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Smart System for Forest Fire Using Sensor Network

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Abstract

Wireless sensor network systems deploy a dense array of small, low-cost sensors that observe the local environment. The system can be deployed anywhere, even in inaccessible places. This technology can provide real time monitoring for forest fires. Ignition can be determined rapidly, depending on the wake/sleep schedule of the system nodes. This study investigates the coverage and fire detection ability of a wireless network system. Sub-networks in randomly-distributed nodes convert the network from being randomly distributed to being organised, and reduce the operation time and energy consumption of each node. Dividing the network into three sub-networks increases network battery lifetime by 2.7% and increases energy performance by 63% compared to conventional fire detection networks. The proposed network only requires each node to be equipped with a cheap temperature sensor. Analysis of data from multiple sensors can indicate not only the presence of a fire, but also its intensity, behaviour and direction of spread, which can greatly assist firefighting efforts.

***Keywords**: Wireless Sensor Network, WSN, Wireless Sensor Network Coverage (WSN), energy efficient coverage method, Wireless Sensor Network for Forest Fire Detection and Decision Making*

1. Introduction

Forests play important roles in global, ecological, environmental and recreational systems. They greatly affect the amount of greenhouse gases and atmospheric carbon absorption, and reduce soil erosion. They can moderate temperature and regulate rainfall. To a large extent, forest fires are among the most dangerous natural accidents and occur in practically all countries. Forest fires are a dominant disturbance factor in almost all forest vegetation zones throughout the world, and it are considered to be a potential hazard with physical, biological and environmental consequences.

Unfortunately, forest fires are usually observed only when they have already spread over a large area, making its control and stoppage arduous, and sometimes impossible. The result is a devastating loss of lives (of fire-fighter crewmen and others) and property (valuable forest foliage and resources as well as clusters of houses and other buildings in the outlying areas).

The problem with forest fires is that forests are usually remote, unmanaged areas full of trees, and dry wood and leaf litter that act as fuel sources. These elements are highly combustible materials and represent the perfect context for fires. Fire ignition can be caused by human actions like smoking or barbeques, or by natural causes such as high temperatures on a summer's day. Once ignition starts, then the combustible materials may easily fuel the fire. The fire then becomes bigger and wider. The initial stage of ignition is normally referred to as the 'surface fire' stage. This may then spread to adjoining trees, allowing the fire's flames to become higher and higher, thus becoming a 'crown fire'. It is mostly at this stage that the fire becomes uncontrollable. A common rule-of-thumb for

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fire response is: wait 1 minute, use 1 cup of water; wait 2 minutes, use 100 litres of water; wait 10 minutes, use 1000 litres of water. The main aim can simply presented by Figure1:

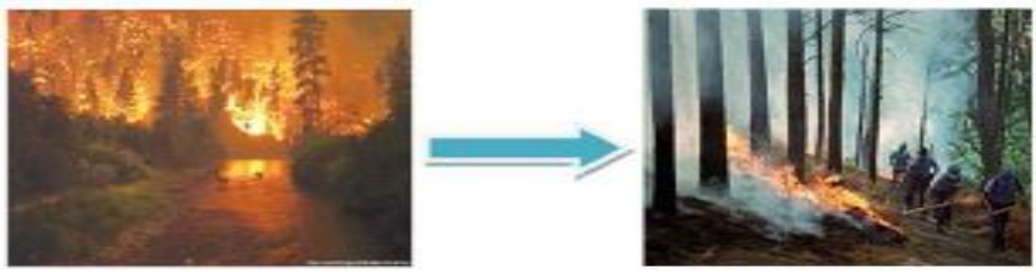

Figure 1. System Aim

2. Coverage.

'Coverage' can be roughly defined as how well a sensor network monitors a certain field of interest, and its corresponding Quality of Service (QoS). Coverage encompasses the need for connectivity— nodes should be able to communicate with other nodes in the network and reach the network sink.

Wireless sensor network coverage can generally be divided into two types: static and dynamic. Static coverage uses fixed nodes which are usually deployed in a predefined shape. An efficient static coverage must provide an overlap between each node's coverage range and those of adjacent nodes. To ensure high quality coverage in various environmental applications, the K-coverage method has been developed. In dynamic coverage, some or all nodes have the ability to move. The method is used when optimal deployment can't be determined due to an uncertain environment. Nodes are deployed by random placement such as air-dropping sensors from aircraft. Random deployment does not provide effective coverage and required more complicated algorithms. To address the lack of effectiveness in coverage, various methods have been developed. The virtual force algorithm (VFA) is an algorithm for optimising sensor deployment to enhance coverage after the initial random placement [1]. Dynamic coverage is popular in military applications.

3. Work Related to Coverage

3.1 Broadcast Communication

Broadcast communication is very convenient in forest fire detection applications. It ensures that messages will be received by many nodes and broadcasted again, enabling messages to following different paths to reach the sink. In order to prevent nodes from re-broadcasting the same or repeated messages, each node will check if the message ID saved in the buffer is unique before re-broadcasting. This function is part of the routing protocol AODV (Ad hoc On-Demand Distance Vector Routing, which establishes connection only on demand) and reduces resource consumption such as power, processing, traffic and collisions, etc.[2] Broadcast communication shall be used in the study to save energy in the network and to ensure signal delivery from the nodes to the sink.

3.2 Random Node Distribution Network Coverage

A simulated GUI shall be used in the study to simulate coverage. Coverage depends on the nodes' deployment density and node distribution. Since node distribution is random, a high coverage QoS is difficult to obtain initially, but depending on the localisation method results, a GUI can be created help identify coverage gaps. Then, those gaps can be filled by redistributing nodes randomly or with flying sensors. The GUI can also help with tracking network events such as node failures, battery exhaustion, coverage gaps and forest fires.

3.3 Methods and Studies in Overcoming Coverage Problems

Various methods and studies were done in order to overcome shortcomings of the *K*-coverage method. This method employs at least *K* nodes to cover the area of interest, where *K* is a predefined number that varies according to the application. Ammari and Das [3] proved that the connectivity of a *K*-covered network is higher than a 1-covered network and introduced different network connectivity measures for both homogeneous and heterogeneous WSNs (homogeneity refers to the similarity of node types).

- **Conversion from 3D to a 2D space:** Huang et al. [4] proposed a method for overcoming 3D coverage problems by converting data from a 3D space to a 2D space. They created a polynomial time algorithm to check whether all locations in a field are *K*-covered or not.
- **Exposure-based models:** Adlakha and Srivastava [5] used an exposure-based model to determine the number of sensors required to achieve full coverage of a region.
- **Directional coverage:** Ai and Abouzeid [6] introduced a directional WSN coverage system using directional sensors, with coverage depending on the sensor orientation. Du and Lin [7] proposed a differentiated coverage system for WSNs, where network areas may have different degrees of sensing coverage.
- **Adjustments for mobile WSNs:** Cortes et al. [8] proposed that asynchronous coverage algorithms can be adapted to mobile WSNs. Zhang and Hou [9] proposed a distributed algorithm to keep a small number of active sensors regardless of the relationship between communication and sensing ranges.
- **Power consumption efficiency:** Li et al. [10] introduced efficient distributed algorithms to provide the best coverage with minimum power consumption.

3.4 Sensing Range and Communication Range

Sensing range and communication range are different concepts- see figure 2. Sensing range is the range at which the device can sense the events that it is designed for Communication Range is the range at which two nodes can communicate with each other.

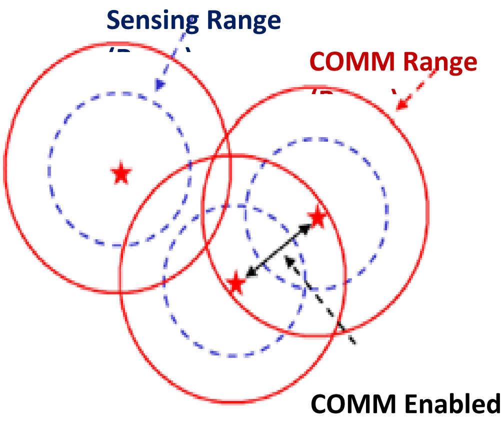

Figure 2. Sensing Range and Communication Range

Nodes capable of communicating over a few hundred meters include Libelium-Waspmote. Nodes can communicate from 500 m (XBee 802.15.4) to 12 km [11]. Sensing range can vary from less than 1 m up to 80 km in very advanced and expensive sensors such as FireWatch.

The importance of sensing range and communication range vary according to the application. Sensor range is very important in forest fire detection because it plays a major role in determining the distance between nodes and node density. Sensing range is always much lower than communication range; in order to detect fire within a short time after ignition, sensing coverage must have only small gaps. This condition leads to the limit of the distance between sensors due to the sensing range distance. Using large sensing range nodes, on the other hand, might lead to reduced accuracy and increases detection times. Small distance sensing ranges can be more accurate and produce less delay. Small distance sensors are deployed at distances that are a little bit larger than their sensing range, where it is acceptable to have small sensing gaps between nodes.

4. Coverage Method

4.1Wireless Sensor Network System

In order to provide accurate sensing and reliable service, the nodes have to be separated by a reasonable distance. The sensors to be used in the research are only able to sense temperature in the surrounding environment, so the communication range has to be limited to a small range of around 30 to 50 metres. Although this distance will create gaps in the sensing range, it will still provide reasonable sensing of the environment. A 50-node network on NS2 is assumed to be existent and is the system that was analysed in the present study. Node locations were already known in the assumed network. Local information was used on the GUI to represent each sensor.

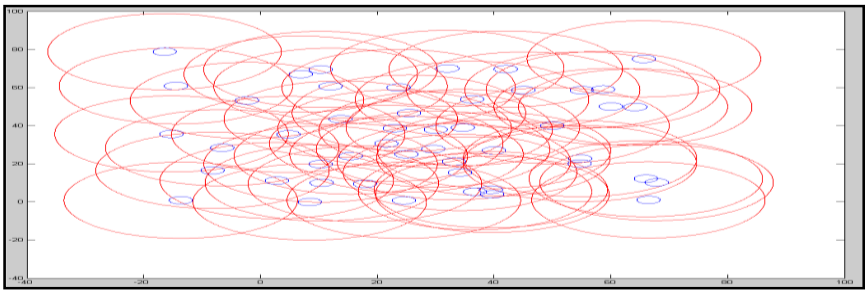

Figure 3. Assumed System for the Study

5.2. Advantages of the Assumed System

The main advantages of this coverage method are as follows:

- Resources are saved through a special deployment scheme, and energy consumption is reduced
- Nodes are distributed randomly, but deployment through the use of location information and sub-network techniques convert the network to organised deployment
- Increased network life span
- Node connectivity is guaranteed
- Sensing coverage is guaranteed
- The operator is easily informed of any changes, gaps, movements or failures

These advantages can be achieved by dividing the network into a number of sub-networks according to node position. In the present study, analysis is limited to division of the network into three sub-networks.

A sub-network shall be turned on every 10 minutes. Thus, this method allows each sub-system, instead of all nodes, to be turned on every 10 minutes for 30 seconds, to sense the environment and then go back to sleep. In the next 10 minutes, the second sub-network wakes up, and so on. Instead of making all nodes wake up three times for 90 seconds in total every 30 minutes, sub-networks 1, 2, and 3 work for 30 seconds every 30 minutes. Overall, all nodes wake up for 30 seconds every 30 minutes.

Through this method fewer nodes are deployed, less traffic is present in the network, and the resources are fully utilised. This method is tested in NS2 and applied in three stages:

1. The network is divided into three sub-networks according to their distances from the node (R), where:
   - Sub-network 1 is composed of nodes located between $(0 + 15n) \leq R < (5 + 15n)$
   - Sub-network 2 is composed of nodes located between $(5 + 15n) \leq R < (10 + 15n)$
   - Sub-network 3 is composed of nodes located between $(10 + 15n) \leq R < (15 + 15n)$

   Where n = {0, 1, 2 ….. [a + 15n ≤ (distance from sink to the edge of coverage area)]}

2. Each node has to check if there is at least one node in the communication range, even when required to borrow from another sub-network. The communication range in the simulator is reduced to 20 meters to make sure most of the nodes have more than one connection.

3. To make sure that we have full connectivity between nodes, the check partner function is created to ensure each node in the sub-network has at least one connection. Otherwise, an appropriate node from another sub-network is selected and used as a partner. The solution is to borrow nodes from other sub-networks and to keep the power balanced in the network. The sub-network keeps a list of all nodes that can be borrowed (alternative candidates) from other networks to cover its gaps. Every time the sub-network wakes up, it uses a different alternative node.

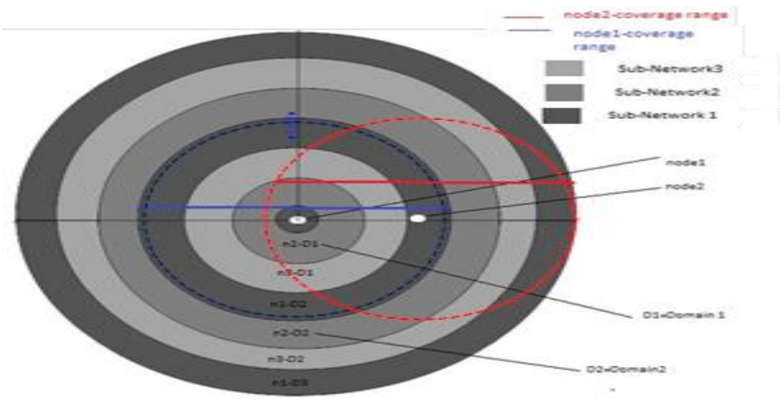

Figure 4. Sub-networks Method

4. Using the location & sub-networks information in GUI to define the gaps, the communication range circles presented in the following pictures.

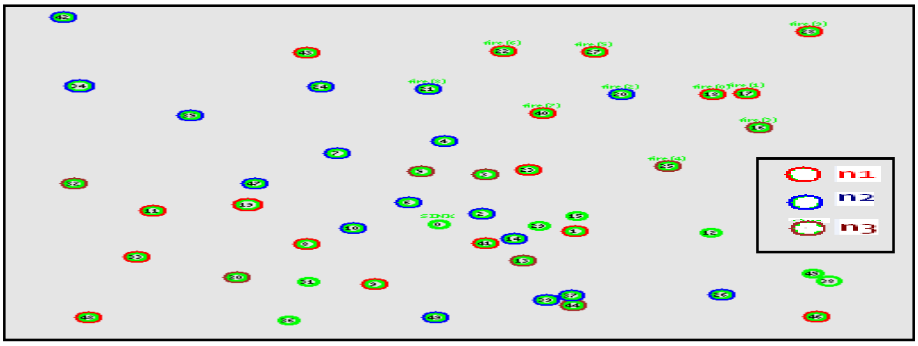

Figure 5. Nodes identified through their Sub-network in Nam

By applying the sub-network method, the network will have more coverage gaps as appears in the following table. The sub-network techniques applied on 50 nodes used in this research, the results show that the randomly distributed nodes helped in providing more distributed coverage and more connectivity with other nodes. The resulting network, with the distinguished sub-networks, is shown in Figure 5. The program Nam was used to clearly identify the network through its GUI. Figure 6 shows the gaps in the network. Figure 7 on the other hand, shows the flowchart of procedures employed for the process.

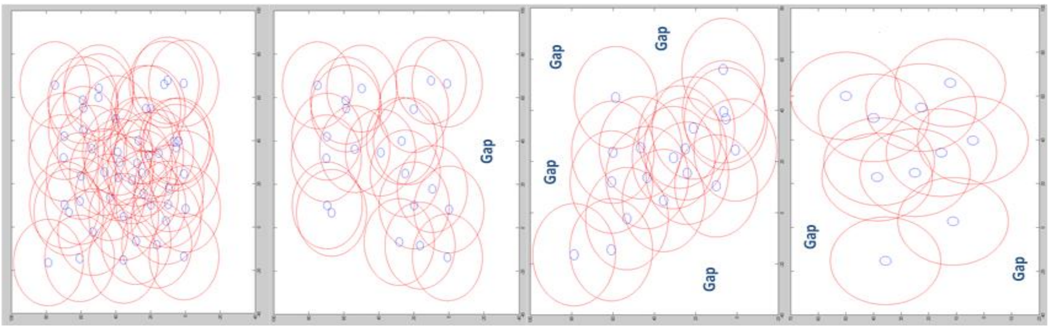

Figure 6. Sub-networks and Gaps as Drawn in Nam

As it appears from Figure. 6 and 7, connectivity is guaranteed by the checking for a partner procedure. The problem of coverage gaps can be solved in three ways:

- A new sensor is sent to these areas.
- The GUI checks if the sensors from other sub-networks can cover these areas, so they become a part of two sub-networks, with the same method of using alternative nodes. If those gaps are reasonable then no action needs to be taken, because those small areas can be covered by the next sensing period of other sub-networks. If not, either a new node has to be placed in this area if it is critical for the network. An example of these critical areas include mountains, where fire spreads rapidly over inclined slopes. Gaps in non-critical areas can be ignored for a short while because if a fire starts in a gap area, the fire will become large enough in a short time and be noticed by one of the neighbour nodes. The operator's judgment will still be essential.

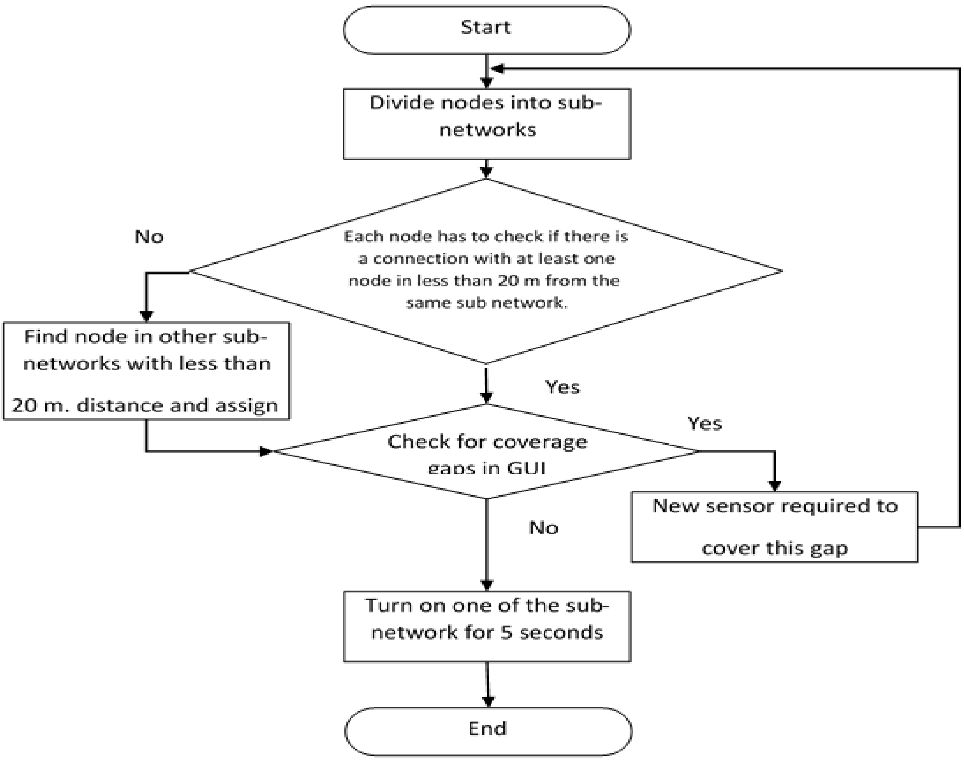

Figure 7. Coverage Connectivity and Gaps Check Flowchart

- The third option is the most suitable and cheapest way because the coverage gap has been checked in the first place as all nodes are part of one big network. If there is a coverage gap that won't be covered by any sub-network, later action has to be taken. On the contrary, if there are no gaps in the mother network and then gaps start to appear in sub-networks, it means that this area will be covered later by another sub-network. If the coverage area considered between (-20,70) in both X&Y so the coverage percentages of the total targeted coverage area is as shown in Table 1.

Table 1. Sub-network Coverage Result

	Coverage%	Number of Deployed Nodes
Full Network	**100%**	**50**
Sub1	**96%**	**21**
Sub2	**92%**	**18**
Sub3	**91%**	**10**

This method expands the network life span by 2.7 times and energy savings will also be increased. It is important to note that randomly-spread nodes can provide more coverage with fewer nodes. The less coverage gaps in the network, the more connectivity that the nodes will have.

The wake up/sleep schedule can affect the network life span and fire detection delay, which can add up to what is already caused by sub-network coverage. It can be changed according to environmental issues. For example, in a camping area in summer it might be every 5 minutes during the day and every 10 minutes at night. Otherwise, it could be every 15 minutes or more. In winter, the network could wake up every 30 minutes. The wake up/sleep schedule is dependent on the weather conditions, the area, and the history of fires in the area. Evaluation of this method using the coverage evaluation parameters mentioned before are shown in Table2.

5. Fire Detection and Decision Making

A WSN can monitor forest fires by using cameras or gas boards to observe fire glow, CO_2 levels, sounds and many other parameters. Gathering large amounts of data can increase power consumption and it may be difficult to make a decision based on the data.

The proposed technique is based on temperature sensor readings and network behaviour, instead of using extra sensors or parts added to the node. Fire propagation will reflect on the randomly-distributed nodes, which can help with decision-making of a potential wild fire or a camping or even a sunny day.

5.1 Previous Work

These previous studies can be summarised into four methods:

- The early methods were based on manned observation towers but this technique was inefficient and not entirely effective.
- Camera surveillance systems were tried, but this also proved an ineffective method for fire detection, due to the need for manual instalment of each camera in an appropriate position. There were problems with line-of-sight images, especially at night and in bad weather.
- Satellite images gathered by two satellites,[12] the advanced very high resolution radiometer (AVHRR), launched in 1998 and the moderate resolution imaging Spectroradiometer (MODIS), launched in 1999. These satellites can provide images of the regions of the earth every two days. However, this is a long delay for fire scanning, plus the quality of satellite images can be affected by the weather conditions. It is impossible to deploy satellites to monitor all forests all the time.
- Finally, WSN started to be considered as a partial solution, where it is combined with other technologies such as IP cameras, and weather and fuel databases.

A number of studies have considered using WSN in wood fire systems. Doolin et al. [13] experimented with 10 sensors equipped with a GPS device that sensed temperature, humidity and pressure, and sent data back to a sink. The problem with this system was that the distance between sensors was too far (approximately 1 km). In case of node failure, a connection between some sensors and the sink could be lost, leaving a gap in network coverage. Lloret *et al.*, [14] suggested deploying a mesh network of sensors equipped with internet protocol (IP) cameras.

Son [15] proposed a project for fire detection in South Korea using camera surveillance with WSN. They proposed a clustered topology for the network. Each cluster had a head node to do some calculations to estimate the fire risk level by measuring temperature, humidity and other parameters. In addition, there were routing and data aggregation tasks included in their algorithm. In this method there is an increase in the power consumption at each head node. Besides, they did not consider the power balancing issue, which may result in some sensors deactivating before others, thus leading to coverage gaps. Hafeeda *et al.*, [16] presented a very smart system. They based their network action on a fire weather index (FWI). This index includes the probability of fire ignition and fire spread rate. The FWI provides the moisture content in relation to weather observations and a fuel code describing the soil content of forest ground.

5.2 Background on Forest Fire Behaviour

Fire can be defined as: "*Combustion is a complex process in which fuel is heated, ignites, and oxidizes rapidly, giving off heat in the process. Fire is a special case of combustion—self-perpetuating combustion characterized by the emission of heat and accompanied by flame and/or smoke. With fire, the supply of combustible fuel is controlled by heat given off during combustion "[17].*

Maintaining fire requires three factors to be present. If any one factor is missing, the fire will go out. There must be a source of fuel available for combustion, a source of heat to promote the reaction (the fire itself), and oxygen in sufficient concentration to maintain the reaction[18].

A wildfire burning in constant environment takes the shape of an ellipse. The fire environment can be variable within time once a fire grows beyond the ignition area. A fire might have different parts burning in different environments, due to the wind direction, slope, moisture content of fuel, wind speed, etc. This heterogeneity of fire environments can result in a very complex fire shapes, even if each part of the fire spreads in an elliptical shape [19, 17]. The different parts of a fire are (Figure 8): [17]

- A *finger* is a long, narrow extension of the main body of fire.
- A *pocket* is an unburned indentation of the fire perimeter surrounded on three sides by fire.
- An *island* is an unburned area within a fire that is wholly surrounded by burned area.
- A *spot fire* is a fire ignited outside the main fire by a firebrand

Figure 8. Fire Different Parts [17]

These parts can occur at many different scales. For example, a finger can be a few feet or more than a mile. The fire might have fingers on fingers and spot fires from spot fires.

Since the fire shape under a constant environment is elliptical, the long axis of the ellipse is the *direction of the maximum fire spread*, as shown in figure 9. The *relative spread direction* is the angle between the flame front orientation and the direction of maximum spread, measured in degrees clockwise from the direction of maximum spread [18,17].

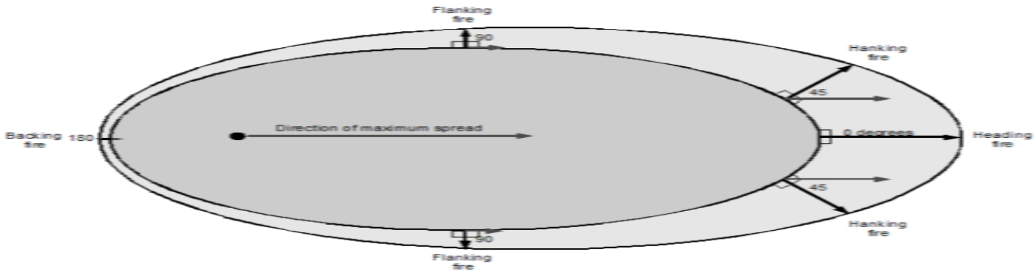

Figure 9. Wildfire Spread under Constant Environment [17]

In a heterogeneous fire environment, the direction of maximum spread can be different in the various areas of the fire. Each area has its own environment and, therefore, its own direction of maximum spread. But no matter how complex a fire is, by examining the orientation of the flaming fire front with respect to the direction of maximum spread (heading direction; shown by arrow), wildfire morphology by relative spread direction can be related to fire shape [19, 17].

Three main regimes of fire propagation are: ground fire, surface fire and crown fire. Forests are the perfect fire environment, typical its shrubs and small trees create a low canopy base height which commonly initiates crown fires. A crown fire occurs when a surface fire grows vertically and reaches the tree crowns, see figure 10. At this stage, the fire will start to propagate as a dangerous crown fire and will be hard to extinguish [18].

Figure 10. Crown Fire

5.3 Fire Detection

All fire monitoring systems rely on images or databases such as weather and fuel index models, gas boards and intelligent sensors. In this study, all nodes have known locations. Nodes only use temperature sensors and are programmed for a certain threshold temperature. Above this, the node will send an alarm message to the sink. This concept relies solely on node behaviour to alert of possible fires. Simple node components provide fire detection and information on whether it is a peaceful fire or the beginning of a wildfire. The key to this method is in making decisions by tracking the fire propagation and checking the logic behind it rather than using complicated databases or imaging technologies. The most convenient method is to monitor forests by using a GUI to represent the events and displaying alert messages on the monitoring screen using logical evaluation to come to a decision. Fifty nodes were tested in NS2 with multiple scenarios. See Figure 11.

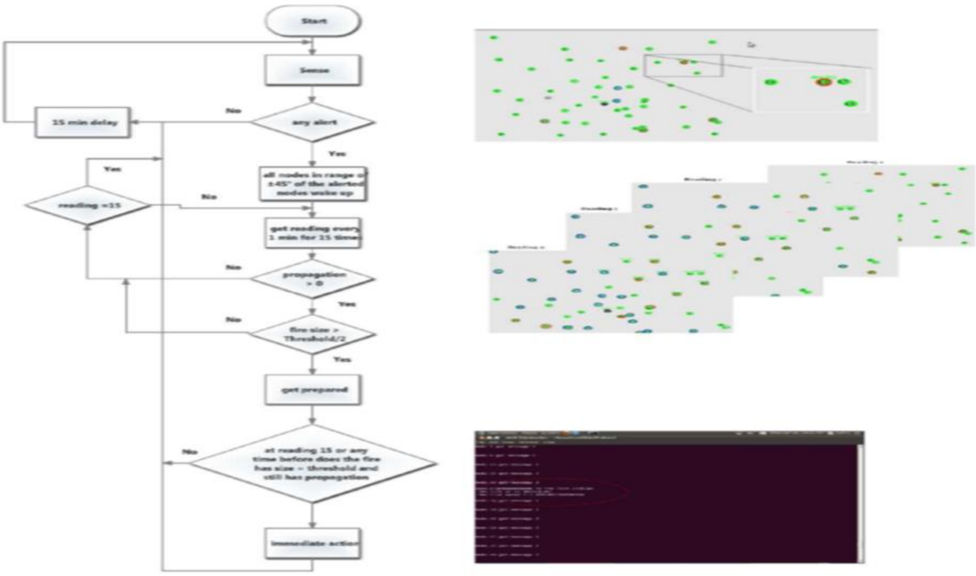

Figure 11. Fire Detection and Decision Making Flow Chart

Without going into details of fire propagation models, this study describes all possible cases for fire propagation as follows:

- Case 1: node *x* provides a fire alert at time *t*. After *t* + 1, another nodes provides an alarm, then nothing at *t* + 2…10. This indicates there is a peaceful fire such as a camp fire, and no action is required.
- Case 2: node *x* send a fire alert at time *t*. After *t* + 1, another node sends an alarm, then at *t* + 5 another node sends an alarm. At this stage, the risk increases. At *t* + T,

the propagation rang is bigger than a threshold value which means the fire is dangerous and requires immediate action. See figure 12.

Figure 12. Medium Propagation Fire

Figure 12 shows typical fire propagation where the fire gets bigger with time it can be easily detected by triggering many sensors.

Figure 13 shows a slow propagation fire which is a tricky type to predict. It might be extinguished on its own because fire growth is very slow and stops at certain times. On the other hand, it might grow and become dangerous. In that case, the nodes keep tracking the fire growth until it is larger than the threshold value.

Figure 13. Slow Propagation Fire

- Case 3: a very hot sunny day might raise the temperature over the threshold value. Since it's a sunny day, temperatures will be almost the same everywhere, causing all sensors to provide alarms at once. In this case, the threshold value must be increased to a more suitable value.

During hot days, sensors might be under trees or directly in sunlight. Therefore, some sensors might give alarms and others do not, but the apparent propagation is not logical. The alarm will come from many different discrete nodes at the same time, which does not indicate any fire propagation or growth.

- Case 4: during a cold day where there is a reduced risk of fires, the temperature threshold might be reduced to a suitable value.

Relationship between the sensor deployment scheme and early detection: When the early detection goal is considered, again, regular and moderate density deployment schemes are more successful. In random deployment cases, the average distance between a fire ignition location and the closest sensor node decreases as density increases. This means it will take less time until a sensor node detects increased temperature due to fire ignition. Additionally, the distribution among the sensor nodes provides a difference in sensing performance. Also, when the number of nodes increases, fire detection is much faster because of overlapped coverage with short gaps between sensing ranges.

An environment-aware scheme's performance is much better in terms of this metric. During the non-fire season months, the fire threat level is low, so the period of sleep time can be set longer. However, in fire season, the average fire detection time of the environment-aware model is too short, since the fire threat during that period is taken into account.

By using the sensing result, simple information can be provided for the firefighters about the fire's behaviour, such as its ignition point, fire spread speed and direction of maximum spread. The simple simulation result for fire behaviour can improve firefighter safety and fire extinguishment. The teamwork of firefighters can be organised according to these results. For example, if the fire spreads toward an inhabited area or precious properties, the team's target is to stop the spreading in that direction. Hence, more firefighters can be deployed to the flame front in the spread direction. In the contrary, if the fire needs to be extinguished as soon as possible, more firefighters can be deployed to the back of the fire to weaken the flame front, reduce the fire intensity, limit spreading, reduce danger and make it easier to extinguish see figure14.

Figure14. Fire Management Example

6. Power Saving

In this work, Libelium[Tm]Waspmote nodes and XBee-802.15.4 will be used to calculate energy consumption. Tables 2&3 summarise the parameters extracted from the Waspmote datasheet [11].

Table 2. Wapmote Parameters

Waspmote	
ON	**15mA**
Sleep	**55µA**
Deep Sleep	**55µA**
Hibernate	**0.06µA**

Table 3. XBee 802.15.4 Parameters

XBee- 802.15.4	
ON	50.36mA
Sleep	0.1mA
OFF	0
Sending	49.56mA
Receiving	50.26mA

Energy consumption calculations for a 'Waspmote node' are divided into two parts: the XBee and Waspmote device.

$$E_{total} = E_{XBee} + E_{Waspmote} \quad \text{(A1)}$$

$$E_{total} = [E_{tx} + E_{rx} + E_{on} + E_{sleep}] + [E_{on} + E_{sleep}] \quad \text{(A2)}$$

$$E_{total} = [P_{tx} * t_{send} + P_{rx} * t_{recieve} + P_{on} * t_{on} + P_{sleep} * t_{sleep}] + [P_{on} * t_{on} + P_{sleep} * t_{sleep}] \quad \text{(A3)}$$

According to the above tables' parameters, the power can be calculated for each part as follows:

$$P = I * V \quad \text{(A4)}$$

Table 4. XBee & Waspmote Power Consumption

XBee-802.15.4	Waspmote
P_{tx}= 1 mW	P_{on} = 4.2 V * 15 mA = 63 mW
P_{rx} = 20.172 mV * 50.25 mA = 1.014~1 mW	P_{sleep} = $P_{deep\ sleep}$ = 4.2 V*55 µA = 0.231 mW
P_{on} = 50.36 mA * 20.172 mV = 1.016~1 mW	$P_{hibernate}$ = 4.2 V * 0.06 µA = 0.252 µW
P_{sleep} = 0.1 mA * 20.172 mV = 2.0172 µW	

It appears that the power is mostly consumed by Waspmote. The energy consumption in the node during different statuses will be:

- If XBee is in transmission/reception or ON (idle) status, the Waspmote has to be turned on.
- Otherwise, Waspmote sleeps then XBee sleeps.

The following calculations (4 scenarios) compare between scenarios of normal network performance and performance with the proposed approach over one full year:

Scenario 1: The node is continuously working and has to provide feedback every second. Since it employs a broadcasting network, it is assumed that a reception occurs every second as well.

t = 1 year = (3600 * 24 * 365)s.

$E_{total} = [E_{tx} + E_{rx} + E_{on} + E_{sleep}] + [E_{on} + E_{sleep}]$

E_{total} = [1 mW * (3600 * 24 * 365) + 1 mW * (3600 * 24 * 365) + 1 mW * (3600 * 24 * 365) + 0] + [63 mW * (3600 * 24 * 365) + 0]

= 2081.376 KJ

Scenario 2: Nodes observe the environment and send results continuously to the base station for 30 s every 10 min, instead of continuous observation for the whole year.

t_{on} = 30 s/10 min ➔ 180 s/hr ➔ 1576800 s/year.

t_{sleep} = 10 * 60 – 30 = 570 s/hr ➔ 29959200 s/year

$E_{total} = [E_{tx} + E_{rx} + E_{on} + E_{sleep}] + [E_{on} + E_{sleep}]$

E_{total} = [(3 mW * 1576800) + (2.0172 µW * 29959200)] + [(63 mW * 1576800) + (0.231 mW * 29959200)] = 111.1398089 KJ

ΔE = (2081.376 KJ - 111.1398089 KJ /2081.376 KJ) * 100% = 94.66027%

Using this technique, energy performance is improved by 94.66%. The energy consumed in one year is reduced by 18.7 times compared with Scenario 1.

Scenario 3: This is similar to Scenario 2 but assumes that there is no transmission unless there is an event to report (according to the fire detection method). Assuming no events occurred during the network lifetime and only data packets are taken into account in this calculation, any other messages such as ARP, routing messages, etc. are ignored.

t_{on} = 1576800 s/year

t_{sleep} = 29959200 s/year

$E_{total} = [E_{tx} + E_{rx} + E_{on} + E_{sleep}] + [E_{on} + E_{sleep}]$

E_{total} = [0 + 0 + (1 mW * 1576800) + (2.0172 µW * 29959200)] + [(63 mW * 1576800) + (0.231 mW * 29959200)] = 107.8962089 KJ

ΔE = (111.1398089 KJ - 107.8962089 KJ/111.1398089 KJ) * 100% = 2.92%

Energy performance is improved by 2.92% compared to Scenario 2, which means that energy consumption is reduced by 1.03 times.

Scenario 4: Similar to Scenario 3 but applying the subnetwork coverage method.

t_{on} = 30 s/30 min ➔ 60s/hr ➔ 525600 s/year.

t_{sleep} = 3600 - 60 = 3540/hr ➔ 31010400 s/year.

$E_{total} = [E_{tx} + E_{rx} + E_{on} + E_{sleep}] + [E_{on} + E_{sleep}]$

E_{total} = [zero + zero + (1 mW * 525600) + (2.0172 µ * 31010400)] + [(63 mW * 525600) + (0.24 mW * 31010400)] = 41.1435 KJ

ΔEs3 - s4 = 61.87%

ΔEs2 - s4 = 63%

Table 5. Energy Results Comparison

Comparing Scenario 4 with other Scenarios		
	∆E	Energy consumption
Scenario 3	**61.87%**	**2.622times**
Scenario 2	**63%**	**2.701272times**
Scenario 1	**98.023%**	**50.6time**

The most common scenario in WSNs in forest fire applications is Scenario 2, where the whole network wakes up every 10 minutes to sense the environment and send the data to the base station. The sub-network coverage method makes improvements in the energy performance by 63%. It reduces energy consumption by 2.7 times compared to the normal routine, which means the power used in one year can be used to deliver the same functionality for 2.7 years. Most of the nodes used in forest fire applications can work between one year (as in Waspmote) to three years. The present study can increase this dramatically to 2.7—8.1 years.

7. Conclusion

Two contributions have been made that overcome coverage, fire detection and faulty alarm problems:

1- The sub-network coverage method can convert networks with a random distribution into an organised deployment. Dividing the network into three sub-networks to reduce the number of used nodes can increase network lifetime by 2.7% and increases energy performance by 63% compared to normal fire detection networks.

2- The fire detection and decision-making systems do not require complicated gas boards and specialised devices, connection of the network to databases, or application of complicated models. Only a simple, cheap, temperature sensor is required at each node. It helps in decision-making by distinguishing between peaceful fires, false alarms and potential danger that requires an immediate reaction. Plus, the low possibility of false alarms and information about fire behaviour can improve the performance of firefighting.

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References

[1] Z. Chuan, Z. Chunlin, S. Lei, H. Guangjie, "A survey on coverage and connectivity issues in wireless sensor networks", Journal of Network and Computer Applications, vol. 35, no. 2, **(2011)**, pp. 619-632.

[2] V. Rao, "The Simulative Investegation of ZibBee/IEEE 802.15.4", Department of Electrical Engineering And Information Technology Dresden University of Technology. Master of Science, **(2005)**.

[3] H.M. Ammari and S.K. Das, “Coverage, Connectivity, and Fault Tolerance Measures of Wireless Sensor Networks,” Proc. Eighth Int’l Symp. Stabilization, Safety, and Security of Distributed Systems, **(2006)**, pp. 35-49.

[4] C. Huang, Y. Tseng, and L. Lo, “The Coverage Problem in Three Dimensional Wireless Sensor Networks,” Proc. IEEE GLOBECOM,04, **(2004)**, pp. 3182-3186.

[5] S. Adlakha and M. Srivastava, “Critical Density Threshold for Coverage in Wireless Sensor Networks,” Proc. IEEE Wireless Comm. and Networking Conf, **(2003)**, pp. 1615-1620.

[6] J. Ai and A. Abouzeid, “Coverage by Directional Sensors in Randomly Deployed Wireless Sensor Networks,” J. CombinatorialOptimization, vol. 11, no. 1, **(2006)**, pp. 21-41.

[7] X. Du and F. Lin, “Maintaining Differentiated Coverage in Heterogeneous Sensor Networks,” EURASIP J. Wireless Comm. and Networking, vol. 5, no. 4, **(2005)**, pp. 565-572.

[8] J. Cortes, S. Martinez, T. Karatas, and F. Bullo, “Coverage Control for Mobile Sensing Networks,” IEEE Trans. Robotics and Automation, vol. 20, no. 2, **(2004)**, pp. 243-255.

[9] H. Zhang and J. Hou, “Maintaining Sensing Coverage and Connectivity in Large Sensor Networks,” Ad Hoc & Sensor Wireless Networks, vol. 1, nos. 1-2, **(2005)**, pp. 89-124.
[10] X. Li, P. Wan, and O. Frieder, “Coverage in Wireless Ad-Hoc Sensor Networks,” IEEE Trans. Computers, vol. 52, no. 6, **(2003)**, pp. 753-763.
[11] Libelium **(2013)**. Waspmote Datasheet v.4.2. fromhttp://www.libelium.com/development/waspmote/documentation/waspmote-datasheet/.
[12] The Advanced Very High Resolution Radiometer (AVHRR) [cited jul/ 2011]; Available from: Http://noaasis.noaa.gov/noaasis/ml/avhrr.html/
[13] D. M. Doolin, N. Sitar, “Wireless Sensor Nodes for Wildfire Monitoring in SPIE Symposium on Smart Structures and Materials”, **(2006)**.
[14] J. Lloret, M. Garcia, D. Bri, S. Sandra, “A Wireless Sensor Network Deployment for Rural and Fire Detection and Verification Sendor Nodes”, vol. 9, no. 11, **(2009),** pp. 8722-8747.
[15] B. Son, “A Design and Implimintation of forest fires surveillaince System Based on Wireless Sensor Network for South Korea Mountains”, International Jornal of Computer Science and Network Security, vol. 6, **(2006)**, p. 124-130
[16] M. Hafeeda, “Bagheri, Forest Fire Modling and Early Detection Using Wireless Sensor Networks”, Ad Hoc Sensor Wireless Networks, vol. 7, **(2009)**, pp. 169-224.
[17] J. H. Scott, “Introduction to Wildfire Behaviour Modeling”, National Interagency Fules, Fire, &Vegetation Technology Transfer. Wild Fire Managment RD&A, **(2012)**, pp. 7-15.
[18] D. Viegas, "Fire Behaviour and Fireline Safety", Annual Maditerranean Burns Club, vol. 6, no. 3, **(1993)**.
[19] M. A. Finney, “FARSITE: Fire Area Simulater-Model Development and Evaluation”, f. s. US department for agriculture, USDA: research parer RMRS-RP-4 Revised, **(2004)**.

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