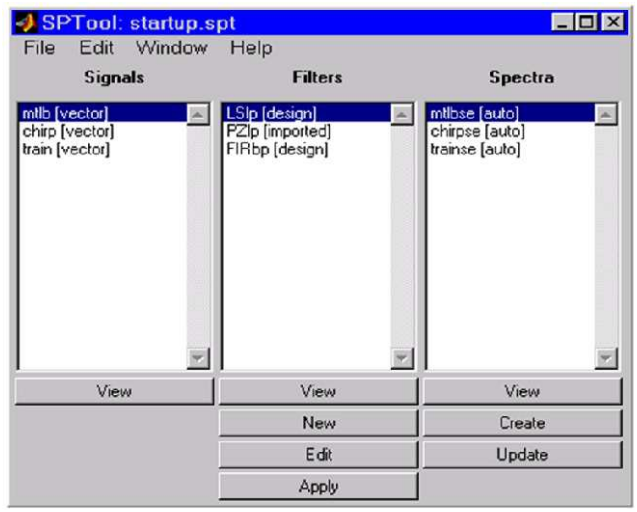

Fig. 10. Signal Processing Tool

The wav file is loaded into MATLAB using 'wavread' command. This is downsampled to reduce the data rate. In SPTool, in File menu 'Import' is selected (Fig. 11). 'Import as' is set to signal. Select from workspace and the name of the vector containing the sound data is selected and the data is imported. The sampling frequency is set from the workspace variables and imported. The View button is used for visualising the signals. Play button is selected in the toolbar to listen to the output.

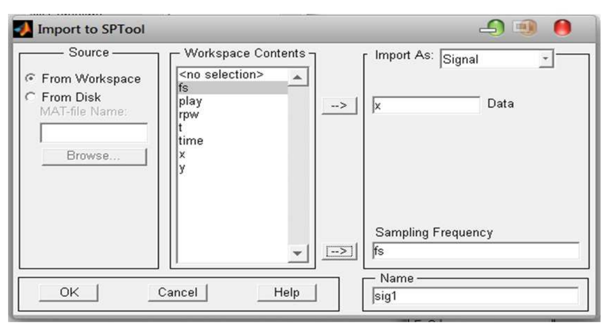

Fig. 11. Import Signal

D. Filtering

The recorded sound from the palm trees by the acoustic sensors consisted of surrounding environmental noise and noise due to weather disturbances. These are found to be at a wide range of frequencies. An efficient band pass filter is designed to eliminate all the other frequencies and retain the RPW ***larvae*** sounds. The band pass filter is designed for the fundamental frequency of the RPW ***larvae*** sound. The fundamental frequency of the RPW ***larvae*** is determined with a MATLAB program where we import the RPW ***larvae*** sound obtained from its natural environment. Three samples of RPW ***larvae*** sounds were obtained from the "United States Department of Agriculture - Agricultural Research Service (USDA-ARS)" website. The Fundamental frequency of the RPW ***larvae*** is found to be in the range of 200-300Hz by trial and error method. The Band pass filter of pass band 200-300Hz is designed using SPTool (Signal Processing Tool) which is part of the MATLABs signal processing toolbox. The first stop band frequency is given as 150Hz and the second stop band frequency is given as 350Hz. The pass band gain is set for 2dB and the stop band attenuation is set for 20dB with the sampling frequency set for 11025Hz.
The Unfiltered and filtered sound signals are shown in Fig. 12 and 13 respectively.

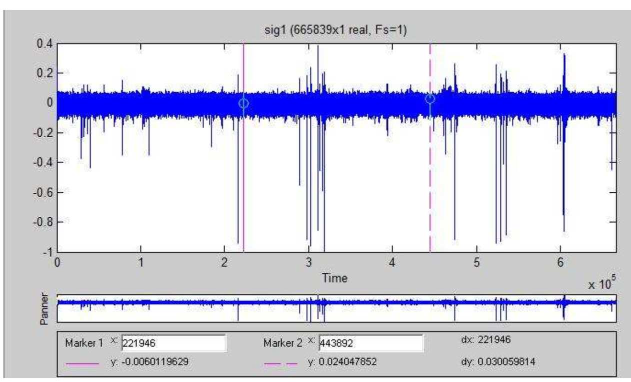

Fig. 12. Before Filtering

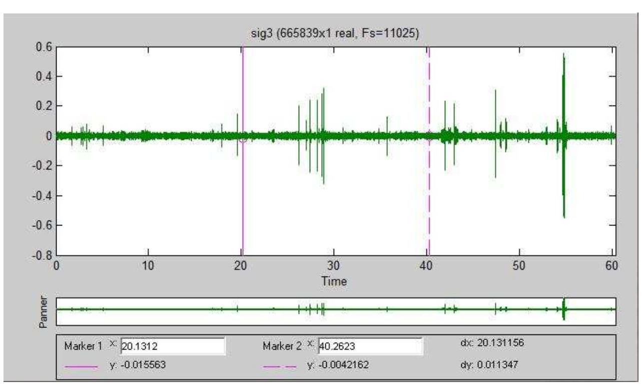

Fig. 13. After Filtering

V. Wireless Sensor Network

Network Simulator-2(NS-2) is a discrete event simulator targeted at networking research. NS provides substantial support for simulation of TCP, routing, and multicast protocols over wired and wireless (local and satellite) networks. NS-2 was built in C++ and provides a simulation interface through OTcl, an object-oriented dialect of Tcl. The user describes a network topology by writing OTcl scripts, and then the main NS-2 program simulates that topology with specified parameters. It runs on Linux, FreeBSD, Solaris, Mac OS X and on Windows using Cygwin.

A. Experimantal Scenario

1) Basic Model Configuration: The nodes are positioned for palm trees in the Star Topology(Fig. 14). All nodes of the star topology are connected to a single hub node (Access Point). The hub requires greater message handling, routing, and decision-making capabilities than the other nodes. In case a communication link is cut, it only affects one node but if the hub is incapacitated the network is destroyed.

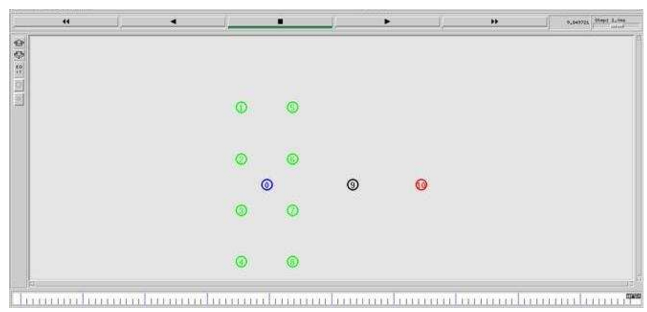

Fig. 14. Topology of the Wireless Network

2) Experimental Analysis and Results: A TCL program is written to simulate the wireless network scenario in NS-2 and the topology for the required network is defined. The wireless simulation related parameters are defined as follows: Channel Type-Wireless, Radio-propagation model-TwoRayGround, Network interface type-WirelessPhy, MAC type-Mac/802_11, Interface queue type-Queue/DropTail/PriQueue, Link layer type-LL, Antenna model-Antenna/OmniAntenna, Max packet in ifq-50, Number of mobilenodes-11 and Routing protocol-AODV.
A new simulator is created along with the trace and nam files. The wireless nodes are initialised and their co-ordinates are set and the events(start and stop times) for each node are scheduled. The simulation is run using the Network Animator(nam) file. Nodes 1 to 8 are the transmitters present in the coconut palms. The sound signals from each node(nodes 1 to 8) are sent to the Primary Access point (node 0) situated at the centre of the topology. These are then forwarded to the Secondary Access point (node 9) and received at the Server (node 10). The above processes are

shown in Fig. 15, 16 and 17.

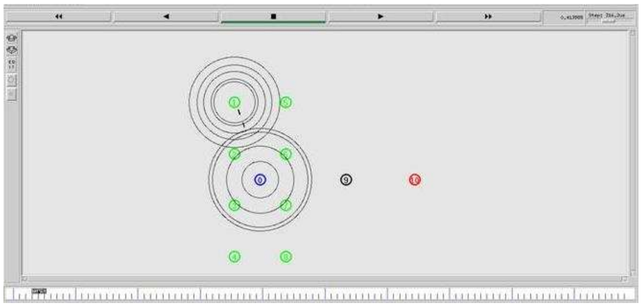

Fig. 15. Signal Transmission from Nodes to Primary Access Point

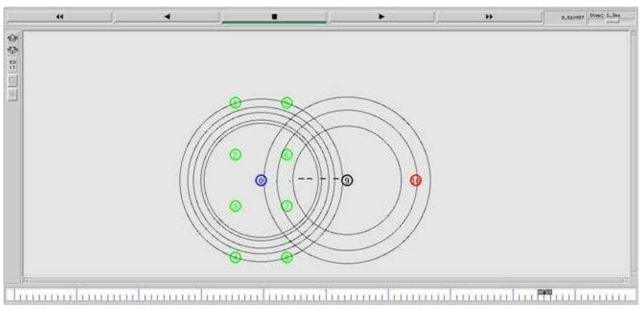

Fig. 16. Signal Transmission from Primary Access Point to Secondary Access Point

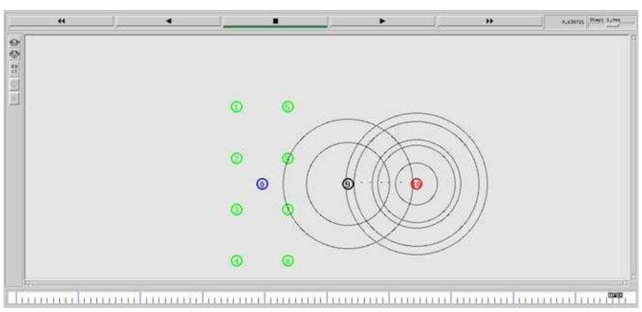

Fig. 17. Signal Transmission from Secondary Access Point to the Server

B. Routing

Routing Schemes include Fixed routing schemes and Adaptive routing schemes. The Destination-Sequenced Distance-Vector Routing (DSDV) protocol is a Fixed routing scheme which uses Routing Tables that dictate the next node to be routed to, given the current message location and the destination node. Routing tables can be very large for large networks, and cannot take into account real-time effects such as failed links, nodes with backed up queues, or congested links. The Ad hoc On-Demand Distance Vector (AODV) Routing protocol is an Adaptive routing scheme which depends on the current network status and can take into account various performance measures, including cost of transmission over a given link, congestion of a given link, reliability of a path, and time of transmission. It can also account for link or node failures. Hence, AODV protocol is implemented for the routing in the palm tree network.

The Media Access Control (MAC) data communication protocol sub-layer of type Mac/802_11 is used. It is a sublayer of the Data Link Layer specified in the seven-layer OSI model, and in the four-layer TCP/IP model. It provides addressing and channel access control mechanisms that make it possible for several terminals or network nodes to communicate within a multiple access network that incorporates a shared medium. The hardware that implements the MAC is referred to as a Medium Access Controller.

VI. CONCLUSION

This study indicates that damage to palm plantations can be prevented by determining the presence of Red Palm weevil ***larvae*** by using acoustic instruments, signal processing tools and wireless sensor networks. The sharp clicking sounds made by the weevil are extracted from the recorded sounds using band pass filters. The sensor network for every array of 8 trees is set up at different heights on each tree so that infestation in any part of the tree can be detected efficiently. It uses wireless sensors which capture the weevil sounds even in a noisy environment and helps in the detection of ***larvae***(grubs) thus managing to stop the life cycle before it forms the cocoon of RPW. This is comparatively much efficient than other traditional methods like bucket traps, acoustic detection in isolated environment and microwave irradiation which are being followed.

Concerning the RPW ***larvae***, the data on its diurnal activity patterns is insufficient, such as eating and resting cycles. Even the recorded sound for an entire day may not contain the click sounds. Therefore, each tree has to be monitored on a daily basis.

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Biography

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