A Design and Implementation of Forest-Fires Surveillance System based on Wireless Sensor Networks for South Korea Mountains

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Summary
Wireless Sensor Networks (WSNs) become an important issue such as environmental monitoring, home or factory automation, logistics and so on. Many wild fires cause to damage on forest and a mountain which have valuable natural resources during the dry winter season. Current surveillance systems use a camera, an infrared sensor system and a satellite system. These systems can not support real-time surveillance, monitoring and automatic alarm. In this paper, we develop a forest-fires surveillance system in South Korea Mountains. We call this system ***FFSS*** (Forest-Fires Surveillance System). The developed FFSS consists of WSNs, middleware and web application. The WSNs measure temperature and humidity, and detect smoke. The middleware program and the web application analyze the collected data and information. The FFSS is possible to detect the heat. It let to know early alarm in real time when the forest-fire occurs.

Key words:
Wireless Sensor Networks, Surveillance System, Middleware, Minimum Cost path Forwarding

1. Introduction

Wireless Sensor Networks (WSNs) become an important issue such as environmental monitoring, a home/factory automation, logistics, and so on. The WSNs consist of small size, low-power, and low-cost devices that integrated with limited computation, sensing, and radio communication capabilities. The WSNs suppose that solve potentially on many emergency situations with early alarm [1].

WSNs will be popular over the next ten years. The WSNs based on sensing technologies are a kind of sensors with micro electro mechanical systems (MEMS) technology. It has been growing for various applications. Many research used the WSN. It has been conduct a structural health monitoring for buildings and civil engineering structures in recent years [4]. Some of these researches have focused on wireless sensing technology. The WSNs evaluate and analyze on the environmental information, such as temperature, humidity, sound, vibration, smoke as well as pictures of a building and forest. The WSNs based on the FFSS will give an early fire alarm of fire in forest or a mountain area using to analyzed on environment information.

Forest-fires in South Korea occur frequently in spring and fall seasons because these seasons are drier than summer and winter seasons. The warning period of South Korea against forest-fires starts from 15th February to 15th May in spring season and from 1st November to 15th December in fall season. Figure 1 show the locations which are burnt in forest-fires while the fire seasons in South Korea [8]. Table 1 also shows the number of times, areas, amount of damages that forest-fires break out during the period of 1998-2005 [13].

Table 1. Forest-fires occurrence state

	count	Area (ha)	Damage (ha)	Accumulated damage (㎥)	Cost ($1000)
ave	***402***	***3,666***	***9.1***	***195,071***	***9,197***
'98	265	1,014	3.8	44,092	2,516
'99	315	473	1.5	6,377	665
'00	729	25,953	35.6	1,373,302	65,242
'01	785	963	1.2	33,753	2,717
'02	599	4,467	7.5	324,120	8,953
'03	271	133	0.5	2,444	277
'04	544	1,588	2.9	52,787	4,069
'05	516	2,067	4.0	113,830	7,526

In Figure 2, South Korea is classified into 16 eco-regions by cluster analysis. Among the 16 eco-regions, the forests of three regions, Kangwon coastal, Woolyong coastal, and Hyungsan-Taewha coastal (eastern coastal region of South Korea), are vulnerable to fire because there is very low rainfall. The reason of low rainfall is due to the foehn and quasi-foehn winds abruptly in a day. Because of these meteorological and geographical conditions of the 3

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regions, forest-fires or wildfires spread into a large area rapidly.

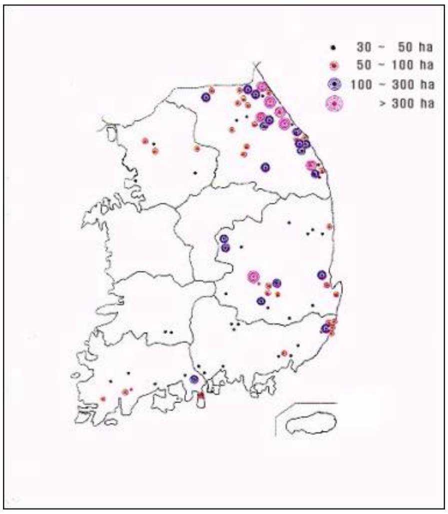

Figure 1. Forest-fire while 1980-1999

In April 2005, the large forest-fire burned in YangYang and Kosung in Kangwon coastal eco-region, and 300 ha were destroyed by the fire. The fire caused by updraft sparks flames. The flying sparks such as pine cones; branch and bark catch fire and fly to the forward direction of the fire movement. The flying sparks flew 1.5 ~ 2km high during the fire in April 2005. The extensive forest fires are hard to control and damage the environment severely. There are about 3.4ton of soil loss per ha in burned areas. It takes at least 3-4 years to recover the soil loss. Once the forests are damaged by fires, it takes about 40 ~ 50 years to recover the destroyed ecosystem.

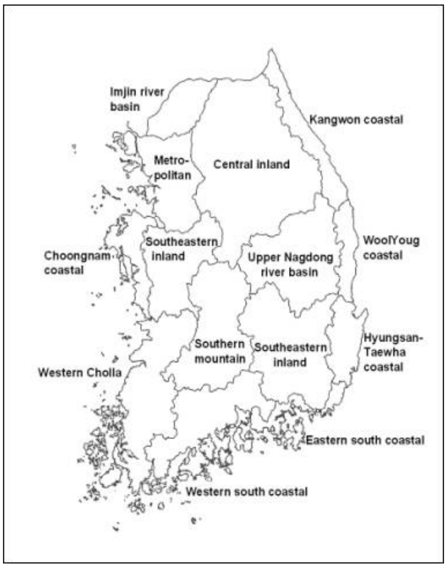

Figure 2. Eco-regions of South Korea

To prevent forest-fires and have an early fire-alarm in real-time, we develop Forest-Fire Surveillance System (FFSS). The FFSS can detect forest-fires earlier than other systems. This early alarm alerts people to extinguish forest -fires properly before it grows. Therefore, it saves the economical loss and environment damage. The FFSS consists of WSNs, transceiver, middleware and Web-application.

In Section 2, we introduce the existing forest-fire detection systems. We explain the used WSNs, sensor node, operating system and protocol routing for the FFSS in Section 3. In Section 4, we present the developed FFSS. Conclusion is presented in Section 5.

2. Related Works

Most existing forest-fire detection systems rely on the satellite imagery. The first Moderate-resolution Imaging Spectroradiometer (MODIS) instrument [9], was launched in December 1999. MODIS provides global daily forest fire products based on the satellite imagery. MODIS views the entire surface of the Earth every one to two days. And its detectors acquire data at three spatial resolutions: 2 bands in 250m, 5 bands in 500m, and 29 bands in 1,000m. It is far away from providing real-time forest fire detection. In [3, 7], the images from MODIS and AVHRR are used to evaluate forest fire risk and detect forest fire in China and Canada respectively. T. J. Lynham et al. [5] reviewed potential requirements for space-based observations in fire management including fuel mapping, risk assessment, detection, monitoring, mapping, burned area recovery, and smoke management. Weather condition (e.g. clouds) will seriously decrease the accuracy of satellite-based forest fire detection as the limitations led by the long scanning period and low resolution of satellites.

3. WSNs for FFSS

3.1 WSNs and Sensors

The WSNs can be connected to the Internet so that the information can be used for future risks. Wireless sensor nodes are easy to install, remove, and replace at any location, and are expected to become smaller using Micro Electro Mechanical Systems (MEMS) technology. The WSNs will provide a ubiquitous sensing network environment in anywhere. In the hazardous condition like earthquake and forest fire, the acceleration and strain at numerous locations on each beam and column, temperature and light in each area, and images and sounds in desired regions can be obtained by the sensor nodes, as illustrated in Figure 3.

Additionally, a single type of sensor node such as a microphone can be used for multiple purposes. For example, a microphone can be used to detect earthquake, fires and intrusions [6]. Furthermore, a fiber optic network is not only utilized as infrastructure for information technology, but also as a "wired" sensor network. Table 2 shows hazards, possible applications and combination of sensors.

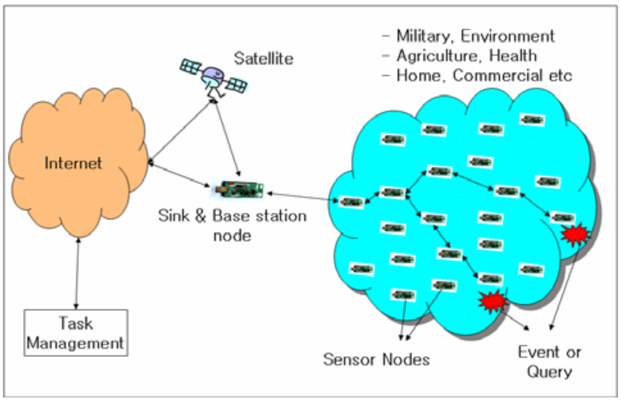

Figure 3. Structure of WSNs

Table 2. Sensors applications Hazards

Hazard	Application	Sensor combination
Earthquake /Wind	Observation	Acceleration
	Experiment	Acceleration/Strain
	Structural control	Acceleration
	Health monitoring	Acceleration/Strain/ Displacement
	Damage detection	Acceleration/ Strain/Displacement
Fire	Fire detection	Temperature/Smoke/Acoustic/ Olfactory/Acceleration
	Gas leak detection	Olfactory
	Alarm, warning	Sounder
	Evacuation control	Temperature/Smoke /Acoustic/Light/Olfactory
Crime	Surveillance	Acceleration/Light /Acoustic/Camera
	Security alert	Sounder

3.2 Sensor Node

The FFSS uses TIP50CM (such as Telos clone) [12]. TIP50CM is a kind of equipments that can utilize various sensors and realizes Single Frequency Network (SFN) application as device node to compose SFN. It uses 2.4GHz band. The applications are sensor network technologies for ubiquitous computing infrastructures, Multi-hop ad hoc network solution, Low power communication technology and intelligent context-aware middleware service.

TIP50CM is an ultra low power wireless module for sensor networks, monitoring applications, and property application. TIP50CM leverages industry standards like USB and IEEE 802.15.4 to inter-operate seamlessly with other devices. By using industry standards, integrating humidity, temperature, and light sensors, and providing flexible interconnection with peripherals, TIP50CM enables a wide range of mesh network applications. With TinyOS support out-of-the-box, TIP50CM leverages emerging wireless protocols and the open source software movement. TIP50CM is part of modules, featuring on-board sensors to increase robustness with low cost and small package size. Specifications of TIP50CM are shown in Figure 4 and Table 3 [10, 12].

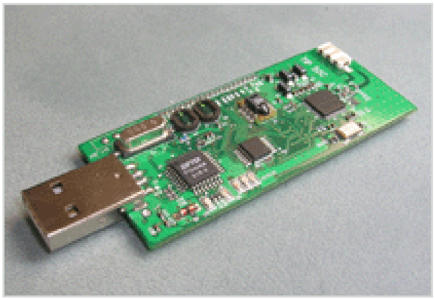

Figure 4. Sensor node

Table 3. Specifications of sensor node

Item	Description
Processor	16bit RISC, 8MHz
Memory	256KB Program Flash
Operating System	TinyOS
Multi-channel Radio	2.4GHz
Data Rate	250Kbyte
Sensor	Temperature, Humidity and Light
Network	Multi-hop and Ad hoc
Interface	USB(UART)
Size	68×29mm
Power	3.0~3.3V
Range	70m in lab

3.3 Sensor Node Operating System

TIP50CM is one of the popular and commercially available sensors which are marketed by Maxfor co. Ltd. Applications for TIP50CM motes are developed on an Operating System called TinyOS [11]. TinyOS is an event based OS. It waits for stimuli upon occurrence, and it executes a set of function. It is written in a language called Nested C (NesC). NesC is similar to the C programming language. Therefore, only one application runs on a sensor. Since single application runs on a sensor, TinyOS does not support memory management or process management. Since memory manager is not part of TinyOS it discourages applications from allocating or using dynamic memory.

3.4 FFSS Network Protocol

In the forest-fires sensor network, the routing protocol uses similar to other flat routing protocol using Minimum Cost path Forwarding (MCF) [2]. MCF finds shortest paths from all the sensor nodes to the base station and requires no explicit routing tables to maintain each node. Routing all the data along a shortest path might potentially drain all the energy from upstream nodes. Thus, there might be lost-coverage regions of the network. In our method, we mitigate this possibility by limiting the amount of energy each node and can spend in a round. MCF design has been driven by the following three goals: Optimality, Simplicity and Scalability.

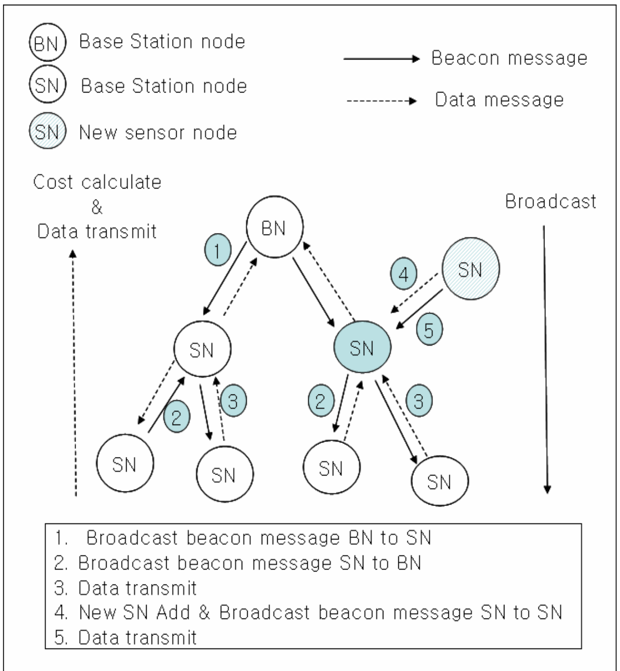

Figure 5. Configuration Step of the FFSS Network Protocol

Sensor node starts when its power on. It has random timer and processes periodically. FFSS network consists of five steps such as shown in Figure 5. Figure 6 illustrate topology of the FFSS network.

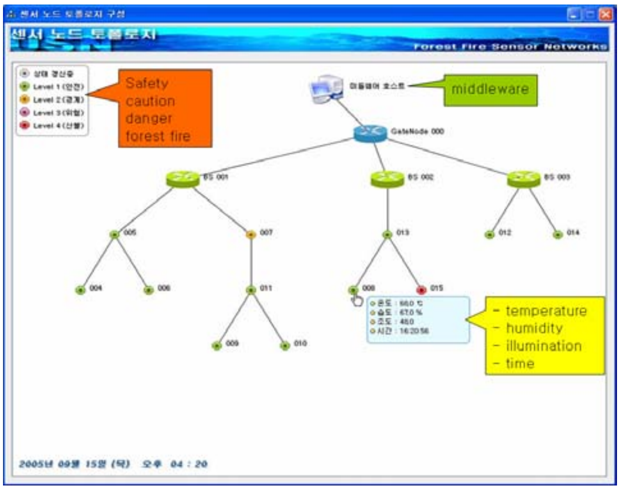

Figure 6. Topology in the FFSS Network

4. Forest Fire Surveillance System

4.1 Transceiver (Gateway)

The FFSS senses environment state and determines forest-fires risk-level by formula of the Office of Forestry. Then, the FFSS provide automatic alarm as shown in Figure 7. The WSNs consist of sensor nodes that sense and communicate to send the temperature, humidity and illumination data.

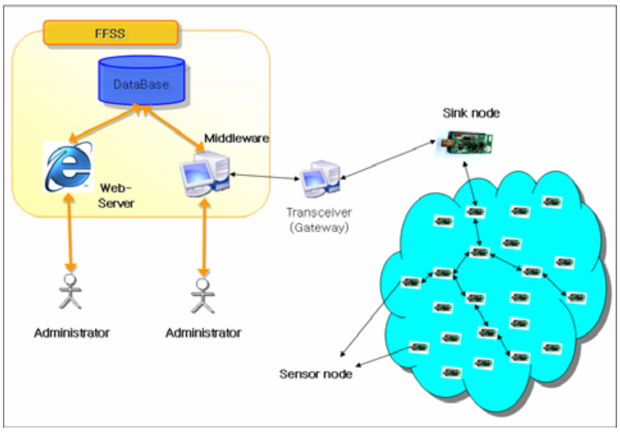

Figure 7. Structure of FFSS components

A Sink-node is one of sensor node of WSNs. This node concentrates packet of the WSNs and forward it to a transceiver (gateway). The transceiver transports packets received from the sink node. When the transceiver received packet, it verify packets and analysis packets for middleware program. The packet structure is shown in Table 4 and Figure 8.

Table 4. Packet field definition

Field Name	Contents
length	packet total length
fcf-hi	CC2420 FCF check(high, low bit)
fcflo	
seqno	tos_msg number
dest-pan	object pan ID(FFFFh)
addr	basenode address
type	transmitted message type
group	group ID
source-addr	object node address
origin-addr	packet happen node address
seqno	total node packet number
origin-seqno	packet number from SN to BN
hop-count	route number to BN
type	sensing data type(0h)
ivolt-data	voltage
parent-addr	parent node address
seqno	data transfer number
temp-data	temperature value
hum-data	humidity value
par-data	illumination value
waste	packet length padding

field name	length	fcfhi	fcflo	seqno	dest pan	addr	type	group	data
byte	1	1	1	1	2	2	1	1	28

field name	source Addr	origin Addr	seq no	origin seqno	hop count	data
byte	2	2	2	2	2	18

field name	type	ivolt data	parent addr	seqno	temp data	hum data	par data	waste
byte	2	2	2	4	2	2	2	2

Figure 8. Packet format

The transceiver shown in Figure 9 is a gateway of the general WSNs. Each WSNs can connect to outside network through this transceiver. As the transceiver works as TCP/IP socket server, middleware program can connect the transceiver and receive parsed packets. Also the transceiver displays receiving status so that an administrator can monitor easily.

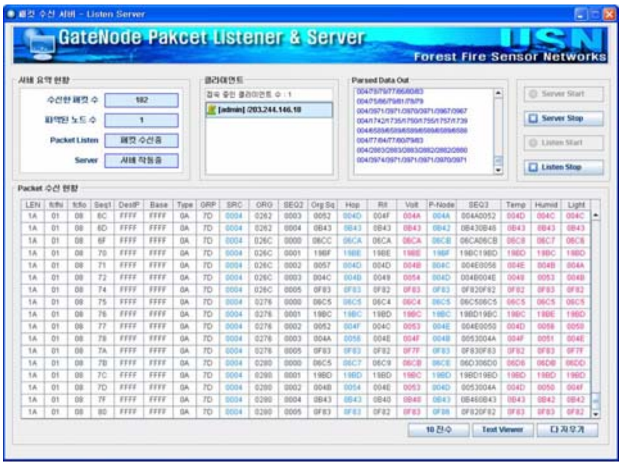

Figure 9. Transceiver screen-shot

4.2 Middleware

In Figure 10, middleware receives and processes packets from the transceiver and displays its results. The results contain the forest-fires risk-level. This level is calculated by formula defined by the Office of Forestry in equation (1). Then, the FFSS can provide an automated surveillance system. The middleware stores received packets to the database server. Figure 11 shows the screen-shot of main window of middleware. The middleware is composed with some components so that the administrator can grasp the situation easily. The components provide a statistics viewer about recoded data based on the database.

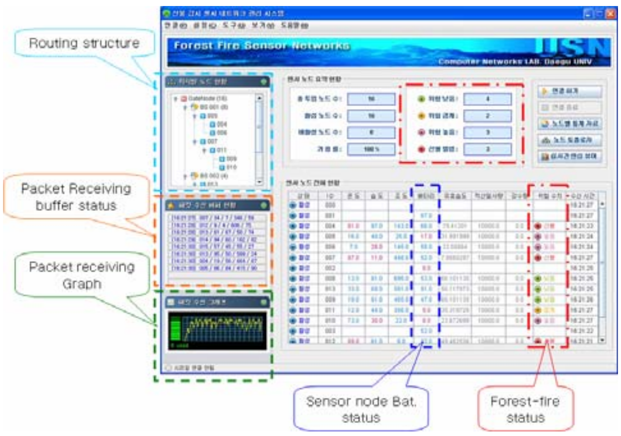

Figure 10. Middleware screen-shot

The administrator can see the statistic graph and table. Components provide real time graph about receiving data that containing temperature, humidity, illumination and battery level. Also, the administrator can grasp sensor status information. Component is topology viewer. The administrator can grasp WSNs logical topology. This view shows present condition of fired sensor nodes.

$$\begin{aligned} Y &= 6.87 \\ &+ (0.64 \times P) \\ &+ (0.15 \times EF) \\ &+ (1774.94 / CS) \end{aligned} \quad (1)$$

EF = Effective humidity(%)

CS = Solar radiation of the day(MJ/㎡)

P = Precipitation (㎜)

$$EF = (1 - r)\begin{bmatrix} H0 \\ + (r \times H1) \\ + (r^2 \times H2) \\ + (r^3 \times H3) \\ + (r^4 \times H4) \end{bmatrix} \quad (2)$$

r = 0.7

H0 : Relative humidity of the day

H1 : Relative humidity of a day ago

H2 : Relative humidity of two days ago

H3 : Relative humidity of three days ago

H4 : Relative humidity of four days ago

Table 5. Forest Fire Danger Index

Y	10	11	12	13	14	15	16
Danger Index	100	90	80	70	60	50	40

Table 6. Forest Fire Danger

Fire danger levels	state and color
81 - 100	**Extreme (red)**
61- 80	High (yellow)
under 60	Low (blue)

4.3 Web Application

In Figure 11, web application consists of web-application and database server. It provides that administrator can monitor through the Internet. It is comprised of web pages and applet. Applet communicates with data-base server and displays information. Web application provides all most of functions of middleware. Table 5 and Table 6 are Forest Fire Danger Index and levels. These values computed in (1) and (2). If forest fire occurs, FFSS give alarm automatically to user and administrator to extinguish the fire earlier. Figure 12 illustrates forest fire occurrence situation and automatic alarm.

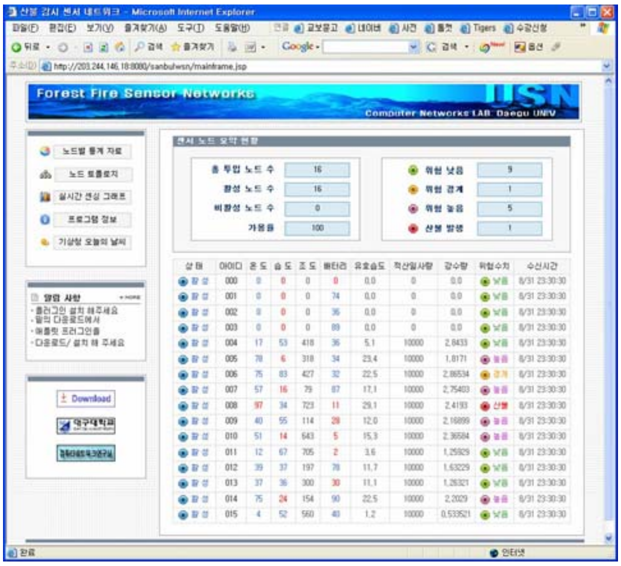

Figure 11. Web application implementation screen

Figure 12. After a forest fire breaks out, implementation screen of FFSS

5. Conclusion and Future Work

In this paper, we developed Forest-Fire Surveillance System (FFSS) based on Wireless Sensor Networks. The developed FFSS consists of WSNs, middleware program, and web application monitoring program. As a result, the FFSS observes real-time forest's state in everywhere. If a forest-fire breaks out, FFSS alarms to fire station or neighbor residents. In real-time observation with FFSS, it provides early extinguishing of a forest-fire so that damages and injuries will be reduced. For future works will be more researches about effective modes of communication that facilitate no data loss to achieve the WSNs for the other applications.

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