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Modeling of Wireless Sensor Networks for Detection Land and Forest Fire Hotspot

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Abstract — **Forest fires in Indonesia is one of big issue and disaster because of Indonesia located in tropical region, furthermore some of region consist of peat land that high risk for fire especially in dry season. Riau Province is one of region that regularly incident of forest fire with affected the length and breadth of Indonesia. This research proposes development of Wireless Sensor Networks (WSNs) for detection of forest fire hotspot in Indonesia, further case location in Riau province one of the region that high risk forest fire in dry season. WSNs technology used for ground sensor system to collect environmental data, any change by the times reporting to the data center to be analyze. Data training for fire hotspot detection is done in data center to determine and conclude of fire hotspot then potential to become big fire. The deployment of sensors will be located at several locations that has potential for fire incident in previous case and forecast location with potential fire happen. Mathematical analysis is used in this case for modelling number of sensor required to deploy and the size of forest area. The design and development of WSNs give high impact and feasibility to overcome current issues of forest fire and fire hotspot detection in Indonesia. The development of this system used WSNs highly applicable for early warning and alert system for fire hotspot detection.**

***Index Terms* — WSNs, Forest Fire Hotspot, Detection, Sensors**

I. Introduction

Land and forest fire in Indonesia is a disaster that incident annually happen, especially in summer season. Data shows that total loss because of this fire in 1997 is USD2.45 billion [1], but this loss still smaller compare to 1995, the loss is USD19.1 billion. Riau province is one of the state that high risk to this disaster because of type of land which is peat land. Total economic loss for Riau province in year 2015 because of fire up to USD1.65 billion. Beside economic loss, most of activities stop because of badly environmental (haze) and all of school, government office and other institution no activities. The impact of this land forest fire is not only in Indonesia or Riau Province but to the others country such as Malaysia and Singapore, because of Riau is directly border to that countries. Current procedure is using satellite to detect hotspot then informs to the authority and team will go to the site for action to stop fire, there is no prevention action although there is some socialization and campaign to communities to stop firing land and forest but in some area because of peat land its can be fire by itself.

Therefore, in this research focus on developing ground level smart monitoring system to detect and monitor the environmental behavior in term of temperature, humidity and gasses as represent fire hotspot parameters. The integration of WSNs sensors would have an effect to local community and local authority to access the information through developed real-time database online. It is anticipated to be faster and cheaper solution than to satellite data acquisition and this would definitely be beneficial to social welfare and economy development. In addition, the development of real-time database would also require some support from them as a policy maker to understand how the system works and also understand the pattern of the results so that an appropriate action can be taken.

II. Literature Review

Environmental monitoring caused by land and forest fire can be done in many ways, most of technology currently use is satellite images, by capture earth image to find hotspot for environmental detection. In Indonesia, satellite used as well for detection land and forest fire by government to monitor status of fire hotspot. A new technology use for hotspot detection is wireless sensor, this technology ability to detect potential of fire by analyze environmental changing. Proposes new method for land and forest fire detection and monitoring system to be able to give early warning system before fire disaster is happen, by analyze environmental changing with various sensors and detection method this system able to give accurate information of location as well early warning for prevention action. Fig.1 shows a satellite image for Indonesia hotspot status by mid of year 2017, most of hotspot located in central of Sumatera and west of Kalimantan Island.

Fig. 1. Fire hotspot in Indonesia based on satellite image [2].

Wireless Sensor Networks (WSNs) can be apply in many applications, such as in remote environmental monitoring, industrial automatic control, remote sensing and target tracking. The similar application system is in environmental monitoring system which is for fire hotspot detection that can make a real-time monitoring and detection. WSNs consists numerous number of small nodes in most situations, which small nodes are deployed in remote and inaccessible hostile environments or over large geographical areas. The large number of sensor small nodes sense environmental changes and report them to cluster head node or sensor base station, then through a gate way to transfer data to the servers which the deployment and maintenance should be easy and scalable.

A system to development of a simulator for approximates behavior of a wireless network of temperature sensors deployed in the area affected by a wildfire. Based on a new signal processing to approach in which the temperature experienced at a sensor due to a spreading of fire front is modelled as the mixture of two-dimensional Gaussian distributions as discussed [3]. WSNs based Wildfire Hazard Prediction (WFHP) system is a systematic description of architectural details and requirements of WSN for WFHP applications. The model measure in terms of network latency, energy consumption, and scalability is analyzed through simulation. Verification of model sanity and performance are carried out taking real weather datasets and their corresponding wildfire hazard outputs as benchmarks and elaborate in [4].

Modeling forest fires according to the Fire Weather Index (FWI) system which is one of the most comprehensive forest fire danger rating systems. Then, a model the forest fire detection problem as a node k-coverage problem (k ≥ 1) in WSNs. Approximation algorithms for the node k-coverage problem which is shown to be NP-hard. The simulation shows that algorithms: activate near-optimal number of sensors, converge much faster than other algorithms, significantly prolong (almost double) the network lifetime, and can achieve unequal monitoring of different zones in the forest [5]. Development of WSNs based on multi-sensor system and artificial neural network (ANN). Sensors (CO, CO2, smoke, air temperature and relative humidity) were integrated into one node of WSNs. An experiment was conducted using burning materials from residual of forest to test responses of each node under no, smoldering-dominated and flaming-dominated combustion conditions. For achieving higher identification rate, an ANN model was built and trained with inputs of four sensor groups: smoke; smoke and CO2; smoke and temperature; smoke, CO2 and temperature as discussed in [6].

Several research on Wireless Sensor Network (WSN) as discuss in [7], the WSN Simulator is developed based on proposed Sensor model and WSN model. The WSN Simulator address important design issues as: coverage of the area under surveillance in relation to initial sensor deployment, number of sensors needed for targeted deployment, and coverage change as function of time. A new approach for forest fire monitoring and detection as discussed in [8] which using data aggregation in WSN. The proposed approach can provide faster and efficiently reaction to forest fires while consuming economically WSN's energy, which has been validated and evaluated in extensive simulation experiments. Wireless sensor network be able to provide better solution for disaster management and rescue operations such as earthquake detection and alert system, flood detection, landslide detection, forest fire detection, water level monitoring of Himalayan Rivers, monitoring of glaciers, pilgrimage and tourist management are various examples where WSN can be used. Sensors are deployed for measuring various parameters and on [9, 10].

WSN algorithm to identify malicious data injections and build measurement estimates that are resistant to several compromised sensors and even when they collude in the attack. The methodology to apply this algorithm is in different contexts and evaluate its results on three different datasets drawn from distinct WSN deployments [11, 12]. The others research have been done is application of WSN in predicting natural disasters like hailstorm, fire, rainfall etc. by WSN are infrequent and stochastic [13]. As well as in design and implementation of a smart fire detection system using a WSN and Global System for Mobile (GSM) communication to detect fires effectively and reduce false positives, the system uses smoke and temperature sensors [14]. Application of WSN in energy conservation, reducing data transmission delay and improving the network lifetime. Used of cluster-chain mobile agent routing (CCMAR) for low energy adaptive clustering hierarchy (LEACH) and power-efficient gathering in sensor information systems (PEGASIS) [15].

III. Modeling of WSNs in Fire Hotspot Detection

Nowadays, many kind of monitoring system based on aim and objective as well as parameters to be monitor. Environmental monitoring for fire hotspot detection is implemented in some of institution or agency to monitor latest status of environmental. Current technology using is mostly from satellite data to detect hotspot of fire hotspot, this technology has some weakness and limitation such as only detect when fire already happen and in some case for example in bad weather or cloudy then satellite unable to penetration of cloud and image will not update. Ground sensing technology which is WSNs enable to penetrate smoke environmental as well as to detect fire hotspot. WSNs sensor will deploy in the area with high risk of fire to collect data such smoke detection, temperature, particle changing, etc. All the information collected by sensors will send to sensor base station as gateway to transfer data to monitoring system (data center) because the distance between sensor base station to monitoring system very far away more than 100 km in some area to monitor data to analyze any changing of environmental image. Beside new technology and smart sensors as elaborate previously, common environmental parameters such as temperature, humidity, wind speed and direction are applying in this monitoring system as supporting data to analyze potential of fire.

The use of WSNs sensors and base stations will setup at difference area to collect information from environmental and sensors deploy surrounding. Information collected by sensor forward to base station and will keep in internal database then send to monitoring system (data center), because of sensor base station locate in rural area that far away up to 200 km then solar panel system will use as power supply for system. Latest technology of communication system also proposes such as 4G technology or even 5G technology for future in order to achieve real-time data to display to monitoring system. In the end of this system expected be able to gives early warning before fire is happen to authority for prevention action. Fig. 2 shows a map of fire hotspot detected in Riau Province in Indonesia.

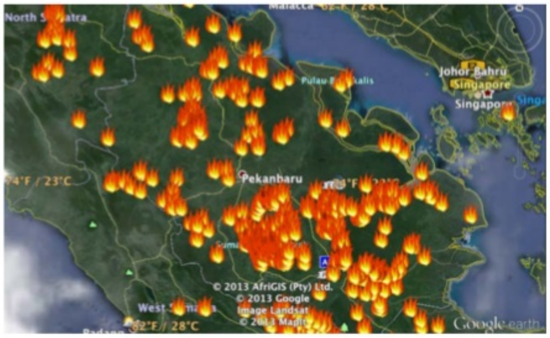

Fig. 2. Fire hotspot detected by satellite image in Riau Province.

The impact of land and forest fire to the land as shows in fig. 3, there are a few fire hotspots in smoke environmental. The point and typical of hotspot is very important to design and model of sensors in detecting of hotspot on the field, whether fire is spreading or point to a central of hotspot.

Fig. 3. Example of fire hotspot detected in a land fire.

Another model of fire in a forest with big fire is required to design WSNs sensor to detect how big the fire spreading and impact to the forest as shows in fig. 4.

Fig. 4. Example of fire hotspot detected in a forest fire.

The area of fire hotspot modeling coverage assumes a set of WSNs sensors distributed over a geographical region of land or forest area, in this case Riau Province in Indonesia is model to monitor that coverage area. Coverage function P is given as:

$$P = f(x, y, t) = \{(x_1, y_1), \ldots (x_n, y_n)\},$$
$$(x_k, y_k) = f(t), k = 1,2,3,\ldots,n \quad (1)$$

where (x, y) are coordinates of sensor within the monitored region, and t is time. Model is using a projection in the 2D space of a fire surveillance region, which is a 3D sphere. In the case of network is stationary, without mobile WSNs sensors, but the sensor positions are time dependent, since sensor nodes of WSNs are expected to stop operating in time. In this cease operation can have different causes: hardware faults, accidental, battery depletion, and intentional sensor removal, etc.

Assume to define coverage index IP as a scalar value representing the percentage of coverage for the area under the monitoring at a specific time as:

$$IP = \frac{\text{area covered with sensors}}{\text{the total area of the surveillance region}} \cdot 100\% \quad (2)$$

The basic model component is a WSN sensor node defined as a vector:

$$S = (d, E(t)) \quad (3)$$

where d is a range of sensor transmission, or radius of transmission area, the area covered by radio signal for data exchange with a neighboring node. E(t) is energy available for sensor power supply. Assume a homogenous sensor network with n unified type sensors and one hub-sensor for communication with a dispatcher node.

Network parameters are described as a vector:

$$M = (n, f_0, \Delta E) \quad (4)$$

where n is the number of sensors, fo is the frequency of regular transmissions, and ΔE is energy consumption per transmission. Assume that sensor nodes periodically transmit the data collected to the neighboring nodes. Energy consumption ΔE includes also energy spent in sensing and data processing. Each node has two roles:

(a) sensing environmental data and its transmission.
(b) receiving data from neighboring nodes and forwarding.

The sensing role is defined in accordance with the WSNs sensor network application, and can be easily influenced with sensor node type selection. Energy consumption ΔE is thus linked to the sensor node type and its value is listed in the sensor node data sheet. The forwarding neighboring sensor node data role is primary defined by communication protocol. WSNs simulator having knowledge of sensor nodes positions and defines paths for data forwarding employing optimization algorithms. Assume that routing optimization would be implemented in the real protocol as well. In order to simplify the model, each sensor node is aware of its GPS co-ordinates, which are used in communication as an identification code. It is also assumed that the hub node initially broadcasted across all the nodes. Based on these assumptions it is possible to implement optimized routing algorithm. Energy consumption needed for receiving and forwarding neighbor data is ΔE. Object under surveillance is modeled as four-side stationary polygon defined as a set:

$$O = (A, B, C, D) = \{(x_A, y_A), (x_B, y_B), (x_C, y_C), (x_D, y_D)\} \quad (5)$$

where A, B, C and D are polygon points with co-ordinates (x, y).

The role of WSNs hub sensor node is to collect data from each sensor node and forward the data to base station or co-ordination center. Data package received and forwarded by the hub node contains originator sensor node address and measurement values (temperature, humidity and CO_2). The WSN hub node has uninterrupted power supply and that communication channel between the hub node and co-ordination center is unremitting. Hence, simulation is treating the hub sensor as "constantly available". The main objective of the simulation is to optimize network routes for data transmission from sensor nodes to the hub node [7].

In addition of the use and model of fire hotspot sensor to prevent incident of fire, the environmental sensor in WSNs system to detect several of parameters that normally appear because of land and forest fire such as Carbone Dioxide (Co2), Haze, Air Temperature and Humidity. Fig. 5 shows impact for environmental because of land or forest fire, case recorded from Pekanbaru City in Riau Province Indonesia.

Fig. 5. Topology of WSN sensor nodes deploy in forest for fire detection.

IV. Development WSN in Forest Fire Detection

Forest fires are a natural and recurrent phenomenon or manmade, in many case of the world. Burning areas are mainly located in temperature climates where its rainfall is high enough to enable a significant level of vegetation, but in summers session are very hot and dry environment, be able to create a dangerous fuel load. Global warming will contribute to increase the number and importance of these disasters. In every season, not only are thousands of forest hectares destroyed by wild land fires, but also properties, assets and public resources and facilities are destroyed because of fire.

A forest fire in general a dynamic phenomenon that may changes its properties and behavior by the time from one place to another and with the passage of time. In the fact that the forest fuel available in a given location is limited, for a fire to continue it must spread to neighboring fuel. This is performed through the complex heat spread to neighboring fuel and performed through the complex fire behavior. Another approach is also based on the WSNs paradigm has been designed and developed in the context of a research project that included all the key actors in forest as well as fire fighting for operations. This unique proposed ecosystem has provided the solution with a holistic perspective that results in a set of distinguishing features, which all node types can include environment and meteorological sensors.

Another scenario is in fig. 6 shows a schematically structure proposed of the development ZigBee-WSNs-based system for land and forest fire detection and protection management, consisting of multi-sensor nodes, coordinators, cluster heads, routers and remote decision server. This cluster-tree network topology structure proposes design to reduce the loss of energy and data package while transferring. ZigBee technique is a global standard based on IEEE 802.15.4 applicable for low-rate wireless Personal Area Networks (PAN). ZigBee is one of the wireless network standard targeted at low power sensor that apply in multi frequencies 868 MHz or 915 MHz and 2.4 GHz. The technical advantage proposes of ZigBee is to offer a system with long battery life, small size, low-cost, high reliability and automatic or semi-automatic installation. Therefore in this development design WSNs node to achieve an optimal choice for forest fire detection and monitoring [16].

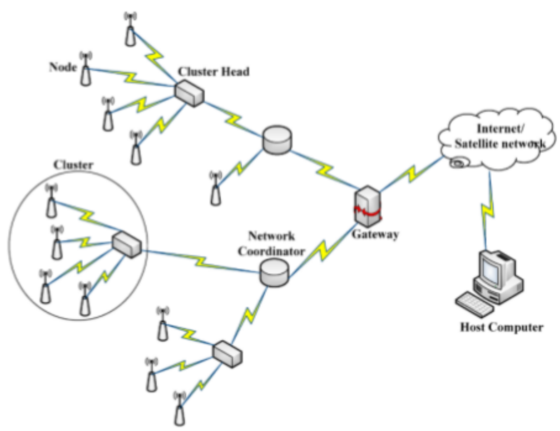

Fig. 6. A WSN sensor nodes propose use ZigBee standard.

Actual hardware on WSNs node for fire hotspot detection and monitoring can be found in many types in the market. Where temperature, humidity, smoke and carbon sensor installed in the node to detect all the parameter that high relation to the forest fire. Fig. 7 shows actual fabricated sensor ready to deploy, before sensor node deploy in the field the sensor nodes have to configure based on design and requirement. All the nodes will send a data or message to the WSNs coordinator that has function to receive all information from node scattered.

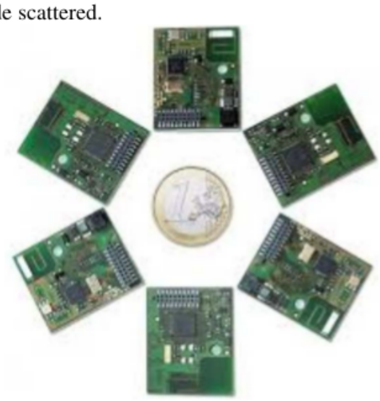

Fig. 7. A WSN sensor nodes propose use ZigBee standard

Proposed monitoring system expected to detect any abnormality in environmental for land and forest fire, monitoring system normally used by government institution or agency assign to do a monitoring. With a new technology proposed with smart sensors, the system may adopt by many company to detect and monitoring environmental based on they are purpose. For example, a paper and pub company may use this monitoring system for detection fire or hotspot at they are farming area. Furthermore, the monitoring system can be used for community for they are to know environmental status such as air quality, temperature, humidity, etc. A mobile application can be done based of data collected then community be able to check environmental by remote in mobile phone or others mobile device. The application and product potential for market and new novelty based on smart sensor developed, a decision easier to do because have some background and real data. During research and development of smart monitoring system, government and some private institution such as industrial and community have to involve in this project. Information of area with high risk and placement of sensor base station in correct location is very important to achieve faster and accurate data to send to monitoring system. Thus, some information from local community is really helping to determine sensor location. Government institution as well because to get license to enter in some of area that under control of government for example protected forest area and special land for industrial etc.

V. Conclusion

Development of WSNs nodes for land and forest fire detection, furthermore for monitoring have been modelled. In this case the design and analysis use mathematical approach according to the area have to cover which in the whole Riau Province in Indonesia. Air temperature and humidity, haze and Co2 sensor are high light in this case because of those parameters are basic parameters to the fire hotspot case either in the land or forest area. Proposed design sensors node use ZigBee model, with low power then sensor nodes can use in long life as node powered by battery. In order to cover the whole of Riau province, minimum have to create network coordinator in each of area and a gateway to access in server (cloud database) as well monitoring computer. Theoretical proposed concept of WSNs very applicable to use for detection forest fire, especially in Riau Province in Indonesia.

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