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Evaluation of Forest Fire Awareness System Performance Characteristics

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***Abstract* - Modern sensors systems have been designed and developed to monitor remote areas like forests utilizing wireless communication means. Nevertheless, deployed systems do not operate as expected, lacking reliability. This is due to the fact that deployment strategy does not employ thorough environmental effects. These conditions imply network performance degradation or even failure under certain circumstances. Thus, technology and network limitations should guide design and deployment of forest fire sensor networks towards sophisticated alternatives to cope the gap. Such alternatives should not only overcome the narrow communicational limits, either physical or logical, but also improve operational characteristics.**

This paper describes a methodology to improve forest fire sensors network effectiveness under near real environmental conditions. In order to evaluate the impact of the actual operational characteristics towards the manufactural ones we utilised simulation tools like Opnet. Modeling the sensor networks under different conditions we draw out the outline of the environmental effect.

Keywords – Forest fire wireless awareness systems, weather conditions, system availability and reliability, simulation.

I THEORETICAL BACKGROUND

Forest fires are devastating not only for the environment but for the people's quality of life as well. Most crucial about forest fires is the early stage counter fighting. In order to become aware of a fire event as soon as possible sensor networks are involved. Wireless sensors technology is the most cost effective solution for this application and several products have been developed for this cause.

But technology does not solve all the problems, as the environment imposes extra requirements and drawbacks. At first, air as a medium deteriorates the transmitted signal due to the selective absorption of its ingredients as oxygen and water vapors. In fact, their contribution to communicational deterioration is limited in comparison to the environmental conditions. These conditions are critical because they change continuously, altering the communications characteristics. In conjunction with the immediate environment of communication devices, the forest, they constitute a dynamic environment. Moreover, forest environment implies an operational envelope that moderates communicational characteristics according to rain and wind intensity along with trees geometry (in or out of leaves). Bellow the core model of FITU-R is presented [1]:

With leaves:

$$L_{FITU-R}(dB) = 0.37 \cdot f_1^{0.18}(MHz) \cdot d^{0.59}(m)$$

Out of leaves:

$$L_{FITU-R}(dB) = 0.39 \cdot f_1^{0.39}(MHz) \cdot d^{0.25}(m)$$

These equations take in mind the effect of tree shape in wireless signal transmission along with their leaves. Leaves, relative to branches, play a certain role in signal transmission as their dimensions are comparative to transmitted wave length λ (10 cm to 1 m). Due to their physical characteristics, they compromise a reflection surface and along with the ground they constitute a form of waveguide. Of course they also absorb signal energy. It is shown [2] that these effects are magnified when weather conditions deteriorate. Namely, air and rain intensity can multiply absorption effect by a scale of 100 [3].

The above is more or less probable in an alpine forest where mountain slides are covered with trees in almost linear slopes. If we take in mind that there are areas burned trees from past years then the above model becomes vital for any forest area watched about. These forests do not suffer from low vegetation and as such the model can apply just fine.

In order to understand the difference between the wireless signal transmission in forest with or without leaves let as see the following example. In the following figures, the free space loss has bee incorporated along with the environmental loss.

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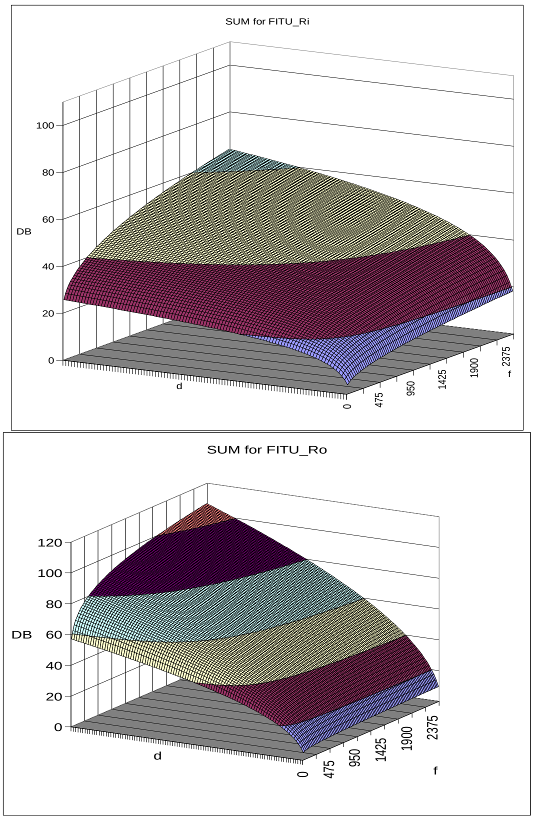

Figure 1 Power (dB) absorbtoin under in-leaf and out-of-leaf forest transmission in regard of forest depth (d=0 to 1000 m) for diverse frequences (f=250 to 2400 MHz) under FITU-R model. Free space loss icorporated.

The difference between the two models (in and out of leaves) is tremendous: at a range of 1000 m the excessive loss is more than 30 dB for a wide range of frequencies. Thus, the specific conditions of the area of application determine significantly the operational characteristics of the deployed sensor network.

II TECHNOLOGICAL BACKGROUND

For our research we adopted technologies like ZigBee (802.15.4) and WiFi (IEEE 802.11) but others as well, like RF. As a result, we cover a wide range of physical layer frequencies, as shown at Table 1. For our scope, we supposed that all the other operational characteristics are the same. The available link budget, given that the wireless device has 25 dBm gain and -90dBm sensitivity, is 115 dBm or 85 dBW.

Before going on to apply scenarios and come to results we should also take in mind the effect of environmental conditions to device operational characteristics. In particular, systems are design to operate within certain limits, like humidity and temperature values. Batteries are among the most sensitive parts, affected directly by weather conditions. In real conditions, temperature in summer time could exceed 45° C the battery potential drops to 60% of its nominative operation [4]. That result to the lowering of the transmitted power and namely the range of the intra-sensor communication. For a given link budget of 85 dB the actual operational budget becomes 51 dB.

Even more, the height that the sensor is placed specifies the range of the sensor, as presented at **T**able 2. This parameter has to do with the tree shape as well as with the affordable device maintenance capability.

TABLE 1 TECHNOLOGIES REVIEWED.

	1st	2nd	3rd	4th
TECHNOLOGY	RF	Public Safety	GSM	802.11
Frequency	240 MHz	700 MHz	900 MHz	2400 MHz
Bandwidth	5 Kbps	10 Kbps	20 Kbps	250 Kbps
Antenna gain	25dBm			
Receiver sensitivity	-90dBm			

TABLE 2 SENSOR RADIUSES (METERS) IN REGARD TO THE HEIGHT OF PLACEMENT ON TREES THAT ARE IN OR OUT OF LEAVES.[1]

h	240				700				900				2400			
	in 51 dB	out 51 dB	in 85 dB	out 85 dB	in 51 dB	out 51 dB	in 85 dB	out 85 dB	in 51 dB	out 51 dB	in 85 dB	out 85 dB	in 51 dB	out 51 dB	in 85 dB	out 85 dB
1 m	1300	270	>[2]	900	500	210	>	680	400	190	>	610	160	150	1760	490
2 m	3000	440	>	1200	1500	340	>	920	1160	320	>	860	430	250	>	660

[1] FITU model is accurate for up to 500 m deep forest, [1] so these are projections.
[2] >: excessive

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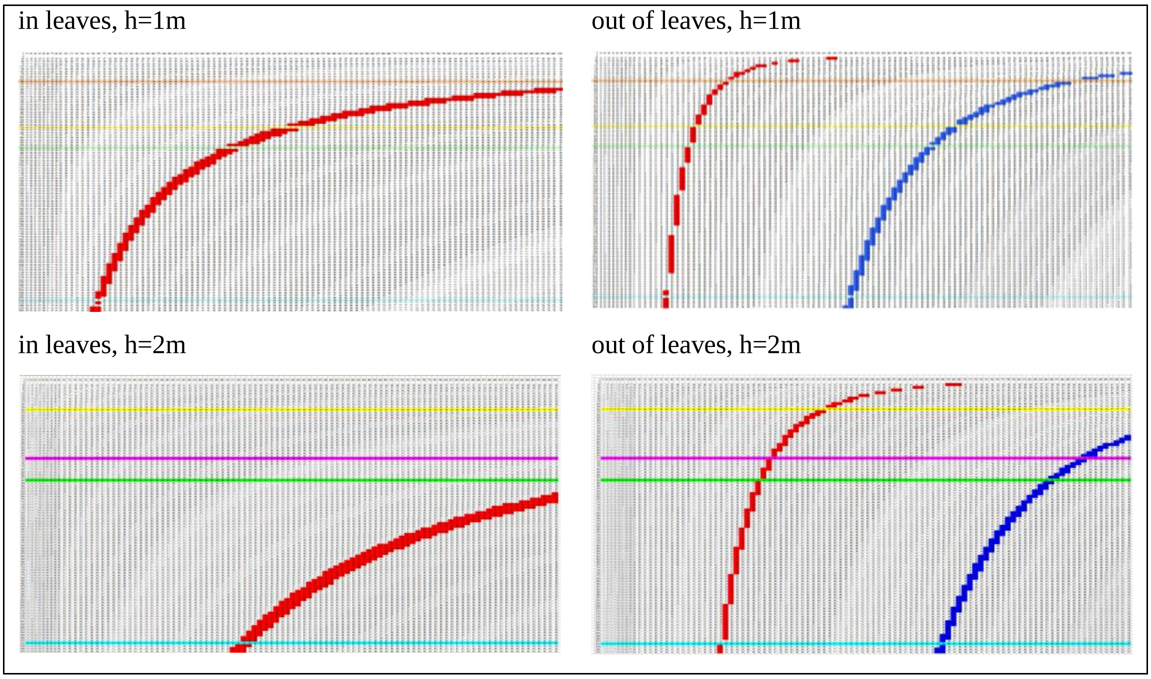

Figure 2 Spatial development of for power limits 51 dB (red) and 85dB (blue). Horizontal axis d (maximum range 1 km), vertical axis f (yellow 250, pink 700, green 900, ciel 2400 MHz), sensors at given hight from ground.

Taking all the above into consideration we come to the diagrams of Figure 2. We can observe the effect of height in the vertical perspective and the effect of leaves in the horizontal one. It is obvious that a network deployed with operational requirements different than the "worst case" ones, meaning the one with the lesser range, can easily be driven to a loose network or even a broken one.

For the technologies reviewed we assumed common operational characteristics as modulation techniques, sensor protocols etc. In this way we are able to evaluate the immediate effect of the environmental conditions to the sensor network and to extract comparative results. In order to maintain the network connective, we imposed that the sensor messages are transmitted in a square nested topology [5], hop-by-hop. The pass through impact on sensors would be to further deteriorate its operational capabilities, namely its power reserves. Nevertheless, this effect is not taken into account as we assumed that sensors perform as they are modeled.

The protocol governs the message generation and traffic over the sensor network. Packet payload (data) numbers 34 bytes for normal conditions and of 103 bytes on crisis [6]. No particular routing protocol has been selected as we intend to evaluate the performance at low levels (physical). We proposed a crisis management scenario were polling takes place once at an hour and alert, when triggered, takes place once a minute for five minutes (then it is supposed to be destroyed by fire). The polling messages cover information transfer such as that required for Fine Fuel Moisture Code (FFMC), and Fire Weather Index (FWI) system [7]. With these data we simulated various scenarios.

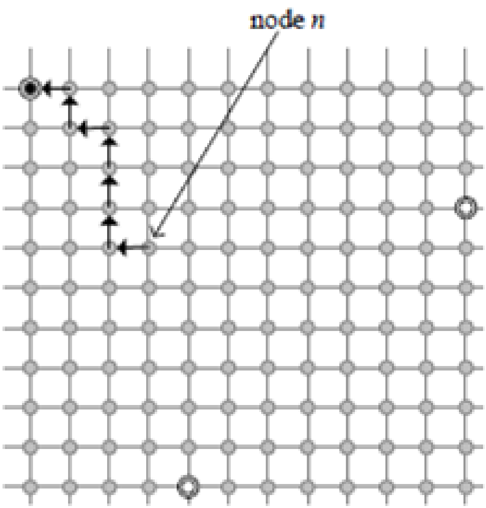

Figure 3 Square nested topology

In order to obtain that, we utilised Opnet platform deploying a similar to wireless sensor topology. "Similar to" because the academic edition that we used did not allowed for extended modification on wireless components, so we customised the deployed network in relevant ways. Another drawback was the limitation of node numbers that drove as to design the network as subnets and not as a square net. The wireless sensors deployed, among other network entities, were fully employed in traffic generation.

III SIMULATION OVERVIEW

Environmental conditions result to differences in spatial perspective. These differences may be dramatic based on technology used. Nevertheless, there is more than the architectural design of the sensor network deployment that

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should trouble us, namely the network's operational characteristics. This is because services provided over it should fulfill certain requirements, as for example the overall delay. Delay is mainly affected by the traffic over the network, especially when the available bandwidth is limited and the transmitters are striving for bandwidth.

We supposed that all sensors transmit at a serial order. We deployed the sensors in a given area of 16 km2 as a net. When applying environmental restrictions, sensor population increased and wireless channel utilisation rose upwards both for normal traffic and for crisis traffic. It can be shown that the factor of network traffic worsening due to environmental conditions implication can be specified at a magnitude of five (5) in the case of 240 MHz. Nevertheless, the traffic did not pose any restriction on the network topology, up to the limits the simulation reached. More crucial is the luck of communication between neighboring sensors, leading to broken network than any other effect.

A realistic scenario was implemented, the fire scenario, where selected sensors are driven into alert mode according to fire slow penetration hypothesis (0,6 m/sec in average while fast is 3 m/sec) [8]. This scenario showed that wireless channel is loaded as passing the time the fire involves a grater surface meaning a grater number of sensors.

The development of situation from normal to crises led the system to higher traffic generation and as result service delay rose. The rise of service delay did not exceeded normal values for all cases, up to the limits the simulation reached.

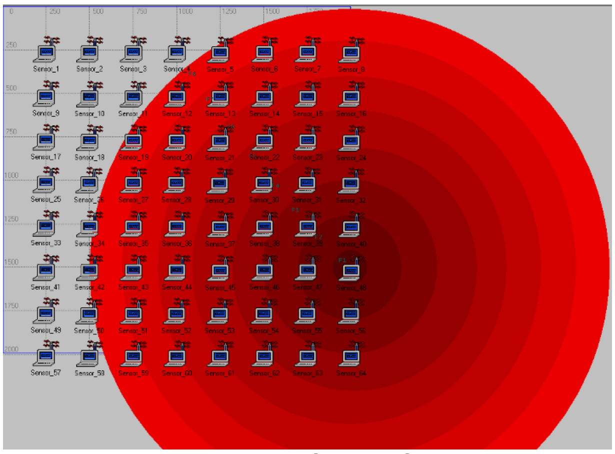

Figure 4 Simulation topology

Simulation results are summarised at Table 3 and depicted at Figure 5. The peaks represent the sensors that are activated at the same time and do represent a real life scenario. Nevertheless, most important is the availability of the network, meaning the average traffic passed over it, and not the single packets, as sensors transmit more than once at alert mode and alerts come from neighboring sensors as well.

TABLE 3 SIMULATION RESULTS ENLISTING.

Frequency	240 MHz	700 MHz	900 MHz	2400 MHz
Bandwidth	5 Kbps	10 Kbps	20 Kbps	250 Kbps
Radius	440 m	340 m	320 m	250 m
Sensor population	81	144	156	256
Normal scenario traffic	150 bps	300 bps	310 bps	554 bps
On fire trend	0.065 bps/sec	0.12 bps/sec	0.125 bps/sec	0.2 bps/sec
service delay	1.5 sec	0.075 sec	0.07 sec	0.028 sec

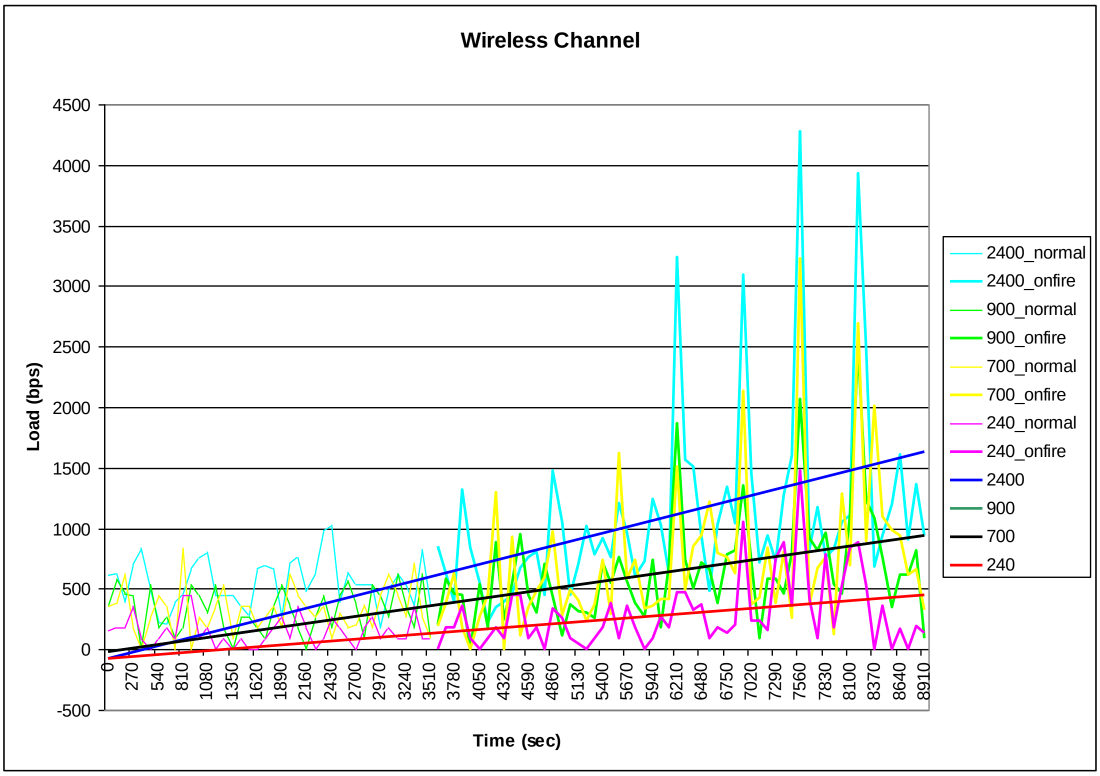

Figure 5 Rreview techologies. Fire scenario (bold lines) starts at time 3600, normal scenario (thin lines) applies before.

IV CONCLUSIONS

Environmental conditions affect directly the performance of any system developed in countryside. The study in this paper showed that common situations can degrade a wireless systems performance by a factor of 10 or more. Namely, vegetation affects the communicational range, in conjunction with environmental conditions. Luck of leaves reduce this range by a factor of 30~40 dB with respect to frequency positive development, more or less 1/3 of the hoped for range.

This affect reduces the range of wireless sensors, increasing dramatically the cost of a reliable sensor network deployment [9]. Though complicated, localization techniques may provide more cost effective solutions but on behalf of the awareness readiness. Signal strength deviation as well as its calibration [9] may reduce the effect of sensor radius devastation but on the cost of viability (energy budget).

Moreover, that the luck of proper maintenance can drive sensors to operate like a shadow of their selves. Battery degradation leads to sensor operational radius redaction in a magnitude of 10 for the case of 2400 MHz (for other cases it is expected as well something like this). This difference is huge regarding the operational cost of a forest fire awareness system but also impacts its operational robustness. Sensor network architecture is directly affected by the area of application and should be design with the worst conditions in mind in order to promote its scope: the awareness for a fire whatever the conditions are. Recent innovations regarding power extraction from plants roots due to PH divergence [10] are promising on the counter fight of wireless devices energy sources maintenance. This could become an alternative as its cost drops.

Important role for such a design play also variables like the height of positioning the sensor. Sensor position on tree may affect the maintenance affordability or even the operational robustness, but for the network system the higher the sensor the better. More or less, the reposition of sensors from 1 to 2 meters triples the range of communication.

By the system's perspective, the network performs fine at any situation with the service being limited within acceptable limits. Though, the simulation was limited in surface (actual coverage could breach 387 km2 [11], the area of interest) and may not provide accurate results for actual systems. This would require a more detailed analysis that would take in mind a vast set of environmental conditions in detail.

Further sophisticated models should be developed in order to include complex computations algorithms and integrated deployment strategies in order to enhance sensor operation and emphasize on their availability and reliability for better service provision, a better life for all of us. These models should be fit with national and international standards in order to maximize the outcome and minimize the resources reserved [12].

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