An Action Activated and Self Powered Wireless Forest Fire Detector

Johan Sidén[1,2], Andrey Koptyug[2], Mikael Gulliksson[2], and Hans-Erik Nilsson[1]

[1] Mid-Sweden University, Electronics Design Division,
851 70 Sundsvall, Sweden
{Johan.Siden, Hans-Erik.Nilsson}@miun.se

2 Sensible Solutions Sweden AB, Storg. 90
851 70 Sundsvall, Sweden
{Andrey.Koptyug, Mikael.Gulliksson}@sensiblesolutions.se

Abstract. Placing fire detectors in a forest is usually associated with powering problems since the sensors do not have access to external power supply and a periodical change of internal batteries is an undesired option. This paper presents an approach where the fire sensor itself, when heated by nearby fire, generates electrical energy to power a radio transmitter. Presented energizing fire sensor is environmentally friendly and can be mass produced at a very low cost. Upon activation the sensor produces enough power necessary to operate most standard radio transmitters depending on what communication system is chosen for operation. The fire detector unit can be deployed from either helicopter or manually from the ground. The sensor can be designed to activate itself at different temperatures to suit different climate zones. Rough guidelines are given for estimation of attenuation of radio wave propagation in forest areas in order to predict maximum transmit distance.

Keywords: Forest Fire Detectors, Action Activated Tags, Energizing Sensors

1 Introduction

Forest fires, particularly those occurring in dry windy weather pose serious risks. Such fires can cause significant deforestation, resulting in the loss of wild life and its habitat, seriously changing ground water levels and river flows, changing microclimate etc. Private and industrial properties are also damaged and it can result in the loss of human lives. As populations and the attractiveness of “green living” increase, forests are being subjected to more and more exposure to human activities, which in turn, can lead to the triggering of forest fires.

In order to avoid the serious consequences associated with forest fires, improvements in fire prevention, detection, monitoring and fighting are constantly being carried out. It is commonly accepted that forest fire prevention and its detection at the earliest possible stages are the most critical exercises. Significant progress is currently being achieved in all the above mentioned areas, but fire detection and progress monitoring are more dependent on technology than are the preventive measures.

Early forest fire detection and precise localization significantly reduce both the problems and costs associated with fire fighting because of the increased efficiency involved in tackling the fire. At the same time, there should be a corresponding system able to provide real time information with regards to the initiation and progress of a fire which is neither too complex nor excessively expensive [1]. Several approaches to achieve this have been suggested, some of which are already in use at the present time and involving the use of remote sensing, area imaging and laser-based detection. This paper proposes a different approach, based upon wireless sensor-nodes with energizing sensor elements to power the radio unit.

2 Existing Fire Detection systems

Area imaging systems are either based on stationary ground towers [2], [3], or are air-born [4] or satellite based [5]. In this instance, fire detection is based on the computer analysis of the images, often acquired in multiple spectral bands [6]. In recent years, satellite imaging in forest fire detection has received increasing attention, primarily due to its possibility to scan large areas. Significant progress has been achieved in this case, through the development of better imaging sensors [7] and also in improvements to image processing [8]. At the same time, complex processing algorithms may require both very high resolution images and significant processing time, which makes real-time fire detection an impossibility. Airborne (airplane and helicopter based) imaging systems are commonly less expensive than satellite ones, but they require far more complex management and cannot compete with satellite imaging in either area coverage or the continuity of monitoring.

Imaging systems also often lack the necessary resolution and sensitivity in cases involving thick clouds and thick smoke generated by the fire itself. Laser-based systems, referred to as LIDAR type [9] help to overcome these problems. However, laser beams are very narrow and almost non-diverging and in order to provide adequate area coverage using a single LIDAR unit, it should be operated in a sweeping mode, as is the case with RADAR. Such mechanical systems, capable of fast angular LIDAR area sweeping, can be complex and rather expensive. Another serious disadvantage of the above optical and laser based systems is that they not only require constant technical attention and thus could not be easily maintained in inaccessible areas, but also utilize a serious amount of power in order to operate.

Small stationary sensors provide an attractive alternative or a valuable addition to the systems involved in the early detection of forest fires. Such sensor systems can provide almost instantaneous fire detection combined with very high localization precision. Wired fire sensor networks commonly used inside buildings are not really applicable in this case because of the costs and technical difficulties involved in covering large forest areas. Consequently, to be effective such networks must use radio communication. Thus, each sensor should not only be able to detect the fire but also be able to send this information to the nearest monitoring station.

Because such sensors must be permanently deployed in the forest, certain preconditions must be fulfilled. Ideally such system should meet following requirements:

- The system should be able to cover large forest areas;
- The system should be able to recognize which sensor has produced the alarm signal (localization);
- Sensor units should be relatively small and easy to deploy (includes deployment from air);
- The sensor units should have a very long lifetime and, once deployed, should be maintenance free for several years;
- Sensor units should not contain materials or components potentially dangerous to the environment, wild life or humans;
- The sensors should not emit dangerous chemicals when destroyed by fire.

Presently, the most promising area is considered to be that utilizing the concept of networked sensor nodes, which either use existing wireless networks such as GSM/GPRS or through the formation of separate dedicated networks, including those based upon TCP/IP [10]. In the case with TCP/IP, the individual sensor node is not forced to radio-communicate its signal directly to a monitoring station, but only to the nearest re-broadcasting node. This assists in significantly reducing the transmitter output power and thus enabling it to be kept within specified limits.

Mentioned existing wireless sensor node solutions are rather bulky and use heavy-duty batteries which somewhat limits their application in forest fire detection systems since such units require regular service such as battery replacement and are relatively expensive. They must also be deployed in accessible places and contains significant amounts of potentially harmful chemicals (the battery, solder, plastics etc.). Promising concepts involving power harvesting from various environmental processes like light, vibrations, etc. [13] has not yet yielded a satisfactory solution which enables maintenance-free power sources for such sensor nodes, but has been able to significantly prolong the lifetime of traditional batteries.

This paper presents a solution, based on the new maintenance-free Action- Activated Tag (AAT) concept. Upon activation, this sensor provides sufficient electric power for a radio-transmitter to operate before being completely destroyed by the triggering fire.

3 The Action Activated Tag Concept for Forest Fire Detection

The Action Activated Tag concept refers to systems using the detected physical quantity (in this case heat) to produce or release sufficient power to operate the necessary electronics. These sensors can be compared with printed dry batteries and were originally developed for wetness detection in incontinence diapers where a sufficient amount of wetness powered a low-power radio transmitter when a diaper required changing [16]. These sensors were modified for use as secondary sensors in a fire detection system. In this case, raising temperatures triggers the release of a small amount of water, stored in a small container inside the sensor body. The water activates the small energy cell, providing power for the sensor node electronics. The construction of the discussed fire sensor unit is outlined in Fig. 1.

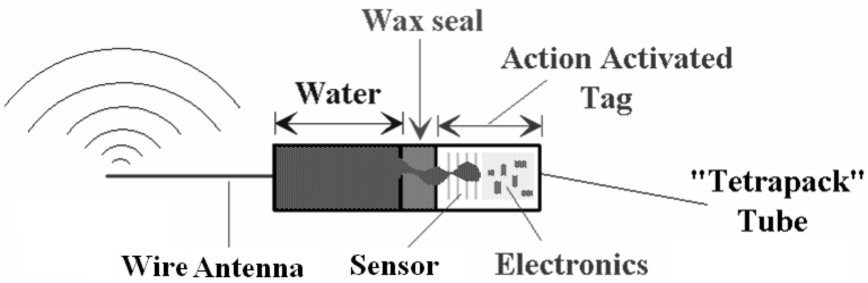

Fig. 1. Functional drawing of the AAT fire sensor node illustrating how water is entering a moisture sensor when a protective wax seal melts under significant heat.

The small water container in the sensor is separated from the sensor element by a plug that melts at a given elevated temperature, allowing water to flow over the sensor, which in turn produces sufficient electrical power to operate the radio transmitter. The construction of the sensor involves printing using special inks and layers of absorbent paper and fibrous materials and is cheap and suitable for bulk manufacturing. The transmit antenna is made of thin wire and the components of the sensor node are encapsulated into an impregnated carton tube, using technology similar to that the food industry uses for juice and milk packages.
The AAT sensor node is constructed in such a way as to minimize any possible environmental impact. Paper-based and other fibrous materials are sufficiently robust in order to withstand seasonal weather changes for several years, but will biodegrade in the longer term. The main triggering chemical is ordinary water and the overall metal and plastic content is almost negligible as it is measured in milligrams per sensor. Instead of using a conventional printed circuit board (PCB), the few necessary electrical components are mounted on a bio-degradable wooden chip substrate using silver ink for conductive traces. Thus, if the sensor is burnt in the fire or degrades over time, dangerous substances will not be produced as a by-product.

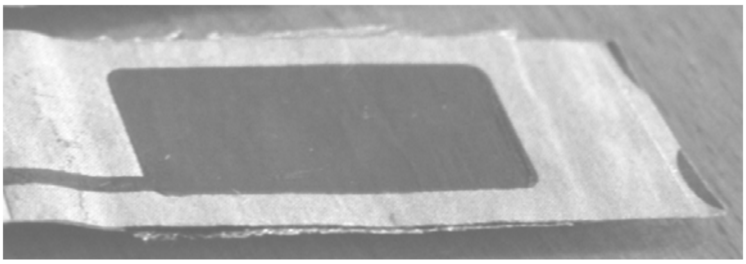

Fig. 2. Example of a single sensor element consisting of layers of “newspaper grade” paper with zinc- based (top layer) and carbon based ink (bottom layer). Absorbing layer (doped with electrolyte and dried) is placed between the active layers.

If the sensor unit would be tampered with, the thin wire antenna and the sensor casing will both readily break. The wax plug at normal ambient temperatures is solid and mechanically stronger than the water container, why the water does not enter the sensor area if it for example is stepped upon, but will exit the casing in the opposite direction and not result in a false alarm. It is also a necessity that the wire antenna break easily in order to prevent any harm coming to animals accidentally stepping on a fallen fire sensor and an additional aid to prevent false alarms from vandalism.

The sensor cell is assembled by stacking a few individual paper strips together, each printed with inks with different electrical properties. One of the possible constructions of the printed sensor is shown in Fig. 2. Ink is applied to a paper base using traditional rotary screen or flexographic printing which is a common roll to roll manufacturing process. The inks used are mainly mixtures of carbon, zinc and manganese dioxide. The absorbent layers are doped using a non-harmful electrolyte such as citric acid or cooking salt. The sensors have a very long lifetime and start to produce electric power as soon as a few milliliters of water reach the active area [16]. The sensor element illustrated in Fig. 2 has an active area of a few cm^2 and gives about 1.2 V when wet. To increase the delivered power, sensors are made of several cells rolled together into a compact cylindrical shape.

The wax plug material can be selected to melt at pre-determined temperatures. Tests have been carried out using several different wax substances known to be environmentally friendly and melting points from about 50 to just over 100°C have been observed. Other alternatives include natural asphalt and tar materials depending on the required temperature. It is possible, that minor sensor unit modifications would be required for different climatic zones because of significant differences in the highest summer and lowest winter temperatures. Both the sensor and the node electronics are capable of surviving at temperatures well in excess of 100 °C thus providing proper functionality after the wax seal is broken.

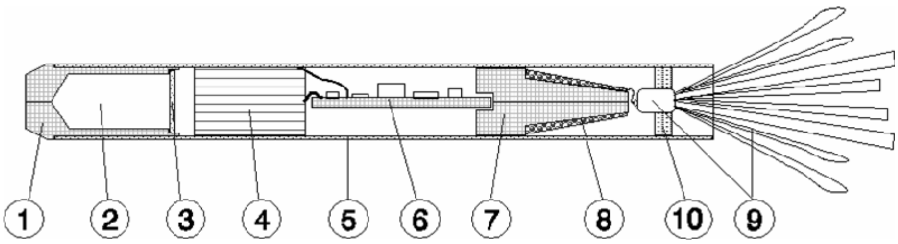

Fig. 3. Cut-through view of the sensor node unit, ready for deployment. (1)- water container with water (2) and wax plug seal (3); (4)- dry sensor element . (5)- paper- based tubular casing; (6)- board with electronic components; (8)- antenna wire, rolled onto the conic rear plug (7); (9)- fluffy tail; (10)- tail fixing plug. See text for further comments.

The AAT sensor node in the present design has a similar formation to that of a small lightweight “rocket” with a fluffy tail that is about 2-3 m long and 2-3 cm in diameter. A cut-through view of the model sensor node unit is displayed in Fig. 3. The nose and tail cone plugs (1 and 7 in Fig. 3) are made of wood. The outer shell (5) is rolled from a few paper layers. Water in a small container (2) is sealed using a wax plug (3) and placed near the rolled moisture-activated sensor element (4). A small board containing the electronic components is fixed in the slot of the rear conic plug (7). To protect the electronics from outer water, it is protected by a layer of environmentally friendly lacquer. The antenna wire, rolled onto the conic part of the rear plug, is pulled out by the fluffy paper strip “tail” (9). The tail is initially fixed in place using a felt plug (10).

To improve the sensor activation, some ethanol (boiling point 78°C) can be added to the water. At seriously elevated temperatures the ethanol vapors and increase the pressure behind the wax seal, assisting it to burst, when it becomes soft. This is helpful in order to inject the liquid into the sensor when the unit is not oriented in a direction that allows injection by gravity. It also assists in the prevention of sensor destruction caused by freezing liquid expansion.

Using the node construction and materials described above it is estimated that it is possible to bring the manufacturing cost per unit down to approximately € 1-3 in the case of mass production depending on the total number of units and choice of radio system.

In order to ensure that the overall system cost remains as low as possible, a simple means of sensor node deployment is necessary. Because AAT sensor nodes are relatively lightweight, they could be deployed from the ground with the assistance of a “slingshot” or similar. At the deployment the coiled thin wire antenna is removed by the flow of air in the fluffy tail and is meant to entangle itself in tree branches or in a bush.

When the sensor node is deployed it may be necessary to record its location, particularly if the monitoring station is at a distance. This is possible by including a short-range and low-cost RFID tag [18] within the sensor unit. The RFID tag’s unique ID number and current position is automatically read by an RFID reader within the deployment mechanism and recorded into a database together with aid of a GPS receiver. The same identity number is used when the sensor transmits the alarm signal.

In order to cover significant areas, this system must be supported by a number of more powerful “Zone nodes” where each will have a number of the presented sensor nodes within reach (see Fig. 4). These Zone nodes could be GSM/GPRS based, and would be able to provide direct links into existing networks, or form separate network of their own, linked to the fire monitoring station.

Alternatively, Unmanned Aerial Vehicles (UAVs) could be used as mobile relay stations to scout the air space above the forest, listening for the alarm signals [19]. Modern medium and small UAVs are capable of being in the air for up to 24 hours, constantly maintaining radio links with the “base” directly, via satellite or via GSM/GPRS systems.

An advantage of a UAV-based intermediate system is that one UAV, high up in the sky, is able to cover a much greater area than an earthbound zone node because a radio signal emerging from an alarming sensor is attenuated much less when propagating through air than through forest foliage in an uneven landscape.

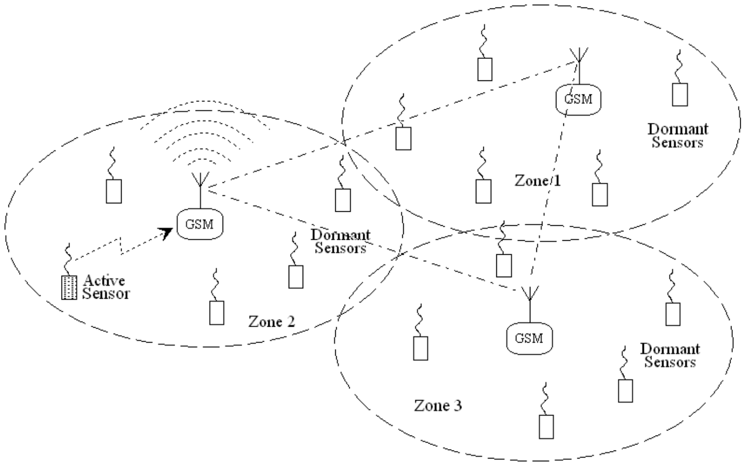

Fig. 4. Simplified hierarchical network structure of the Forest Fire alarm system, based on the AAT sensor nodes.

4 Radio Communication Challenges in Forest Fire Detection Systems

A high sensor unit cost may force the use of a relatively low sensor density in the forest (say, one sensor per several square kilometers), thus reducing the system's capability of detecting the initiation of a fire sufficiently rapidly. If the sensors for example are placed in a square grid with a grid distance of 1 km, and the assumption is made that a fire will spread uniformly in all directions from a starting point, an average circular area of 0.39 square kilometers will be burnt before the sensor unit produces an alarm. A dedicated radio communicating system therefore appears to be more appropriate for the sensor nodes and the use of GSM/GPRS should be used at the zone nodes.

5 Radio Wave Propagation in Forested Areas

There are factors limiting the transmitted power such as the limited capacity of the power source and the legal restrictions for the used communication band, such as those put up in the "free bands" found in [20]. Maximizing the alarm detection distance is therefore of importance. Additionally, in the forest environment the signal will be attenuated by the foliage and branches, further reducing the communication distance.

The most basic formula for the estimation of received power P_r from a unit transmitting with power P_t at a distance R and at a frequency f is the *Friis Transmission Formula* [21]:

$$P_r = \frac{P_t G_t G_r \lambda^2}{(4\pi R)^2} \tag{1}$$

where λ is the free space wavelength, $\lambda = c/f$ and $c = 3 \cdot 10^8$ m/s is the speed of light. G_t is the gain of the transmitting antenna and G_r the gain of the receiving antenna. Gain is a measure of how an antenna directs its radiated and received power. The preference for this specific application is that an activated alarm unit transmits with equal power in all directions, as it is not possible to predict the spatial orientation of the antenna in a sensor dangling in the trees. The receiving antenna should also have similar properties and should be of circular polarization to minimize the risk of a polarization mismatch. The proposed linear sensor antenna radiates almost omni-directionally, acting either as a traditional half- or quarter-wavelength dipole- or monopole antenna with a toroidal directivity pattern [21] and gain factor of approximately $G \approx 1.6$.

Analysis of (1) provides the general conclusion that with a fixed transmitter power P_t available for radio transmission and fixed threshold received power P_r for alarm signal recognition, the lower transmission frequency (larger wavelength) will provide a longer communication distance R. It should be noted that this conclusion is drawn without taking the frequency dependence of the radio waves attenuated by the forest into account. Unfortunately, this conclusion can also not be fully utilized in present form as it assumes that the antenna size is changing with frequency, which is a significant part of the wavelength. In reality, a sensor unit antenna of length greater than 1-2 meters would be impractical since modules with antennas of such length would be hard to deploy. The correct analysis should take into account the change in the antenna efficiency (gain factor) and the attenuation of the signal by the forest and soil at chosen frequency bands allowable within such systems.

To be efficient, this type of antennas must have dimensions close to one quarter- or half wavelength [21]. Also, the ideal shape for a longer antenna of a sensor deployed in a forest and which will be possibly be dangling in the tree branches has an increased chance of becoming distorted (i.e. not being straight). Corresponding correction factors for the system performance in such a case could be taken from [22] where the performance of bent dipole antennas is characterized. There is also the possibility to redesign antennas in order to achieve higher robustness without seriously degrading their performance [23].

Among the frequency bands, allowed by the EU authorities for license-free transmissions are 13.56 MHz ($\lambda/_4 \approx$ 5.5 m), 27 MHz ($\lambda/_4 \approx$ 2.25 m), 433 MHz ($\lambda/_4 \approx$ 17 cm) and 865-869 MHz ($\lambda/_4 \approx$ 8.7 cm) [20].

Friis Transmission Formula does not take into account additional signal losses caused by the environment of the antenna, however many models exist which allow for this scenario. One of the simplest, but most accurate, models is a *two-ray* model. This model considers two antennas elevated above the ground (transmitter antenna at H_t and receiver antenna H_r), and takes into account one direct radio-signal and one reflected from the ground as illustrated in Fig. 5.

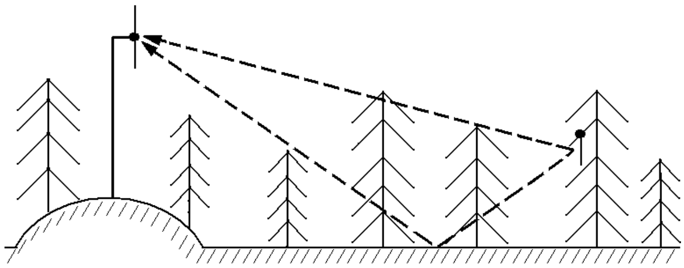

Fig. 5. Two-ray radio propagation model where the activated fire alarm unit is deployed on a tree branch and the alarm unit's antenna is hanging down. The alarm unit transmits a signal that reaches the base station both directly and via reflection in the ground.

In the case where the working frequencies are lower than approximately 50 MHz, the ground wave should be taken into account. In the forest environment the ground wave is actually a "canopy" one, traveling along the tree top line. The propagation of both the direct- and reflected waves is calculated using the Friis transmission formula and the total received power due to the superposition of both signals is expressed in the two-ray model as [24]:

$$P_r = \frac{P_t G_t G_r \lambda^2}{4(\pi R)^2} \sin^2\left(\frac{2\pi H_t H_r}{\lambda R}\right) \quad (2)$$

where H_r and H_t are the receiver and transmitter antenna elevations, respectively, and all other values are as in expression (1).

The second term in expression (2) describes the interference pattern, caused by superimposing two waves with different phase lag. For larger distances $H_t \cdot H_r << \lambda \cdot R$ the approximation $\sin x \approx x$ can be used and expression (2) can be simplified as:

$$P_r = \frac{P_t G_t G_r (H_t H_r)^2}{R^4} . \quad (3)$$

Interestingly, but as according to (3), the communication distance R is no longer dependent upon the working frequency (or the wavelength, which is the same) for a fixed transmitter power P_t and the fixed threshold receiver power P_r.

Losses due to the soil and forest foliage can be also taken into account:

$$P_r = \frac{P_t G_t G_r (H_t H_r)^2}{R^4} \cdot e^{\alpha R} \quad (4)$$

In this case it is possible to use the empirically determined attenuating factor $\alpha \approx 0.2$ dB/m, (measurements were carried out for different kinds of forest terrain [25]). Fig. 6 presents a comparison of the propagation attenuation dependence on the distance from the transmitter, as calculated using expressions (1)-(4).

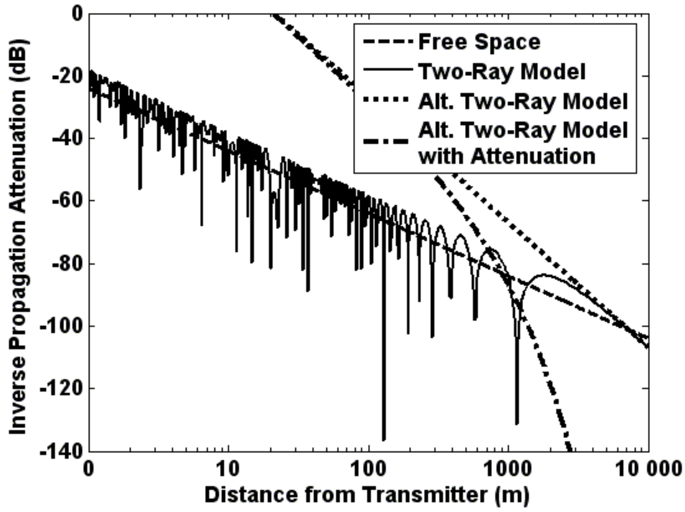

Fig. 6. Attenuation of radio waves transmitted with 2W ERP as modeled using equations (1)-(4). See text for the details.

The attenuation plotted in Fig. 6 was calculated for the frequency f=866 MHz with the transmitter power of P_t=2 W [27]; $\lambda/_4$ dipole antennas with G_t= G_r= 1.64; antenna elevations of H_t=10 m, H_r=20 m; attenuation factor α=0.2 dB/m, using equations: (1) {*"Free Space"*}, (2) {"*Two-Ray Model*"}, (3) {*"Alt. Two-Ray Model"*} and (4) {*"Alt. Two-Ray Model with Attenuation"*}.

Modern radio communication integrated circuits for digital communications have the sensitivity of approximately 130 dB or better, thus the communication distance between the sensor and receiving station could be several kilometers.

These very basic and generalizing calculations in fact only consider the received power. A more accurate *link budget* should consider the Signal to Noise ratio (SNR) for the specific modulation scheme, Bit Error Rate (BER), codes for Forward Error Correction (FEC) and, preferable, even more variables that affect the overall system performance. Overviews of more thorough link budget calculations are found in [24] and [29]. Generally, it is however possible to state that as long as an efficient antenna is available, the lower the wavelength, the longer the maximum communication distance. This does not follow from equations (1)-(4) but certain benefits may be gained, and it is characterized for forested areas in for example [25]. A similar rule of thumb holds for the bit rate where the lower this is the more reliable the communication is which is advantageous for this application since a minimum amount of data is required.

Mentioned models offer *estimates* for reliable communication ranges. For a specific application and area, the only means of achieving genuinely reliable numbers is to perform field tests using the designated equipment.

6 Conclusions

A new electronic forest fire detection system built on the concept of distributed sensors, referred to as Action Activated TAGs (AAT), is presented. The system comprises low-cost sensor units, easily deployed from air or ground. The AAT sensors are dormant and start to transmit the alarm signal only when subjected to the significantly elevated temperatures of a forest fire but not when they are tampered with. The presented sensors are able to overcome serious problems which are present when other electronic forest fire detection sensors are used. The sensor units are lightweight, have a significant life span, are environmentally friendly and are inexpensive to mass produce.

Further development of fire detection systems using AAT sensors is required as is additional work on the sensor construction to maximize the communication distance.

References

[1] D. L. Martell, R. S. McAlpine "Forest Fire Detection Economics", *Wildfire Detection Workshop, March 25 - 27, 2003, Hinton Alberta, Canada*

[2] E. Kührt, J. Knollenberg, V. Mertens "An Automatic Early Warning System for Forest Fires", *Annals of Burns and Fire Disasters - vol. XIV - N 3, September 2001*

[3] D. Schroeder "Evaluation of three wildfire smoke detection systems", *FERIC, Vancouver, B.C. Advantage Report, 2004, Volume 5 , No. 24, p.8*

[4] "Firehawk™, Electronic Forest Fire Detection and Management System", *IFFN No. 23 - December 2000, pp. 105-108*

[5] Y. Rauste, E. Herland, H. Frelander, K. Soini, T. Kuoremaki, '"Satellite-based forest fire detection for fire control in boreal forests", 1997, *International journal of Remote Sensing V18, N.12, pp. 2641-2656*

[6] Y. Li, A. Vodacek, R.L. Kremens, A.E. Ononye, C. Tang, "A hybrid contextual approach to wildland fire detection using multispectral imagery", *2005, IEEE Trans. Geosci. Remote Sens. V.43, pp.2115-2126*

[7] J. Leijtens, A. Court, J. Hoegee, "Microbolometer Spectrometer, Instrument and Applications", *Proceedings of The 4th Symposium Small Satellites, Systems and Services, La-Rochelle, France, 20-24 September, 2004*

[8] A. Ononye, A. Vodacek, R. Kremens, "Improved fire temperature estimation using constrained spectral unmixing", *Proc. 10th Biennial USDA Forest Service Remote Sensing Applications Conference, Remote Sensing for Field Users. Salt Lake City, USA, 2005*

[9] A. Utkin, A. Fernandes, A. Lavrov, R. Vilar, "Eye-safe Lidar Measurements for Detection and Investigation of Forest-fire Smoke", *Intl. Journal of Wildland Fire, V13, 2004, pp. 401- 412*

[10] A. Dunkels, T. Voigt, J. Alonso, H. Ritter, J. Schiller, "Connecting Wireless Sensornets with TCP/IP Networks", *Proceedings of the Second International Conference on Wired/Wireless Internet Communications (WWIC2004), Frankfurt (Oder), Germany, February 2004, Springer-Verlag.*

[11] N. Rodriguez, G. Bistue, E. Hernandez, D. Egurrol, "GSM Front-End to forest fire detection", *Proceedings of ISTAS 2000, Roma, September 2000*

[12] R. Kremens, A. Seema, A.Fordham, D. Luisi, B. Nordgren, S. VanGorden, "Networked, Autonomous Field Deployable Fire Sensors", *Proceedings of the 5th International Wildfire Safety Summit, Missoula, MT, USA, November 2001*
[13] M. Philipose, J. R. Smith, B. Jiang, K. Sundara-Rajan, A. Mamishev, S. Roy, "Battery-Free Wireless Identification and Sensing", *IEEE Pervasive Computing, V4, N. 1, Jan 2005*
[14] J. Schiller, A. Liers, H. Ritter, R. Winter, T. Voigt, "ScatterWeb - Low Power Sensor Nodes and Energy Aware Routing", *Proceedings of 38th Hawaii International Conference on System Sciences (HICSS-38 2005), 3-6 January 2005, Big Island, HI, USA*
[15] S. Roundy, P. K. Wright, J. M. Rabaey, "Energy Scavenging for Wireless Sensor Networks : with Special Focus on Vibrations", *Kluwer Academic Publishers, 2004*
[16] H-E. Nilsson, J. Sidén, T. Unander, T. Olsson, P. Jonsson, A. Koptioug, M. Gulliksson "Characterization of moisture sensor based on printed Carbon-Zinc energy cell", IEEE Proceedings of Polytronic 2005
[17] J. Sidén, A. Koptioug, M. Gulliksson, The "Smart" Diaper Moisture Detection System, Microwave Symposium Digest, 2004 IEEE MTT-S International, Vol. 2 pp. 659 – 662, 2004
[18] K. Finkenzeller, "RFID Handbook", ISBN 0-470-84402-7, John Wiley & Sons 2003
[19] Z. Gouqing, L. Chaokui, C. Penggen, "Unmanned aerial vehicle (UAV) real-time video registration for forest fire monitoring", Geoscience and Remote Sensing Symposium, 2005. IGARSS '05. Proceedings. 2005 IEEE International, Volume 3, 25-29 July 2005 Page(s):1803 – 1806
[20] European Telecommunications Standards Institute, ETSI, www.etsi.org, visited 060515
[21] D. K. Cheng, "Field and Wave Electromagnetics", 2nd edition, ISBN 0-201-12819-5, p., Addison Wesley, UK, 1989
[22] J. Sidén. P. Jonsson. T. Olsson, G. Wang, "Performance Degradation of RFID System due to the Distortion in RFID Tag Antenna" , Proceedings of the 2001 11th International Conference "Microwave & Telecommunication Technology" (CriMiCo'2001), IEEE Catalog Number: 01EX487, 2001
[23] J. Sidén, P. Jonsson, A. Koptioug, "Printed RFID tag antennas with minimal performance degradation when bent", in the Proceedings of Asia Pacific Microwave Conference 2003, APMC'03, 2003
[24] L. Ahlin, J. Zander, Digital Radiokommunikation –System och Metoder, *Studentlitteratur*, p. 36, ISBN 91-44-34551-8, 1992
[25] I. Koviics, P. Eggers and K. Olesen, "Radio channel characterisation for forest environments in the VHF and UHF frequency bands", *IEEE Proceedings 1999*
[26] L. Melin, M. Ronnlund and R. Angbratt, "Radio Wave Propagation. A Comparison Between 900 and 1800 MHz", *IEEE Proceedings,*
[27] European standard, ETSI 302 208, *European Telecommunications Standards Institute*, 2005
[28] D. W. Casbeer, R. W. Beard, T. W. McLain, L. Sai-Ming, R. K. Mehra, "Forest fire monitoring with multiple small UAVs", American Control Conference, 2005, 8-10 June 2005 Page(s):3530 - 3535 vol. 5
[29] Theodore S. Rappaport, "Wireless Communications", Prentice Hall PTR, IEEE Press, ISBN 0-7803-1167-1, 1996