Abstract—Wireless sensor networks are promising to be more efficient in forest area surveillance compared to the traditional way of using watch towers. We propose a forest monitoring system based on WSNs and long dated in-depth researches of Canadian Forest Service, known as Fire Weather Index (FWI).

Our design consists of wireless sensor nodes distributed over a targeted area, a centralized monitoring tool and an adaptive fire prediction and detection algorithm. The initial version of the algorithm is developed by integrating fire spread data gathered from the FARSITE simulator and TOSSIM platform running WSN nodes on a grid topology.

Index Terms—FARSITE, FWI, Tmote Sky, Wildfires, WSN.

I. INTRODUCTION AND MOTIVATION

A. Fire Basics

The need to quantify the forest fire danger has led the Canadian Forest Service to initiate comprehensive researches in 1920’s and since then the findings from these researches have emerged into Canadian Forest Fire Danger Rating System (CFFDRS), which has been implemented fully in other countries like the USA and New Zealand [1].

The basic component of this system is the Fire Weather Index (FWI) and this index is evaluated through fire critical weather elements such as temperature, relative humidity, wind speed and precipitation and thus holds the codes for danger ratings of different purposes. Its main component Fine Fuel Moisture Code (FFMC) shows the relative ease of human caused ignition. Duff Moisture Code (DMC) stands for by lightning caused ignition probability. The Drought Code (DC) represents the amount of moisture in deep organic matter and is combined with DMC to calculate Buildup Index (BUI) which is an indicator of fire resistance in deep organic matter. Initial Spread Index (ISI) on the other hand is an indicator of fire spread rate ignoring the fuel quantity. Lastly, the FWI itself is a combination of ISI and BUI representing fire intensity. The structure of the FWI model is given in Figure 1.

The FFMC related to ignition probability and the appropriate danger levels are shown in Figure 2.a and Figure 2.b[4].

All of the FWI codes are calculated initially from the aforementioned weather observations recorded at noon standard local time [2]. The forest fire danger level quantified by the FWI and the ignition probability quantified by the FFMC are used for fire prediction and detection. In this study, we mainly focus on the adaptation of this system to WSNs.

B. Aim and Related Work

Adapting WSNs to fire monitoring has been mentioned in several studies [3][4][5]. The Firebug is the first real testbed merely for monitoring the fire spread in short grass [3]. The authors of [4] concern about the theory of power efficient monitoring of the targeted area. Finally, in [5], the authors focus on formulating FWI for a specific case, the mountains of Southern Korea. In the light of all these studies, we aim to implement a system which enables us to monitor forests using
WSNs. Here, our primary goal is to integrate CFFDRS into our system to predict forest fires with a high confidence. In this study, the adaptability of the system to varying environmental conditions, such as day and night time temperature and humidity values, and seasonal factors, has also great importance.

II. ARCHITECTURE AND DESIGN

A. Structure of the system

We give the details of our system in Figure 3. We assume that the WSN nodes are deployed into a forest area in a random fashion. All sensor readings are collected at a sink node which transmits these data to the monitoring and fire prediction and detection tool for further evaluation. This tool also integrates a dedicated database. Additional data required by the FWI, FFMC calculations are provided by a connection to the national meteorological service. Whenever the fire prediction tool detects a fire risk, it alarms the fire authorities. The fire officers can access the most recent information about the intensity and spread of fire by using their PDAs which are connected to the monitoring and prediction tool. Here, the number of false alarms should be reduced as much as possible, since they significantly reduce the lifetime of WSNs.

B. Simulation

Testing a fire prediction algorithm on a real testbed is a very dangerous and tedious task. Even for a controlled burn of a small area, the national ministry of forestry should be contacted and several bureaucratic steps should be taken. Therefore, in this study we focus on the simulation of a forest fire, instead. We chose a detailed fire simulator which integrates Rothermel fire spreading model, the FARSITE. This simulator simulates surface and crown fire, spotting, post-frontal combustion, and fire acceleration in 3-dimensions. It also takes various fuel types, wind velocity and diurnal conditions into consideration, as well [6]

This step is accomplished by combining FARSITE with sensor network. We replace node readings with the outputs of the fire simulator generated at the best possible approximate terrain layout. The sensor nodes run our querying application by using TOSSIM (TinyOS SIMulator) platform [7]. Data collected from the FARSITE simulator can either be temperature (computed through energy release rate), carbon monoxide, carbon dioxide or methane release rates. The humidity readings are generated by the help of [3][10]. The sensor data is queried with SQS (SeMA [8] Scalable Querying Protocol for Micro-Sensors [8][9]) and given into the fire prediction and detection algorithm as an input.

C. Fire Prediction and Detection Algorithm

Figure 4 depicts the algorithm running a state machine with three different fire risk states:

1) Green State: This is the lowest risk level for a possible fire danger. In this initial level, the sensor node sensing periods are longer compared to other levels.
2) Yellow State: This is the medium risk level. This state may have transitions to either Green or Red state.
3) Red State: This is the highest risk level. The algorithm can initiate a fire alarm only on this state.

The details of the algorithm are given as follows:
• $P = P_3, T[] = [\text{new readings}], \text{Calculate FFMC.}$

• $(\text{FFMC} \geq \text{FFMC}_0) \text{ v } (\exists T \geq \text{Tnormal} + C) \Rightarrow P = P_2 \Rightarrow P_2 < P_3 \text{ [Enter Yellow State]},$  

$\text{TGmax} = \max(T[]), \text{Tgreen} = \text{average}(T[]).$

• $\text{Time } t = P \rightarrow T[] = [\text{new readings}],$  

$\text{TYmax} = \max(T[]),$  

$(\exists T \geq \text{TGmax} + C) \Rightarrow P = P_1. \text{ [Enter Red State]},$  

$(\forall T < \text{Tgreen}) \Rightarrow P = P_3. \text{ [Back to Green State]},$  

$\text{Tyellow} = \text{average}(T[]).$

• $t = P \rightarrow T[] = [\text{new readings}],$  

$(\forall T < \text{Tyellow}) \Rightarrow P = P_2. \text{ [Back to Yellow State]},$  

$(\exists T \geq \text{TYmax} + C) \Rightarrow \text{ALARM}.$

Here, Tnormal stands for the seasonal average temperature and FFMC_0 represents the threshold for the danger level in FFMC table (Figure 2b).

The algorithm is expected to be adaptive since each FFMC calculation depends on the previous FFMC value. Average values are updated at each data collection step, and the sensing periods are chosen according to the instant FWI values, which indicate the spread rate of a potential fire.

III. TESTS AND INITIAL RESULTS

In initial tests, we studied fixed topologies with a small number of sensor nodes. Due to space restrictions, here, we present the results of a single test case.

![Figure 5. Node formation on FARSITE simulator. The firefront is approaching node 14.](image)

In this test, a short grass area has been chosen on FARSITE simulator. The nodes were assumed to be located on this area on a 5x3 grid topology as depicted on Figure 5. Each node is 30 m apart from their non-diagonal neighbors on the simulation area. Total test duration is 73 min. with query frequency of 1 min. The confidence value is apt to change but it is assumed to be 50°C in this study.

During the test, node 14 was the first to be hit by the spreading fire (9 min. after the start) followed by node 13, 3 min. later. The order of the burnings and the magnitudes of each can be seen in Figure 6. For this test, the periods P1, P2 and P3 were chosen to be 3, 5 and 10 min. respectively.

![Figure 6. Observed arrival time to the sensor nodes placed in the direction of the spreading fire.](image)

IV. CONCLUSION FUTURE WORK

Natural processes are highly complex and thus not easily predictable. Therefore, our work has to be tested against real conditions through medium scale test beds and real monitoring tests of small forest areas. We have already developed a visualization tool supporting real time and offline queries from a database archive. The work will progress by deploying up to 60 Tmote-sky nodes in a controllable forest of about 1 km square area in summer 2008 and integrating the testbed to the visualization tool. Through this outdoor testbed we aim to observe the following: scalability of the fire detection algorithm according to minimized false alarm and success rate requirements, energy consumption rates for different adjustments to the algorithm and system tolerance to multi hop network deficiencies due to environmental and channel conditions.

REFERENCES


