WSN Simulation Modeling for Forest Areas: Topologies, Connectivity and Path Loss

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Received: October 31, 2011 Revised: February 02, 2012 Accepted: April 11, 2012

Abstract: Large Scale WSN deployment is considered to be a very complex operation in terms of both efficiency and cost. Sensor cost has never been low, not even today, though at the same time the large areas to be covered call for a huge number of wireless sensors. The complexity escalates when it comes to forest areas, as such areas consist of an assortment of different landscapes and terrains and therefore, they cannot be modeled in detail. In this paper a first approach to forest area classification is attempted, so that simulation models can describe the attenuation of the alarming signal and the corresponding connectivity in the classified area. A number of models produced by Shawn simulator are provided, for forest areas with dense and scant plantation of trees. The model that best converges to the real experiment metrics per area is determined and is therefore referenced as "the model" for the specific classified area. Provided the fact that the simulation model per classified area is granted, a step to the optimal sensor topology is performed, as the connectivity and path loss problem is mainly and in most cases linearly confined to distance variations. Recent Patents are also covered. The simulation models along with optimal sensor topologies can become a guide in Large Scale WSN deployment primarily for the areas classified as "dense" and "scant" in terms of plantation, with the aim to deploy a reliable WSN for environmental purposes.

Keywords: WSN simulation, large scale, forest areas, Shawn simulator, connectivity, topologies, path loss.

1. INTRODUCTION

Simulation is a fundamental contributory factor to large scale WSN deployments and can minimize the risk of signal failure to any possible extent. Reliable simulation models can assist researchers and environment scientists approach the wild, even hostile, forest landscape, prior to engaging any deployment or decisions design. In the past, remarkable efforts have been done in the field of modeling forest areas and fire incidents as well.

A very recent invention discloses a method for managing WSNs that improves the reliability and stability of the WSN service [1]. Another very interesting research models the forest fire detection problem as a k-coverage problem in WSNs [2]. This approach also prolongs the network lifetime. However, much data are acquired through multihop routing, which constitutes a weakness in redundancy. As far as connectivity is concerned, optimization has been attempted by placing Relay Nodes (RN) in 3D forestry Space [3], yet this also constitutes a problem in redundancy as critical (sink) nodes and multihop routing are still present. Another research suggests the deployment of relay nodes in order to mitigate geometry deficiencies with respect to connectivity and energy provisioning [4]. It becomes quite apparent that placement strategies play a fundamental role in connectivity and coverage. It is shown that static strategies ensure maximum possible coverage with very few sensors of high cost [5], while dynamic strategies serve for other purposes such as military ones. In the latter case the network is self organized and the sensor cost is low.

Moreover, wild fire detection through modeling is suggested by a very important research group implemented by a stochastic fire model in combination with multitemporal Moderate Resolution Imaging Spectroradiometer (MODIS) images [6]. This method appears with fewer errors in fire detection that other relevant models. A research based on discrete event simulator using DEVS formalism, also shows that the complexity of fire position estimation is dependant of network deployment [7]. Modeling and simulation of forest fire propagation using Dynamic Cognitive Map Cellular Automata, with the help of Rule Based Fuzzy Cognitive Maps [8], constitutes another innovative approach to the problem. As a result, a versatile model of forest fire propagation simulation has been produced, that does not leave a lot to the real world data. In literature, a very interesting WSN implementation for forest fires surveillance is also proposed for the mountains of Korea [9]. In this research the alarming signal transmission highly depends on the sink station which is considered a weakness in redundancy terms. EIDOS architecture [10], suggests a wildfire fighting support system using heterogeneous types of information and devices. The system WSN simulation procedure is based on TOSSIM. Nevertheless, in many cases, WSN simulation is not considered along with real world deployments. Therefore, an effort in evaluating WSN simulators has been undertaken [11], showing the pros and cons of three well known simulators (OMNET++ [12], SHAWN [13, 14] and CASTALIA [15]). Considering the importance of network simulation prior to making costly design decisions, this research focuses on the question of which network simulator to use both for general purposes and for forest environments. The research suggests one model per simulator that can be considered to be

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2211-7415/12 $100.00+.00

reasonably safe for the described experiment conditions. Moreover the accuracy and efficiency of the named simulators is examined. Last, a research aided by WSNs and a fire simulator [16], predicts the potential fire front evolution per situation and helps the authorities face the fire incident efficiently from the safer path.

The major contributions of this paper are as follows. In the first place, forest areas fall into the preliminary classification of dense and scant plantation so that prototype areas per class are taken into consideration. Secondly, simulation models per prototype areas are produced with respect to path loss and foliage model. As a third step, an efficient grid of cells topology with overlaps is proposed, which along with the simulation models ensure connectivity and redundancy. Finally, limit distances that ensure connectivity per area model are estimated, both through the real world experiments and simulation.

This paper is organized as follows. In section 2, the material and methods used in the approach are analyzed, including the real world experiments, the simulation –modeling phase and the topologies issues. The results of the analysis are described in section 3. In section 4, discussion is performed upon the results. The paper is concluded in section 5. Finally, future challenges and developments are presented in section 6.

2. MATERIAL & METHODS

2.1. The Real World Experiments

We examined two typical forest areas, with the aim to produce reliable simulation models for them that match the measurements taken during the experiments. First and foremost, the area of Kessariani, a suburb of Athens, has been taken into consideration, as it is occupied by dense plantation of trees, especially pines, and shows different elevation levels. Secondly, another suburban part of Athens, the area of Penteli, has been examined, which is characterized by scant vegetation and plantation of trees.

Measurements have been collected from both of the examined areas. They are illustrated in Tables **1** for Penteli and Table **2** for Kessariani areas. In these tables the x,y coordinates and the elevation h are shown for every NodeID/ PointID which is the spatial point that the measurement took place. They are followed by the receiving signal power in dbms and some comments about the ground infrastructure. The coordinates of the sensors were collected in Garmin format and turned into the Greek Grid Reference System (GGRS).

The wireless sensors had the following characteristics; antenna power 100mW, antenna gain 2db, frequency 433MHz, battery lifetime 3 years approximately. They were placed at about 2m above the surface as well as the gateway. The nodes laid in star topology, forming a cell, sent alarm messages to a central gateway with receiver sensitivity -112dBm (=-142dB). The measurements were taken during the spring sunny days of the Mediterranean climate and the weather conditions were very helpful for our experiment. On a try to avoid the production of false measurements, each one of them was taken 3 to 4 times. This acts as a quality factor for the taken values, as it up to a point verifies that they were correct and had not been accidentally produced.

In the sequel, the coordinates were entered in Shawn simulator in xml format, according to its specification.

A very good question posed here, is why the simulator used is Shawn. Considering a comparison between the three widely well known simulators OMNET++, Castalia and Shawn [5], Shawn seems to be quicker in simulation, easier to use and understand, while at the same time accuracy cannot be considered a problem. The real world experiment can be successfully approached by using the right simulation model.

In Figs. (**1** and **2**) that follow, two google map screen shots, one per area, are illustrated along with the pointIDs. The star topology of the network does not form a regular hexagon-cell but just a cell, which will be thoroughly explained in the topologies section.

2.2. Simulation-Modeling

Various RF propagation models are supported in Shawn simulator, including terrain and foliage models. The models considered are the following:

2.2.1. Free Space Path Loss

It describes the loss in signal strength [13], that would result from a Line- Of –Sight path through free space (usually air), with no obstacles nearby. The equation for FSPL is:

$$FSPL = (\frac{4\pi d}{\lambda})^2 = (\frac{4\pi df}{c})^2$$

where:

- λ: is the signal wavelength (in metres),
- f: is the signal frequency (in hertz),
- d: is the distance from the transmitter (in metres),
- c: is the speed of light in a vacuum, 2.99792458 × 108 metres per second.

2.2.2. Log Distance Path Loss

For the Log-Distance model [17], the mean signal attenuation is expressed in the following equation:

$$L(d) = (\frac{d}{do})^n \text{ , } L(db) = Lo(db) + n \cdot 10 \cdot \log(\frac{d}{do})$$

where:

- L(d) is for a distance d between the transmitter and the receiver
- n is the power of path loss and
- L_0 the mean path loss for a known distance d_0.

In other words, the longer the distance is, the lower is the power of the receiving signal in logarithmic terms.

As propagation models are highly dependent on the landscape relief, the latter must be seriously taken into account. Thus, *Near-Earth Propagation Models* that contain foliage and terrain models are also examined.

Table 1. The Experiment Measurements

PENTELI Area (SCANT Plantation)					
PointID	**x**	**y**	**h**	**RxD (dBm)**	**Notes**
700	487105.65	4213915.99	463.005	-33	Gateway's Possition
701	487104.90	4213917.47	464.005	-64	Beside the G/W
702	487128.00	4213951.40	466.002	-78	no foliage
703	487118.42	4213980.01	467.001	-86	low foliage
704	487109.99	4214008.41	468.000	-90	Lowest signal power
705	487117.43	4214046.83	468.998	#	Near pylon of electricity
706	487109.60	4214085.40	465.997	-85	#
707	487142.09	4214123.69	471.994	-86	Max. distance of signal reception
708	487161.35	4214147.64	474.993	#	No reception
709	487202.48	4214183.48	484.990	#	No reception
710	487241.74	4214158.39	498.990	#	No reception
702	487128.00	4213951.40	466.002	-78	No foliage
711	487267.72	4214149.66	502.990	#	No reception
712	487287.36	4214147.72	504.990	#	No reception
713	487270.11	4214101.55	498.992	#	No reception
714	487236.15	4214008.95	488.997	-88	Below the electricity pylon
715	487231.26	4213983.97	490.999	-80	No foliage
716	487235.45	4213967.84	486.999	-87	No foliage/ near high voltage lines
717	487251.63	4213951.73	483.000	#	
718	487268.46	4213935.86	482.000	-87	Low power because of high voltage power lines and distance
719	487258.19	4213928.48	476.000	-86	
720	487256.01	4213918.43	471.001	-80	#
721	487263.77	4213895.52	472.002	-83	#
722	487277.09	4213889.89	477.002	-79	Low elevation distance
723	487260.79	4213875.99	470.003	-79	Inside a ditch
724	487235.89	4213875.16	464.003	-89	Inside a ditch - near high voltage lines
725	487222.67	4213881.47	462.003	-88	(as above)
726	487207.04	4213889.66	462.003	-81	Low vegetation
727	487200.56	4213903.54	469.003	-75	#
728	487180.54	4213908.14	468.003	-80	Low elevation distance
729	487169.85	4213900.72	464.004	-75	No vegetation - road
730	487140.57	4213901.88	467.004	-58	On Line of Sight (L.O.S.)
731	487129.54	4213907.81	467004	-54	On Line of Sight (L.O.S.)

Table 2. The Experiment Measurements

KESSARIANI area (DENSE PLANTATION)					
PointID	**x**	**y**	**h**	**RxD (dBm)**	**Notes**
130	482643.80	4201487.85	352.672	-20	Gateway's Position
131	482643.14	4201487.60	352.672	-54	Beside the G/W
132	482670.81	4201489.21	358.672	-64	#
133	482704.89	4201483.99	371.671	-60	On Line of Sight (L.O.S.)
134	482729.11	4201492.08	377.670	-83	#
135	482756.46	4201510.63	386.669	-85	High attenuation beyond 100m
136	482767.32	4201491.29	402.669	-91	Very low signal power
137	482771.09	4201458.61	412.671	-95	Limit down value
138	482798.62	4201415.71	424.672	No	High elevation/ distance
139	482780.99	4201374.82	411.674	No	High elevation/ distance
140	482760.69	4201319.26	407.677	No	Max. elevation/ distance
141	482728.24	4201365.04	395.676	-86	Max. distance of signal reception
142	482687.42	4201391.20	389.676	-66	#
143	482683.18	4201417.81	377.675	-72	#
144	482668.24	4201426.22	373.675	-61	L.O.S.
145	482650.15	4201457.26	365.674	-65	No LOS
146	482631.60	4201479.43	370.673	-57	No elevation distance

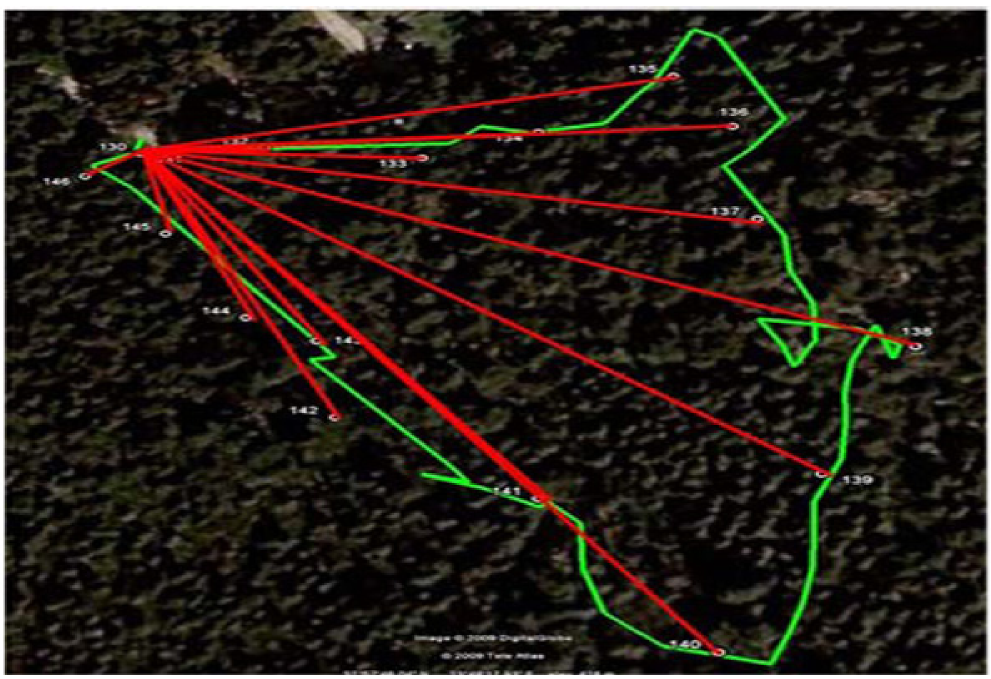


Fig. (1). Star topology in Kessariani area - Dense Plantation.

Fig. (2). Star topology in Penteli area - Scant Plantation.

2.2.3. Weissberger Model

This model [17] is applied for dense and dry plantation with leaf on the L.O.S. The following equation describes the model:

L(db) =1.33 * F $^{0.284}$ * df $^{0.588}$, 14<df <= 400m

L(db) = 0.45* F $^{0.284}$ *df, 0 <=df <=14m

where:

- df: the length of plantation in meters on the LOS
- F: Signal frequency in GHz

2.2.4. Early ITU-Recommendation

Early ITU [17] stands for an early empirical foliage model. Its results come very close to the ones of the Weissberger model. It is described by the following mathematic relationship:

L(db) =0.2 * F $^{0.3}$ * df $^{0.6}$

where:

- df: the length of plantation in meters on the LOS
- F: Signal frequency in GHz

2.2.5. COST235 Foliage Model

COST235 foliage model [13], provides two relationships for the signal path loss due to vegetation factors. The first describes the path loss for an area occupied by trees with leaf and the second comes for an area with trees without leaf.

L(db) =15.6 * F $^{0.009}$ * df $^{0.26}$, for trees with leaf

L(db) = 26.6* F $^{-0.2}$ * df $^{0.5}$, for trees without leaf

where:

- df: is the length of plantation in meters on the LOS
- F: is the signal frequency in GHz

2.2.6. Ground Reflection 2-Ray Model

According to the Ground Reflexion 2-Ray model [13], the earth is presumed to be flat as a board for short distances. To be precise, that counts for a number of tenths of kilometers. As a result, the G.R.-2 Ray Model estimates the transmission distance on the L.O.S. on the one hand, but it also estimates a second distance concerning the reflection on the earth surface. The mathematic representation follows:

$$P_{RX} = P_{TX} G_{TX} G_{RX} (\frac{h_{TX} h_{RX}}{d^2})^2$$

2.2.7. Egli's Model

Egli provided a modification of the Ground Reflection 2-Ray model [17], based on his observation that remarkable deviations regarding different landscape types and frequencies appeared. As a result, a multiplication factor β has been inserted in the "normal earth" transmission equation that describes the deviation. The equation follows:

$$L_{50} = G_{TX} G_{RX} (\frac{h_{TX} h_{RX}}{d^2})^2 \beta$$

where:

$$\beta = (\frac{40}{f})^2$$

The simulation execution has been performed with respect to *terrain and foliage models* as well. In an effort to achieve an as much as realistic simulation, terrain and plantation characteristics had to be taken into serious account.

Therefore simulations have been performed for both areas, for the same path loss models and almost the same foliage ones. In some cases, foliage models had to be a little different as the ones used best describe the experiment conditions. The full simulation results are illustrated in the tables and charts shown in the appendix of this paper. For every simulation execution the mean of absolute difference between the experiment measurements and the simulation results is produced. This sort of statistical analysis can support up to a reasonable point the decision as to which model best converges to a forest area, provided the fact that connectivity is proven to be assured and the potential deviations follow a statistical relationship and not the pure difference between values. The use of the right sort of simulation model can also support critical decisions in forests' crisis management [16].

Next, the five most representative simulation results per Kessariani area are stated in Table **3**.

Table 3. Kessariani Area- Dense Foliage - SHAWN Simulator

Path Loss: Ground Reflection 2-Ray (approximation) Foliage Loss: ITU-r 100% Mean of Absolute difference: 8.58
Path Loss: Ground Reflection 2-Ray (analytic) Foliage Loss: ITU-r 100% Mean of Absolute difference: 8.50
Path Loss: Egli Terrain Model Foliage Loss: COST235_OUT 80% Mean of Absolute difference: 8.00
Path Loss: **Free Space Path Loss** Foliage Loss: **COST235_OUT 50%** Mean of Absolute difference: **7.25**
Path Loss: Log Distance Path Loss (d0=1m, L0=FSP) n=1,8 Foliage Loss: COST235_OUT 70% Mean of Absolute difference: 8.50

In these scenarios, the lower the mean of absolute difference is, the better convergence to the experiment values is achieved. As shown above, the combination of Free Space Path Loss influenced by COST235_OUT foliage model which refers to plantation without leaf for 50% of the distance seems to have the best accuracy. That is despite the fact that for Kessariani landscape, it could be reasonable to use the Log Distance Path Loss which also ensures connectivity and is proper for that area. Log Distance model can be the first choice for such areas as it best describes the situation when the ground is not smooth. However, we choose here the model with the best statistical results.

As a result, the proposed combination of path loss and foliage models can be consider as the simulation model for an area with dense plantation of tress such as pines. What is more, in Table **4**, the five most representative simulation results for Penteli area are presented.

For the area of Penteli, it becomes obvious that the combination of the Free Space Path Loss model affected by the foliage loss COST235_OUT 30% suggesting plantation without leaf for the 30% of the distance, seems to have the best statistical convergence. Therefore it can be considered a model for such areas.

Table 4. Penteli Area -SCANT foliage-SHAWN Simulator

Path Loss: Ground Reflection 2-Ray (approximation) Foliage Loss: Weissberger 100% Mean of Absolute difference: 8.3
Path Loss: Ground Reflection 2-Ray (analytic) Foliage Loss: Weissberger 100% Mean of Absolute difference: 8.2
Path Loss: Egli Terrain Model Foliage Loss: COST235_OUT 60% Mean of Absolute difference: 4.6
Path Loss: **Free Space Path Loss** Foliage Loss: **COST235_OUT 30%** Mean of Absolute difference: **4.0**
Path Loss: Log Distance Path Loss (d0=1m, L0=FSP) n=3 Foliage Loss: Weissberger 20% Mean of Absolute difference: 5.4

As far as the radio range is concerned, a comparison between the two areas is performed. The radius D^{3d} has been estimated for every sensor node showing the length in meters from the gateway. The mathematical type used is:

$$D_{3d} = \sqrt{Dx^2 + Dy^2 + Dh^2}$$

Dx stands for the difference of x coordinates between the node and the gateway. Likewise, Dy and Dh regard the y coordinates and the elevation h of the former and the latter. We consider now a one (1) dbm approximation for distances of -57dbms and -90dbms and the following Table **5**, showing different distances for the same dbms, is produced:

The part that really matters in that experiment are the distances for the corresponding -83, -85, up to -90dbms, which are the more realistic signal power values for which a sensor is placed accordingly. Stronger signals do not make any sense for large scale applications, as they come along with short distances. In Fig. (**3**) the radio range in meters is illustrated for both areas of the experiment.

The distances produced through the real world experiments, can be used as a *quality factor* regarding the simulation results. In this way, an effective transmission range is estimated and connectivity is verified, showing that the simulation models and results are valid. Last but not least, these distances along with the forest area classes are used by our research group in a software package under development, which acts as a large scale network topology simulator.

2.3. Topologies

Simulation models per classified area have so far released connectivity and attenuation issues from some major factors of influence such as path loss and foliage models.

Table 5.

RxD (dbms)	Kesssariani R(m) (DENSE)	Penteli R(m) (SCANT)	DR (m) Absolute Values
-54	0,71	25,57	24,86
-57	23,32	37,87	14,55
-64	27,70	1,94	25,76
-83	89,00	159,69	70,69
-85	119,86	169,48	49,62
-90	133,30	92,66	40,64

Though meteorological conditions have not been considered in detail as an effective factor, connectivity becomes now a simpler problem highly and mainly dependent on distance. Distance is also examined by the simulator through the estimation of signal attenuation. Distance is strongly related to topology but the topology concern is not just limited to it. On the one hand, placing the sensors randomly according to the suitable radio range distance to the gateway would be a very easy task to do. On the other, that would not be enough as topology plays a fundamental role in WSN deployments, especially when the terrain model is not known in big detail and special problems arise.

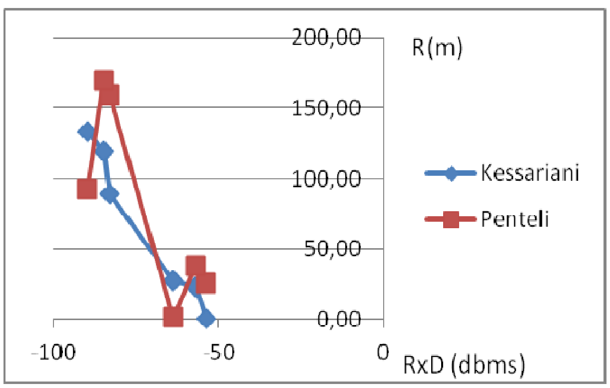


Fig. (3). Kessariani and Penteli distance chart.

For example, grid topology, as shown in Fig. (**4**), offers wide area coverage. Every branch can occupy a long section in the forest, provided the fact that a sensor can forward the measurements of its predecessors. As a result, the first sensor of the grid sends all sensors measurements to the Gateway (Base-1). What is more, such a topology is ideal in terms of cost, as one base station can serve for a number of sensors, considering the fact that the most expensive parts in WSN deployments are the gateways. The more gateways used, the more the cost increases. At a glance, grid topology seems to have a number of advantages regarding long distance coverage and cost effectiveness, provided that multi-hop protocols required to implement the signal transfer from remote sensors, are guaranteed to be reliable.

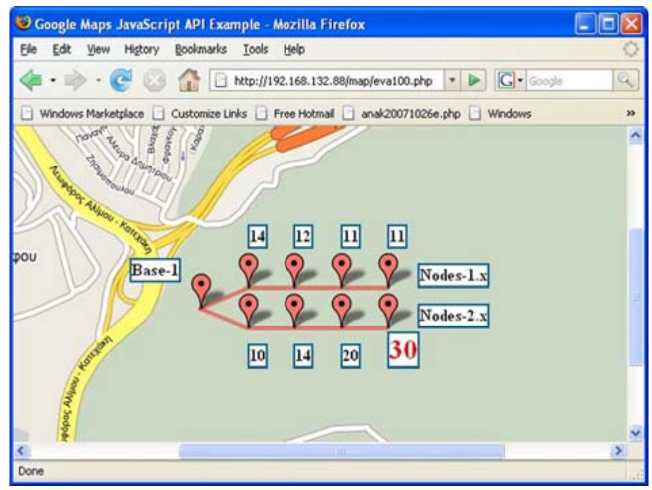


Fig. (4). Grid topology.

Nevertheless, a major disadvantage of grid topology is multi-hop routing. Although multi-hop routing is proven to be a smart and efficient solution for other applications in less "hostile" environments, in our case, forest monitoring for fire detection, it shows important weaknesses due to the nature of the environment itself. For example, if a sensor node becomes inactive or fails for any kind of reason, then the rest of the segment collapses, as no message propagation can be accomplished. Therefore, the messages of the failing sensor and of its predecessors are lost and never transmitted.

Moreover, the nodes next to the gateway act as critical ones as they collect and forward all segment data. Thus, they consume much more energy than all the other sensors. In that way, the possibility of becoming inactive very soon is increased, actually sooner than the others, having as a consequence the network collapse.

It is also quite obvious that the above topology lacks in redundancy not only because of a potential segment failure, but also because of a probable failure of the gateway. Due to the characteristics of the proposed topology, very few sensors can fall into a range of a backup gateway. In any way, it is difficult to place efficiently a backup gateway for every sensor of a whole segment. For all the above reasons, the extremely valuable alarming signal of a sensor may just vanish. This may cause a lot of damage in forest areas, as in an emergency case of fire ignition followed up by rapid expansion, delay in an alarming signal transmission is of vital importance.

A simple and efficient answer to the question of connectivity and redundancy in such applications seems to be the star topology [18]. As illustrated in Fig. (**5**), the whole system resembles up to a point the cellular telephony topology and architecture.

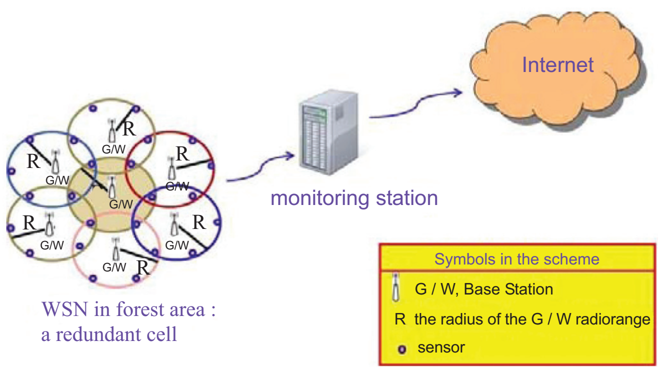


Fig. (5). Star topology.

A gateway is *ideally* placed in the centre of a canonical hexagon and a sensor is placed on every vertex of it. This implementation describes the main idea of the topology. In real world, the gateway may not be placed in the exact geometrical centre of the hexagon and the sensors may not be placed exactly on the vertices of it, as forests' spatial features and landscapes are not known. Sometimes, even the hexagon itself is open to question. However, in any case the proposed topology is a star with a gateway somewhere in the centre and the sensors are placed within a distance of (R1 –R2)m far away from it. That will still be considered a cell. In order to ensure redundancy in that particular core cell, more cells are placed around it. Thus, every sensor of every cell falls into the range of more than one gateways. Likewise, this elementary cell can be surrounded of more cells and so on and so forth. This will lead to the coverage of a desired classified area by a grid of cells with overlaps. A major challenge here is the cost of the network maintenance as it has now become very large (i.e. batteries replacement).

In the sequel, the alarming message can be transmitted by various means (i.e. sms) to a central monitoring station and thus to the internet. The two ways of communication are shown below. In Fig. (**6**), alarming signals are gathered by a USB port, providing the alarming sensor ID and the time stamp of the incident.

In Fig. (**7**) the layout of an SMS sent over GSM by a gateway is reported:

GRPS, is also supported in the operation of the gateway.

3. RESULTS

This research has initially proposed a preliminary forest area classification according to the density of plantation. As a result, the two major forest categories suggested, consist of a forest area with dense plantation of trees and of an area with scant plantation. The full definition of dense and scant plantation is at an early stage for the time being. These areas will serve as prototype areas in which signal transmission procedures, attenuation and path loss are examined.

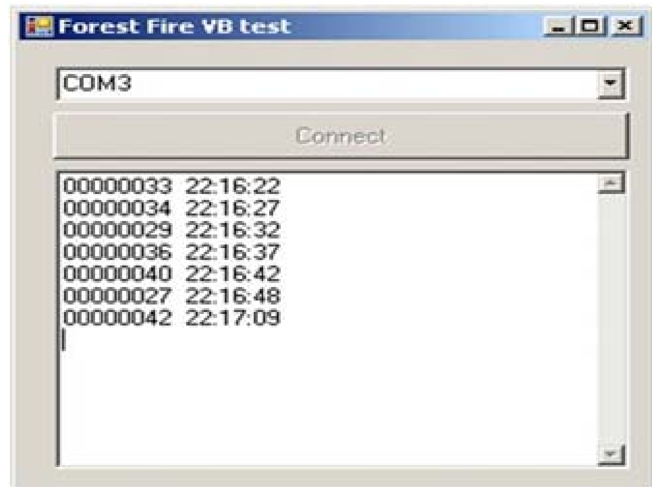


Fig. (6). USB port data collection.

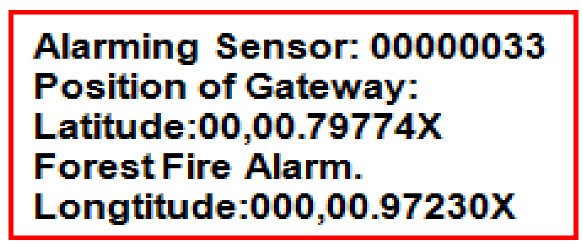


Fig. (7). Alarming sms layout.

The research has so far reached and determined two simulation models, for the two prototype forest areas, that play an important role in Large Scale WSN deployments. An area with dense plantation of trees is best simulated in Shawn, with Free Space Path Loss and COST235_OUT 50% Foliage Loss. Moreover, an area with scant plantation of trees is best approached in the same simulator by Free Space Path Loss and COST235_OUT 30% Foliage Loss. The use of these two models play a fundamental role in real world WSN deployment as they satisfactorily transform the initial complex problem of connectivity and signal attenuation mainly into a simpler distance dependent one. In many cases it can be considered as a liner distance dependent problem. These two reference models per prototype areas comprise a very helpful tool in assistance of a network engineer. They serve the purpose of optimal sensor placement in the already classified areas, with respect to connectivity and redundancy. In this way, large scale WSN deployment in forest areas becomes more feasible, as the risk of implementing an inefficient, costly network gets reduced. Nevertheless, simulation models and the proposed method are always open to future improvements.

Additionally, an efficient cell topology is indicated and its contribution to redundancy and efficiency is supported by a number of arguments mentioned. Cell topology is totally expandable so that it can meet the requirements of large scale forest area coverage. Therefore, the final topology turns out to be a grid of cells with overlaps to their neighbors for redundancy sake. This placement strategy has been mathematically modeled by our research group and a very interesting software package is under construction producing metrics and cost upon this. The full analysis of the grid of cells topology with overlaps will soon be published.

In conclusion, limit distances are proposed for both the examined areas ensuring good connectivity. For a typical area with dense plantation of trees a default distance between the gateway and the sensor is estimated to be at about 40m. As far a typical area of scant vegetation is concerned, the default maximum distance increases to 70m. These are also considered to be "safe distances" for WSN deployment in the prototype areas and they have derived both from the simulation procedure and the experiment itself.

4. DISCUSSION

A significant step to real world WSN deployment has been performed so far. However, major concerns regarding this venture are still present.

After the classification procedure is accomplished at an acceptable degree of fidelity and properly balanced to the cost incurred, the simulation models offer a way to efficiently place sensors in the specifically described forest areas with respect to topology and ensure connectivity to the gateway. Once the simulation models regarding a typical area are granted, different star topology scenarios can be considered with the aim to approach the optimal sensor and gateway placement in the forest. Ground morphology and anomalies cause a prohibiting factor in forming an ideal (normal) sensor cell, as forests provide neither an ideal nor a smooth surface. However, placing sensors at the suggested distances per area can be regarded as a realistic approach for such landscapes. In any case, the proposed metrics per area is prerequisite to be supported by the results of the simulation procedure.

Factors that should be thoroughly examined are the effect of the meteorological conditions and the cost of the network installation. A factor concerning weather data may affect the current simulation models which are the reference models per area. Additionally, attritions to the installation equipment by wild animals cannot be predicted, yet they can slightly affect the operation of the network as they can influence the performance of one or two cells. As far as the cost of the network is concerned, the man months needed for installation and maintenance are too many to be ignored. In addition, simulation and redundancy play a fundamental role in cost. By deploying a denser WSN in terms of sensors and gateways, redundancy is increased along with the cost. However, simulation models drive us to efficient star topologies, including overlaps between them with respect to redundancy. They also help us in finding the best cost to redundancy ratio; a reasonable cost for an accepted level of redundancy and reliability.

CONCLUSION

Simulation is by all means a necessary step as far as High Density WSNs deployment is concerned, for forest fire detection and monitoring applications. Successful simulation modeling will most of the times ensure connectivity in environments not well defined such as forests. Connectivity along with redundancy will substantially contribute to effectiveness and reliability for applications of such a large extent.

Reliability is of vital importance, as no fire eruption incidents will be missed or be lately detected. Sensors' optimal placement, produced by simulation modeling, can contribute in figuring out the velocity of fire, in producing evacuation scenarios and even in finding the best route for the firefighters to safely approach the fire.

The forest area prototyping, along with the corresponding simulation models, the grid of cells topology and the metrics suggested in this paper, constitute a first approach to large scale WSN deployments in forest areas presenting satisfactory results.

CURRENT & FUTURE DEVELOPMENTS

Simulation modeling is only a part of the full procedure for deploying Large Scale WSNs in Forest Areas. Before we step to simulation, detailed forest vegetation classification should be performed. Forest areas must be categorized and become as fully as possible described. Image processing may help in this direction. Aerial photographs are the point to start with and various techniques, including remote sensing and artificial intelligence, will serve in the classification of forest vegetation. What is more, the problem of forest landscape complexity calls for a more thorough area classification, high quality aerial photographs and more than two simulation models. A closer approach to real world dimensions can be implemented by the classification / categorization of a forest area as one of the following: with very dense plantation, dense, medium, scant and very scant. This kind of classification regards only the part of plantation and does not provide information about ground morphology or meteorological data which comprise factors of signal influence. In real world signal attenuation depends on these factors. Further research has to be undertaken in order to model slopes, wide ditches e.t.c., as network simulator parameters.

A great challenge for our research group is a new software development for large scale network topology simulation and is currently under construction.

What is more, another big challenge for the future is the forest areas classification and the production of efficient simulations models for all of them, based on the concept described in this paper and on other efficient techniques.

CONFILCT OF INTEREST

The authors declare no conflict of interest.

ACKNOWLEDGEMENTS

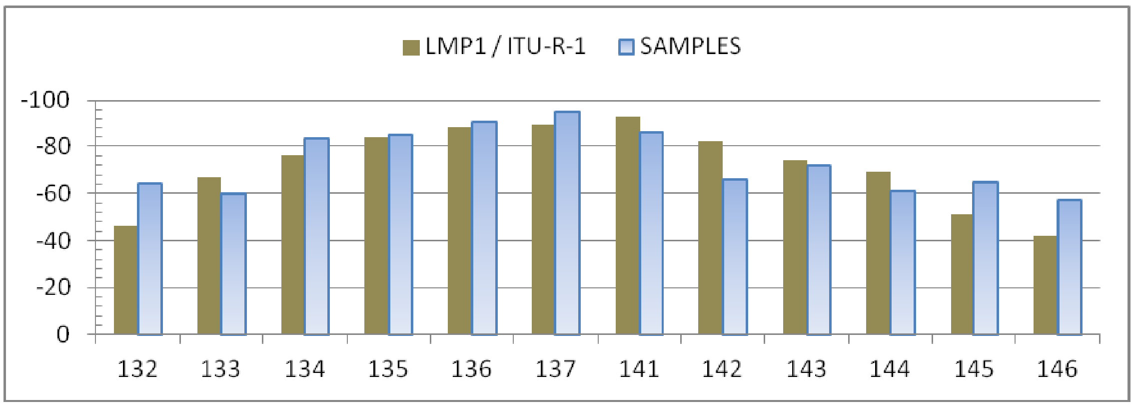
This work has been elaborated within the premises of National Technical University of Athens. We thank the institution for its contribution.

APPENDIX

KESSARIANI Forest Area (DENSE)

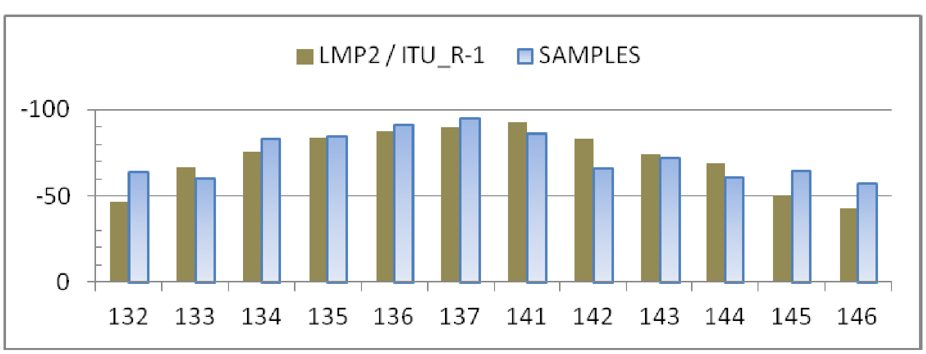
Path Loss: Ground Reflection 2-Ray (Approximation) Foliage Loss: ITU-R 100%

nodeID:	132	133	134	135	136	137	141	142	143	144	145	146
sim RX (dBm):	-46	-67	-76	-84	-88	-90	-93	-82	-74	-69	-51	-42
sample RX (dBm):	-64	-60	-83	-85	-91	-95	-86	-66	-72	-61	-65	-57
difference (dBm):	-18	7	-7	-1	-3	-5	7	16	2	8	-14	-15
MEAN of absolute difference (dBm):												8.58
AVERAGE DEVIATION of absolute difference (dBm):												8.42



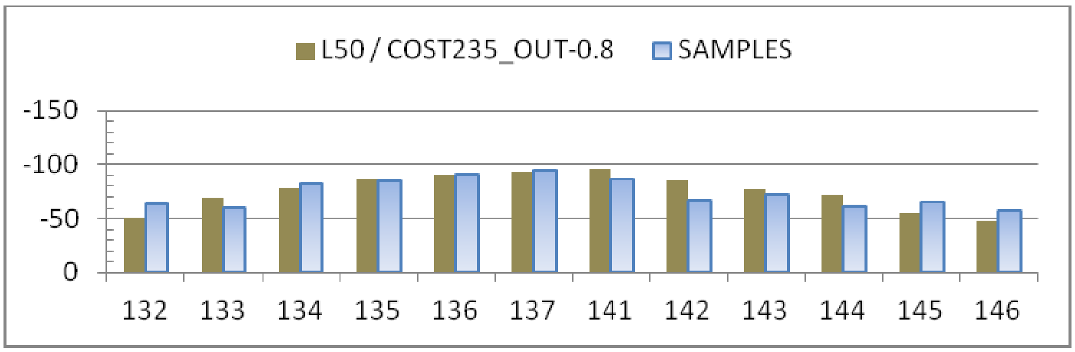
Path Loss: Ground Reflection 2-Ray (Analytic) Foliage Loss: ITU-R 100%

nodeID:	132	133	134	135	136	137	141	142	143	144	145	146
sim RX (dBm):	-47	-67	-76	-84	-88	-90	-93	-83	-74	-69	-51	-43
sample RX (dBm):	-64	-60	-83	-85	-91	-95	-86	-66	-72	-61	-65	-57
difference (dBm):	-17	7	-7	-1	-3	-5	7	17	2	8	-14	-14
MEAN of absolute difference (dBm):												8.50
AVERAGE DEVIATION of absolute difference (dBm):												8.33



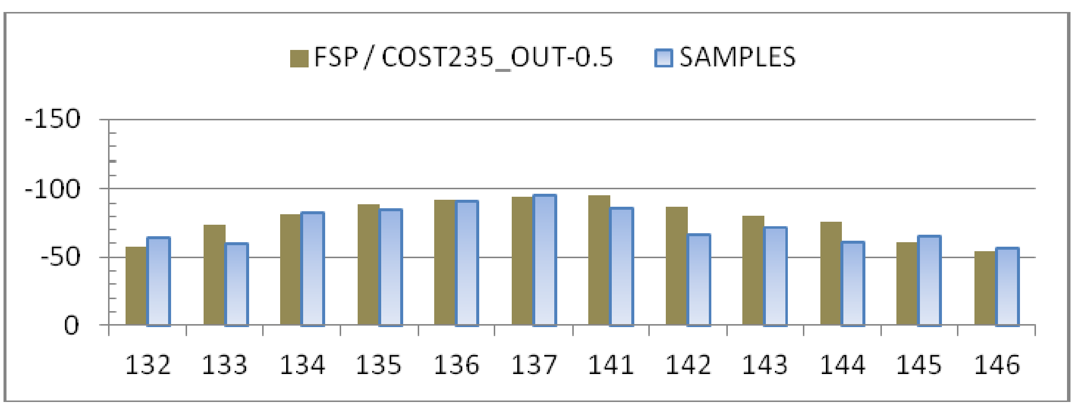
Path Loss: Egli Terrain Model Foliage Loss: COST235_OUT 80%

nodeID:	132	133	134	135	136	137	141	142	143	144	145	146
sim RX (dBm):	-51	-69	-78	-87	-90	-93	-96	-85	-77	-72	-55	-48
sample RX (dBm):	-64	-60	-83	-85	-91	-95	-86	-66	-72	-61	-65	-57
difference (dBm):	-13	9	-5	2	-1	-2	10	19	5	11	-10	-9
MEAN of absolute difference (dBm):												8.00
AVERAGE DEVIATION of absolute difference (dBm):												8.00



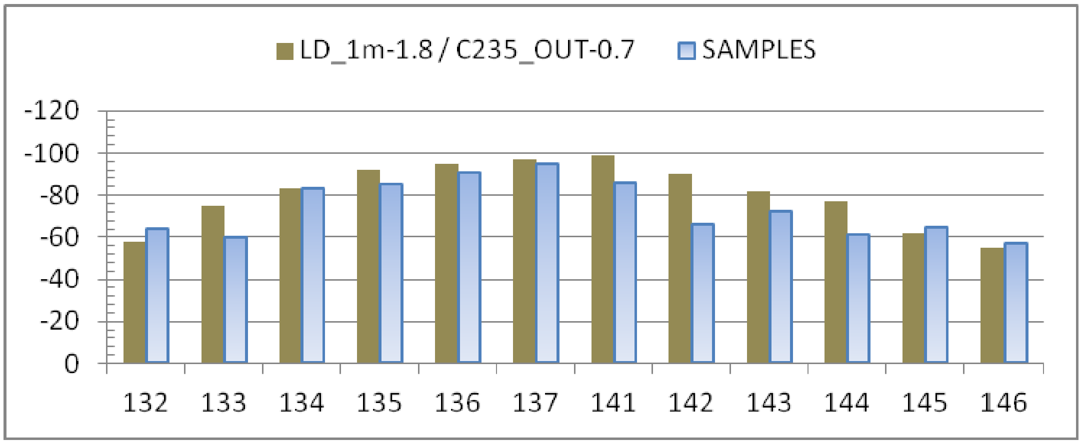
Path Loss: Free Space Propagation Foliage Loss: COST235_OUT 50%

nodeID:	132	133	134	135	136	137	141	142	143	144	145	146
sim RX (dBm):	-58	-74	-82	-89	-92	-94	-96	-87	-80	-76	-61	-55
sample RX (dBm):	-64	-60	-83	-85	-91	-95	-86	-66	-72	-61	-65	-57
difference (dBm):	-6	14	-1	4	1	-1	10	21	8	15	-4	-2
MEAN of absolute difference (dBm):												7.25
AVERAGE DEVIATION of absolute difference (dBm):												7.24



Path Loss: Log-Distance (d0=1m, L0=FSP) n=1.8 Foliage Loss: COST235_OUT 70%

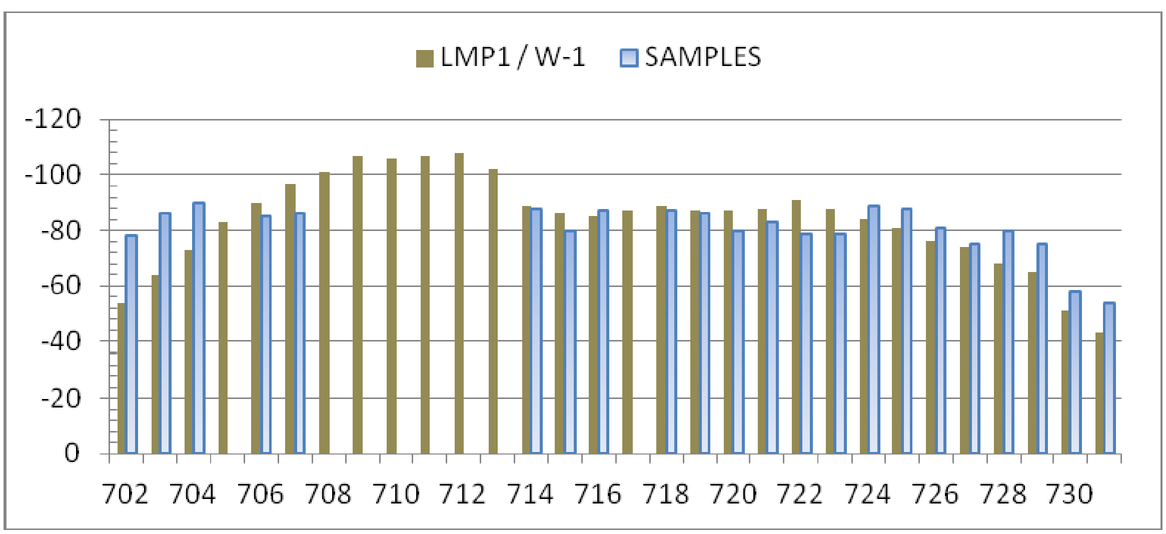
nodeID:	132	133	134	135	136	137	141	142	143	144	145	146
sim RX (dBm):	-58	-75	-83	-92	-95	-97	-99	-90	-82	-77	-62	-55
sample RX (dBm):	-64	-60	-83	-85	-91	-95	-86	-66	-72	-61	-65	-57
difference (dBm):	-6	15	0	7	4	2	13	24	10	16	-3	-2
MEAN of absolute difference (dBm):												8.50
AVERAGE DEVIATION of absolute difference (dBm):												7.50



PENTELI Forest Area (SCANT)

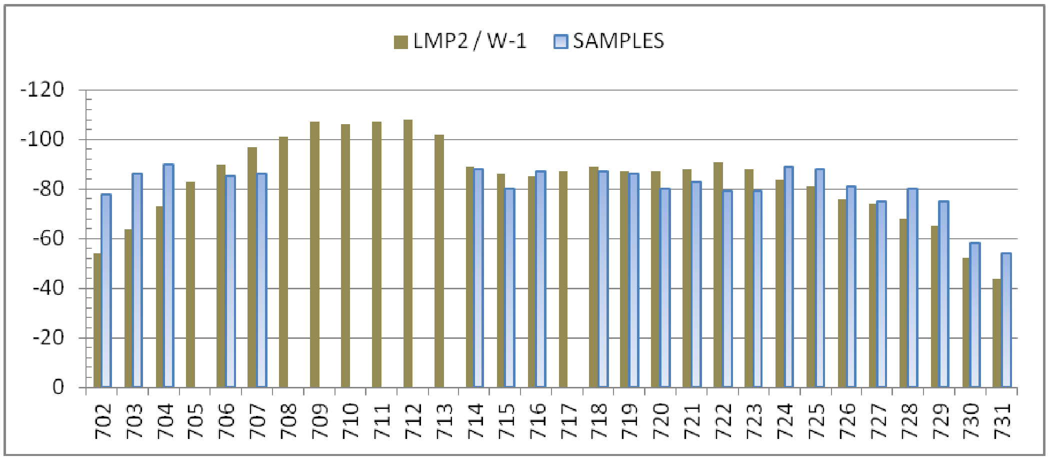
Path Loss: Ground Reflection 2-Ray (approximation) Foliage Loss: Weissberger 100%

nodeID:	702	703	704	706	707	714	715	716	718	719	720	721	722	723	724	725	726	727	728	729	730	731
sim RX (dBm):	-54	-64	-73	-90	-97	-89	-86	-85	-89	-87	-87	-88	-91	-88	-84	-81	-76	-74	-68	-65	-51	-43
sample RX (dBm):	-78	-86	-90	-85	-86	-88	-80	-87	-87	-86	-80	-83	-79	-79	-89	-88	-81	-75	-80	-75	-58	-54
difference (dBm):	-24	-22	-17	5	11	1	6	-2	2	1	7	5	12	9	-5	-7	-5	-1	-12	-10	-7	-11
	MEAN of absolute difference (dBm):																					8.3
	AVERAGE DEVIATION of absolute difference (dBm):																					4.9



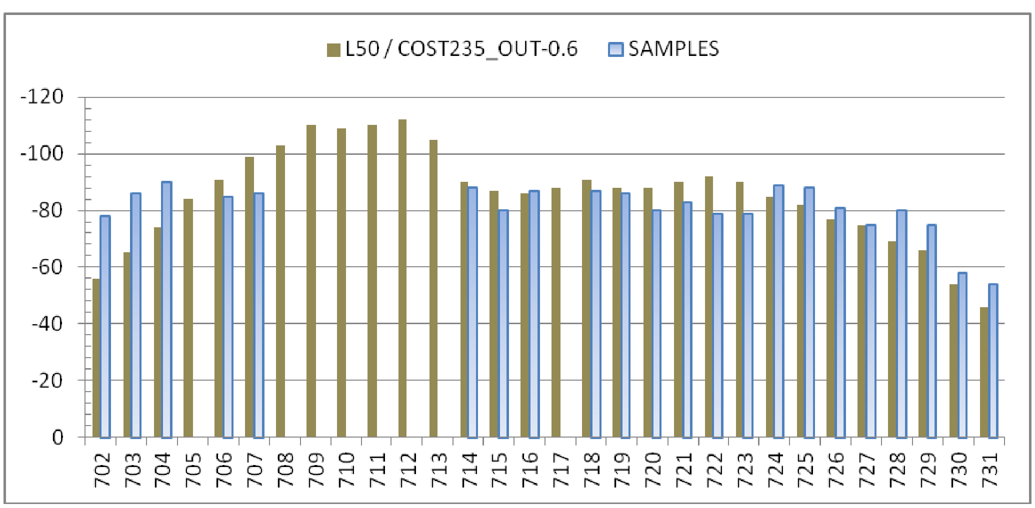
Path Loss: Ground Reflection 2-Ray (analytic) Foliage Loss: Weissberger 100%

nodeID:	702	703	704	706	707	714	715	716	718	719	720	721	722	723	724	725	726	727	728	729	730	731
sim RX (dBm):	-54	-64	-73	-90	-97	-89	-86	-85	-89	-87	-87	-88	-91	-88	-84	-81	-76	-74	-68	-65	-52	-44
sample RX (dBm):	-78	-86	-90	-85	-86	-88	-80	-87	-87	-86	-80	-83	-79	-79	-89	-88	-81	-75	-80	-75	-58	-54
difference (dBm):	-24	-22	-17	5	11	1	6	-2	2	1	7	5	12	9	-5	-7	-5	-1	-12	-10	-6	-10
	MEAN of absolute difference (dBm):																					8.2
	AVERAGE DEVIATION of absolute difference (dBm):																					4.9



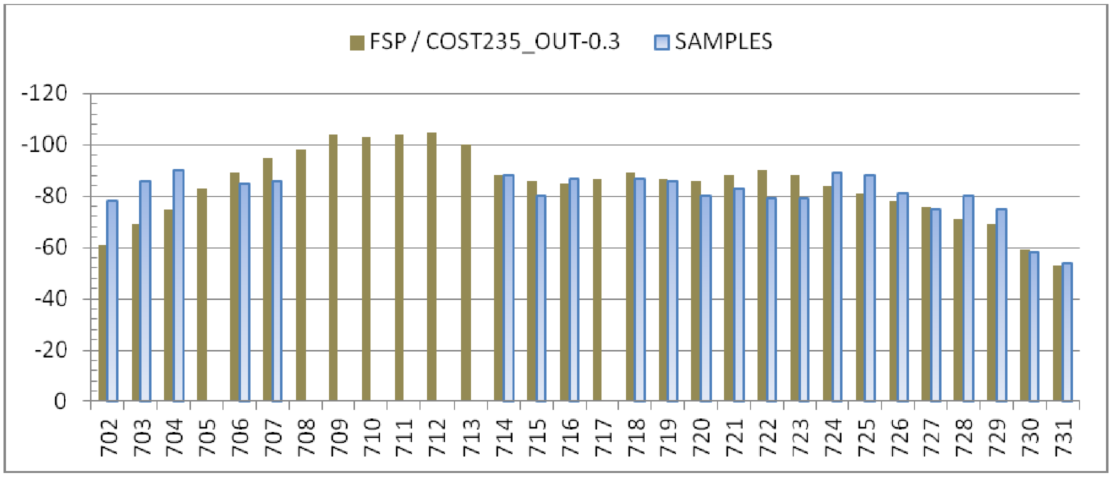
Path Loss: Egli Terrain Model Foliage Loss: COST235_OUT 60%

nodeID:	702	703	704	706	707	714	715	716	718	719	720	721	722	723	724	725	726	727	728	729	730	731
sim RX (dBm):	-56	-65	-74	-91	-99	-90	-87	-86	-91	-88	-88	-90	-92	-90	-85	-82	-77	-75	-69	-66	-54	-46
sample RX (dBm):	-78	-86	-90	-85	-86	-88	-80	-87	-87	-86	-80	-83	-79	-79	-89	-88	-81	-75	-80	-75	-58	-54
difference (dBm):	22	21	16	6	13	2	7	1	4	2	8	7	13	11	4	6	4	0	11	9	4	8
	MEAN of absolute difference (dBm):																					8.1
	AVERAGE DEVIATION of absolute difference (dBm):																					4.6



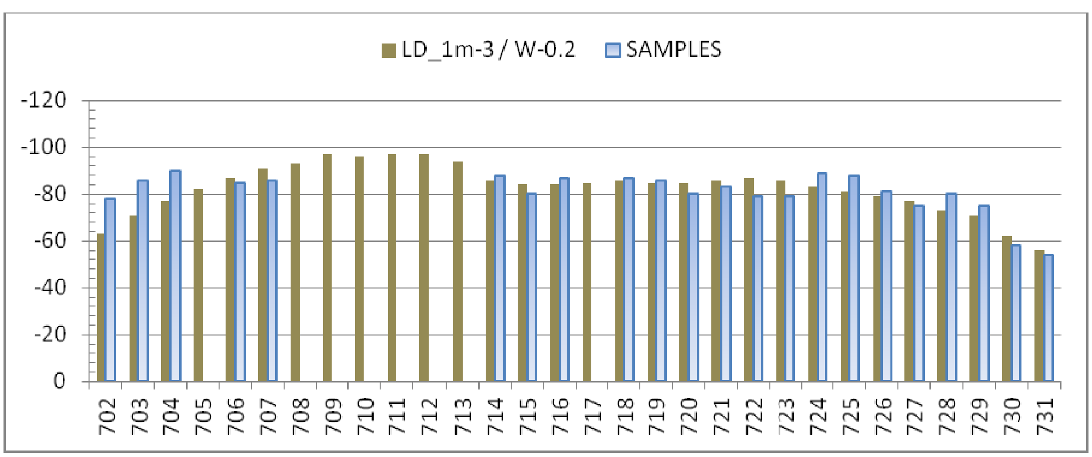
Path Loss: Free Space Propagation Foliage Loss: COST235_OUT 30%

nodeID:	702	703	704	706	707	714	715	716	718	719	720	721	722	723	724	725	726	727	728	729	730	731
sim RX (dBm):	-61	-69	-75	-89	-95	-88	-86	-85	-89	-87	-86	-88	-90	-88	-84	-81	-78	-76	-71	-69	-59	-53
sample RX (dBm):	-78	-86	-90	-85	-86	-88	-80	-87	-87	-86	-80	-83	-79	-79	-89	-88	-81	-75	-80	-75	-58	-54
difference (dBm):	-17	-17	-15	4	9	0	6	-2	2	1	6	5	11	9	-5	-7	-3	1	-9	-6	1	-1
	MEAN of absolute difference (dBm):																					6.2
	AVERAGE DEVIATION of absolute difference (dBm):																					4.0



Path Loss: Log-Distance (d0=1m, L0=FSP) n=3 Foliage Loss: Weissberger 20%

nodeID:	702	703	704	706	707	714	715	716	718	719	720	721	722	723	724	725	726	727	728	729	730	731
sim RX (dBm):	-63	-71	-77	-87	-91	-86	-84	-84	-86	-85	-85	-86	-87	-86	-83	-81	-79	-77	-73	-71	-62	-56
sample RX (dBm):	-78	-86	-90	-85	-86	-88	-80	-87	-87	-86	-80	-83	-79	-79	-89	-88	-81	-75	-80	-75	-58	-54
difference (dBm):	-15	-15	-13	2	5	-2	4	-3	-1	-1	5	3	8	7	-6	-7	-2	2	-7	-4	4	2
	MEAN of absolute difference (dBm):																					5.4
	AVERAGE DEVIATION of absolute difference (dBm):																					3.2



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