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Forest Fire Sensing and Decision Support using Large Scale WSNs

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Abstract: An undeniable and urgent need for environmental protection and preservation has been raised in the last few years. Undoubtedly, great environmental damage has occurred lately which has resulted in the deterioration of the human quality of life. Hardly does a year go by, without the occurrence of extreme environmental damages, especially in forests due to wild fire expansion. Forests have been wiped out of the map, because of inevitable fire incidents which incinerate every fauna and flora and even human lives in their path. In this paper we suggest an application platform for developing a Fire Sensing Management System based on WSNs and further discuss decision support that can be based on such a platform and application software. The use of such a system can assist the appropriate authorities detect a forest fire incident in the very beginning and assess the relative severity of simultaneous forest fire incidents in order to decide how to best exploit availabe resources. Wireless Sensor Networks (WSNs) play a fundamental role in the implementation, being the in-situ detection mechanism. The Management and Decision Support System does the collection of network data, the depiction of temperature values on platforms such as Google maps, and the assessment of the relative severity of simultaneous fire fronts using forest fire simulation. It can also send real-time alarm messages, so that immediate action is undertaken by the crisis management authorities.

***Keywords**:* WSN; sensor; fire; crisis; Fire Sensing Management System.

1. INTRODUCTION

During the last few years, Wireless Sensor Networks' technologies have evolved rapidly. In the meantime, environmental preservation has become an urgent issue, as mankind has experienced many environmental disasters (forests fires, planet overheating, air-water pollution, e.t.c). Recently, due to the availability of low cost and low power WSNs, many goals set by researchers have been achieved in the field of environmental protection by the aid of WSNs.

Much work has been done in treating the threat of forest fire efficiently. According to a suggested method, a wireless system comprising three sensor networks and webcams is used in the forests for fire early prediction -Hartung et al [2006]. Another research group has proposed a web based system that gathers data from WSN and produces fire risk indices for the areas being under monitoring - Byungrak et al [2006]. An idea for data collection through WSN and neural network analysis of this data has also been investigated. Its aim is to detect forest fire through the development of weather indices - Yu et al [2005].

In this paper we propose a platform that gathers data from large scale, high-density wireless sensor networks, depicts them on an open spatial data representation platform, such as Google maps, and produces fire alarm messages. This data can either be real world data gathered directly from the environment through a WSN, or simulation data acquired from the output of a WSN simulation tool. In the latter case, more tools such as forest fire simulators can become part of the system. Especially for fire incidents, the data collected is temperature values sampled by temperature sensors. It can also be just alarming data by itself, as just a single transmission can be considered an alarm. In any case, it is essential to use one or two such sensors on every sensor board to enhance reliability. Adding more sensors on a sensing board increases considerably the cost. However, very large areas can be covered by populated WSNs by using such sensors at a dense spatial distribution. As an indication, 400-800 sensors may be required to cover one square kilometer by deploying a sensor every 30-50 meters. Both star and grid network topologies can be used by the proposed platform; the way they function is explained in detail in the sequel. The star topology can also be regarded as a cellular WSN. The advantage of such deployments is that forest real time monitoring is possible (for every x-y coordinates of any project and for any x-y coordinates as a starting point). The network status can be depicted on Google maps and the alarms may be visual, audio, mobile call, sms, or any other action that can be triggered by an alarm event. Furthermore, in this paper we discuss the platform construction and functionality, the topologies used, their special characteristics, the simulation procedure, some results of our experiment and a few conclusions reached.

2. THE PLATFORM

The platform (see Figure 1) is based on open source software. It consists of a web server (i.e. Apache), a MySQL database system and PHP scripts for the dynamic part of the web pages. A database stores the coordinates of the sensors' location, the sensors' IDs and the temperature measurements for each sensor, along with a timestamp that each value is collected. The temperature values of every sensor located in (x,y) coordinates can be depicted on dynamic real time Google Map web pages. At this point, it must be stressed out that a prerequisite theoretical scenario of sensors' location should exist. The system proposed needs the sensors' exact coordinates and IDs as input. The definition of the sensors' location / coordinates is another interesting project by itself, which is not examined in this paper. As shown in figure 1, data is collected through the Wireless Sensor Network. The collection method is discussed in the following section. Then an IP gateway receives data from the radio channel and routes it through the Internet to a central management and communication server.

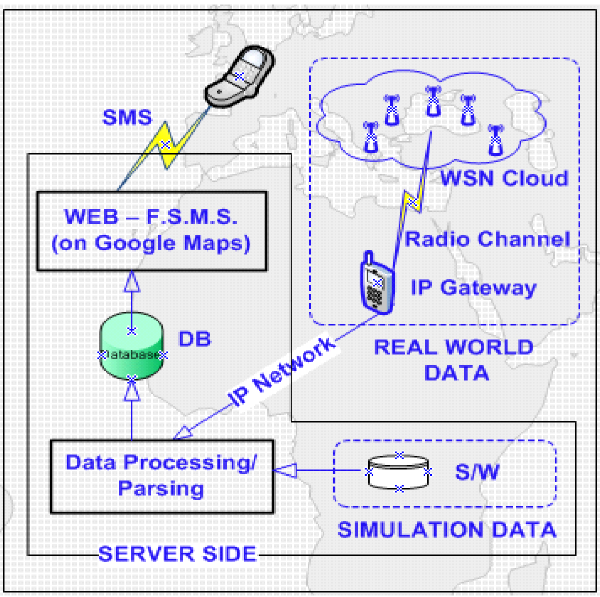

Figure 1. Platform block diagram

As mentioned before, data may also be acquired locally (i.e in the lab), using a forest fire simulation software application, along with a WSN simulator; such a setup is useful for evaluation and design purposes prior to implementing any real system. Whatever the source, data is then entered to the database and depicted on a geographical information platform. Google Maps API has been selected as the open presentation platform in our case. The polling frequency of the database ranges from one to three minutes depending on the particular situation.

3. FUNCTIONALITY - TOPOLOGIES

First and foremost, the system authenticates the user. Then, the user should determine the operation mode for the system. The possible choices offered are: real time forest monitoring and simulation, which has been discussed. In either case, the user should choose the kind of the WSN topologies that will be formed and their special attributes, according to the sensors' positioning requirements. Grid and star topologies are both supported by the current version of the system. The user should provide the number of sensors used, the average distance between them if the grid topology is selected, or the radius R for the star topology. In any case, to classify the system as 'large scale', the distance or the radius should be between 30 and 50m. In this way, a very dense spatial distribution of sensors is achieved. For a typical forest of about 20 sq.km more than 10.000 sensors may be required to achieve the aforementioned density. The nodes, through which the network status will be reported to the central management location of the network, are called base stations or gateways. In the case that the used topology is a star, the gateways are located in the center of a circle with a radius R. When the topology selected is a grid, the gateway(s) usually are at the perimeter of the grid. Moreover, if star topology is constructed the user should have in mind that 6 sensors can be placed on the six vertices of a normal hexagon formed in the gateway range circle. In our simulation, we formed both a simple grid and a simple star. As soon as the gateway starting point (x,y) is provided, a script runs and estimates the (x,y) values for all the involved points, in accordance to the user scenario. These coordinates are stored in a database, with respect to the sensor_ID field. The advantage of such a method in forest fire sensing, is that one can gather very high-density in-situ temperature and humidity values. As a result, we can have a view of different environmental conditions as far as real time environment monitoring is concerned; we are also able to estimate the probability of the natural eruption of a forest fire. Whatever the eruption cause is, sensors at this high spatial density allow the fire to be detected very early, before 15-25 meters of forest is burned.

The topologies supported and the features of the sensors should form a redundant network just in case of sensor or channel failure. In star topology, redundancy is achieved by putting gateways at a higher than theoretically needed density. For example, if the receiver range is 300 m, theoretically gateways can be put at a distance of 600 m to each other. By reducing this distance to 400-500 m, we put many sensors in range of more than one gateways, and thus redundancy is achieved. In that sense, node’s data may able to be routed through more than one gateways if needed, as the alarming sensor node may be in range of two or even three cells.

In the case of a grid network, redundancy criteria are fulfilled by using more than one gateways for each network segment. In earlier work, we have implemented a pilot small scale grid sensor network consisting of 60 sensors - Vescoukis et al [2007]. Nevertheless, grid topology is not suggested for implementation in real time environmental monitoring. The great weakness of such a topology is the segment routing collapse due to a probable failure of a node. In that case, not only will the data of the failing node not be routed to the following ones, but all the data of the previous nodes will get lost as well. In general, grid topology is failure prone because of the fact that segment routing is node dependent and the network re-organization process may be slower than the evolution of a real fire. In the meantime, redundancy costs much more than it does in star topologies due to geometry reasons. As a result, multihop topologies are not suggested for implementation in real time monitoring systems, but only for simulation and study purposes.

In spite of the topology used, cost is a factor that needs to be seriously regarded. As the redundancy level increases, the higher the cost of the equipment becomes. Likewise, a high budget support to a WSN project may ensure as more as possible a reliable and efficient network.

3.1 Simulation

Considering the simulation issue, the whole procedure becomes a server side application. Its aim is to produce as much reliable results as possible, before actually deploying the real time environmental monitoring network. In our first approach, a popular simulation software for Wireless Sensor Networks has been used. In our experiment we used TOSSIM - Levis et al [2003] as it was the default simulator for TinyOS; with TOSSIM experiencing many points of inconvenience. In the sequel, we switched to simulators such as OMNet++ - Xian et al [2008], Castalia -Pham et al [2007] and Shawn - Fekete et al [2007], which have been proven to be more user-friendly. Then, the input of the simulator, referred also as the simulator scenario file, becomes updated with user entries. Javascript for input evaluation, php for input collection and shell programming for execution are used for this purpose. The simulation produces a text file as an output (i.e. execution.txt). Therefore, this output file is parsed (through shell programming, awk e.t.c.) so that sensors’ IDs and their temperature values are extracted. This data can be disposed in a text file to allow for further analysis (see figure 2).

```
NODE=`echo "$line" | awk '{print $1}' | cut -d ")" -f 0-1 |
          cut -c2-50`
VALUE=`echo "$line" | awk '{print $2}' | cut -d "." -f 0-1`
        echo "$NODE,$VALUE" >> $LOC/final.dat
        echo "$NODE" >> $LOC/final-node.dat
        echo "$VALUE" >> $LOC/final-value.dat
…………………………………………………………………
$query = "UPDATE mesurement SET value = '$contents2[$i]' WHERE node_id = '$contents1[$i]'";
…………………………………………………………………
for ($i = 1; $i <= 5; $i++) {
  $sql = "SELECT value,x_co,y_co FROM star
          where node_id='$i'";
  if ($value > 50){ echo "var label_$i = new
          ELabel(new GLatLng($y_co, $x_co),
          \"$value\", \"style2\");"; }
```

Figure 2. Three core code parts of data collection and depiction.

As a next step, the information of this file can be entered in the database in order to update the temperature value field with respect to the sensor_ID one, which is unique for the certain (x,y) coordinates. The simulation and the temperature sampling can be invoked by a cron script, so that values can change every 1-2 minutes. Then an HTML page (including javascript, php and the Google Map API –polylines, markers, e.t.c.-) is loaded and refreshed every minute. In figure 2, three characteristic parts of the total code are shown and represent the core of all the above steps.

Furthermore, a special way of value depiction is followed for very high and alarm temperatures, as shown in figure 3.

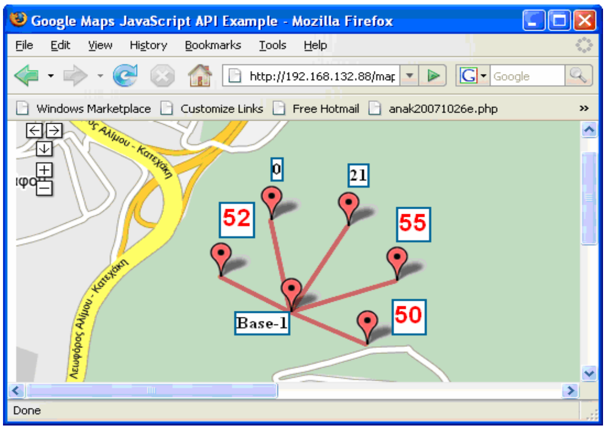

Figure 3. Instance of the F.S.M.S.– star topology

An alert threshold indicating high temperatures is set to 50 oC and an alarm one to 55 oC. In that case, the measurement value becomes larger in font size and it gets red.

Additional code is inserted here, so that this event can be reported by e-mail, sms or even by a telephone call e.t.c. In general, just an sms can be a signal and a trigger by itself for many consequent alarms and actions.

3.2 Real Time Forest Fire Monitoring and Decision Support

This system has a great value in monitoring the evolution of forest fires in real time, in order to provide decision support to authorities in charge of managing forest fire incidents. Prior to discussing how this is done, a few important requirements *during* a forest fire crisis of the decision makers will be presented. *First*, it is important that the real fire area be known at any time. Estimations based on human observations can be unreliable and totally misleading both in under and over-estimating the situation. *Second*, the authorities need to know how fast a fire evolves in order to best decide what to do. Knowing how large an area in fire is, this is a direct indication of the damage done, which, however, can only be considered as an implicit measure of the fire's potential to create even more damage. Other factors come into this estimation, such as the vegetation type and density, the topography, and of course the meteorological conditions. In this context, even if the topography is known, spatial data for the vegetation may not be available, and the same stands for on-site meteorological data. *Third*, and perhaps most important, is the authorities' requirement to relatively evaluate the potential of one or more simultaneous forest fire incidents, so as to support their decisions on resource deployment and thus achieve minimal damage. Back in 2007, about 4 major, large scale forest fires where simultaneously developing in southern Greece and the relative assessment of the potential of each one, could be a valuable asset in reducing the extend of the catastrophy.

The proposed system can be of great assistance to the authorities as a decision support tool in order to evaluate the potential of one or more simultaneous forest fire fronts, provided that few conditions which will be discussed in the sequel are met. This is achieved by receiving and processing all the alarm messages that are sent by all deployed WSNs as fires are evolving and sensors are destroyed. Processing this data can give us metrics of the real fire front speed in any direction, as well as measurements of the areas that are destroyed in given time intervals. Processing the time series of these measurements gives us the trends of the fire to become more or less powerful, which is another important indication of the severity of a forest fire.

In figure 4 development of two simultaneous fire incidents is shown at 30-minute intervals. Both areas are covered by a 30-meter grid WSN which provides real-time alarm messages which are used to indicate the fire front borders at the specified time intervals. Even if no real time meteorological data, topography, or vegetation data is available, the processing of the WSN messages alone, that indicate the order in which sensors are burnt, can give us indications on the relative severity of the two fronts, and support authorities in their decisions.

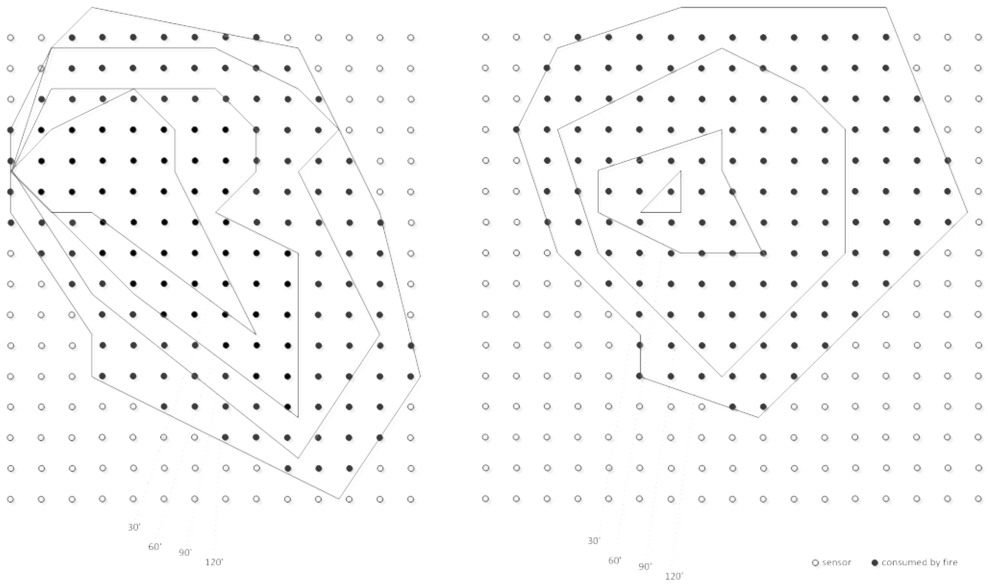

Figure 4. Evolution of two fires that destroy about the same area after 120'.

Table 1

time (min)	30	60	90	120
(left side) total area	20.000	48.759	87.039	126.378
last step	20.000	28.759	38.280	39.339
area/min (total)	666,67	812,65	967,10	1.053,15
area/min (last step)	666,67	479,32	425,33	327,83
(right side) area	800	12.000	57.600	121.280
last step	800	11.200	45.600	63.680
area/min (total)	26,67	200,00	640,00	1.010,67
area/min (last step)	26,67	186,67	506,67	530,67

In table 1, the areas destroyed by the hypothetical fires of Figure 4, along with the fire evolution speed are shown. It is clear that although the fire on the left of figure 4 is bigger and burns a larger area than the one on the right, the latter is much more powerful, as the speed at which it evolves ("area/min(last step)") is raising. Note that this assessment is made possible by processing only data sent by the WSN and does not rely on any other kind of spatial data, meteo data, or measurements.

4. RESULTS

The system presented in this paper is an integrated system based on WSNs, targeted to wild fire detection and evolution monitoring in order to provide decision support to the authorities involved in forest fire management by providing indexes that relate to fire evolution for all the simultaneous fire fronts. It can contribute to forest fire crisis management as far as fire containment, detection and evolution monitoring is concerned. We have already participated in the real world implementation of such a system for the prefecture of Messinia a 3000 sq.km area, located about 200 km WSW of Athens. A screenshot of the real system implemented is shown in Figure 5. Apart from forest fire monitoring, value-added services such as vehicle routing excluding fire areas, are also implemented.

Apart from this, by changing or adding just a single sensor device to each network node we can have a plethora of useful applications. For example, we can add sensors of either relative humidity, radiation, air or smoke on the sensor board and have different results by using the same network. The suggested platform is designed to contribute to early **diagnosis** and **prevention** in general, of a probable fire incident in forests, as well as in any research that requires dense environmental measurements.

Figure 5. Forest fire detection, monitoring and vehicle routing in the Messinia case.

By having an early alarm, even if the sensor gets damaged, the alarm value will be propagated through the network and a sequence of urgent actions and reactions will take place. The reliability of the procedure depends on the accuracy of the temperature values sampled by the sensor and the method used internally in the sensor to produce the alarm; both issues fall out of the scope of this paper. This approach is regarded as being quite beneficial because the alarm comes totally from the environment, without human interference or estimations that are error prone. In addition, if new generation sensors are used the alarm message sent is very much reliable. It also uses low power sensors so that the power **consumption is at least low if not null** and the system is **easier to be maintained and survive** for long. Another key reliability concern is that of the WAN that will be used to transfer alarm messages to the operations center, which is also out of the scope of this paper; it is, however one very important factor that may put quite expensive to implement communications requirements, depending on the specifics of each case. Another possibility for forest fire detection is by the use of cameras, though widely publicized, is beyond the scope of this paper, as cameras are power consuming, optical fire detection is not as reliable, and need more complicated installation facilities. The presented F.S.M.S. offers flexibility and it also supports simulation for result evaluation. Its additional advantage is that even if the fire has burst out, the sensors can indicate the speed and direction of the fire evolution; this information can the be used to guide the fire fighters to the burning area from the safer possible point. Also, considering the fact that the gateway(s) will still be functional, sensors provide a precise spatial indication of the fire which can be more useful for fire-fighting airplanes than smoke alone.

Moreover, the fact that measurements can be gathered for a long time leads to a data warehouse formation with respect to time, co-ordinates, administrative area, e.t.c. As a result, this data can be analyzed by data mining tools (i.e. Weka) so that calculations, estimations and conclusions can be made. These conclusions should contribute to future forest fire **forecast** and **prediction** for various places, that experience similar natural phenomena or circumstances at different times. Needless to say this applies only to naturally-igniting wild fires. For example, areas that happen to have a temperature and humidity maturement profile close to the one of areas that they already have a fire record, can be taken into serious consideration as possible points of fire emergence and expansion.

5. DISCUSSION

Sensor positioning in a real forest is a very critical concern of solutions as the one presented here. Lack of metrics and optimal positioning algorithms, leave no choice but to empirically try to position sensors "as close as possible" to the desired topology, but in no way optimally. We are currently working in proposing metrics for evaluating alternative approximations of a desired topology. It is also important to determine the optimal height where each sensor is placed, as this is an affective factor to the radio range. By placing a sensor a little high in the forest, we expect better radio range; in any case, the topology and DTM of each particular area needs to be considered prior to deciding on the optimal height for sensor positioning. Another effective factor to the results produced is the **spatial density**. The spatial density has a great impact on the signal attenuation of the sensor and along with the different behavior of the tree canopy in different conditions, is another issue that needs further investigation to ensure reliable communications in real-life environments.

Another factor that should be taken into serious consideration is the **sensors’ cost**. The area to be covered is usually large and there is a great need for accurate simulation results at the first place as well as for low sensor costs. The latter is open to question, as there is a variety of sensor boards, sensors and sensor gateways in the market, with scalable operations and cost. Current sensor boards cost ranges from some 80 to more than 200 USD, which alone is a prohibiting factor for large scale deployments. So, a question to be posed here is “Does the ideal sensor exist?”. It seems that there is no low cost sensor suitable for the application that offers the functionality discussed in this paper, yet.

Even if we assume that all the above requirements are totally fulfilled and that the simulation results are accurate and realistic, still painstaking tests have to be undertaken for real time monitoring, so that the System becomes as fully reliable as possible. In general the Fire Sensing Management System proposed here is accurate, reliable but still needs to be tested on various situations for further evaluation, which is not easy to do, provided that experimentation cannot be easily done with actual fires. The point here is that the reliability of such a system except from the characteristics of the systems itself, also depends on external factors such as the reliability of the WAN used to convey alarms from sensors to the operations center. Redundancy, alternative networks, new technologies such as WiMAX need to be considered.

As a decision support system, it is important to emphasize that this is a new approach, especially when used with many, large-scale deployments of WSNs at large administrative areas. Authorities, when more than one forest fires are in evolution at the same time, often need to decide where to assign the limited resources they have available. To do that, they can always rely on empirical assessments by locals. However, if such a tool as the one presented here could also be available, it would undoubtedly be of some use.

Such a system can be easily extended in terms of S/W and H/W. More WSNs can be added adhering a star topology and the base station of every one of them can communicate one level higher with the gateway in order to enlarge the space under monitoring. The gateway has at least one IP network interface as well as a wireless one, in order to communicate with the base stations of the stars/cells. In the case of a grid topology, **though not suggested for real time monitoring**, more grids can be added or more sensors can be added to a grid array. The software extension does not constitute a problem. New arrays can be added in the grid topologies and new clones of stars to the star topologies. Many aspects of the above still need to be worked out but as forest fire prevention becomes more important over time, we can only be optimistic about the things to come.

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