Development of a Resilient Wireless Sensor Network for Real-Time Outdoor Applications

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***Abstract*—** Wireless sensor network deployed for any outdoor applications confronts link variations. The outdoor deployment can be appallingly affected by the precipitous change in the environmental conditions. The effect can vary accordingly with a single hop and a multi hop sensor network. In this paper, we analyze the impact of propagation factors such as shadowing, fading, foliage and rainfall on the link quality, received signal strength and packet reception rate. Then using a packet oriented simulation tool, Qualnet 5.0.2 a simulation framework was created to analyze the aftermath of the aforementioned propagation factors' separate as well as integrated effect on the signal quality. The models developed from the simulation are tested and assessed with the data received from the real time wireless sensor network system for landslide monitoring, deployed at Munnar, India.

***Keywords*— wireless sensor networks, shadowing, fading, link quality, received signal strength, rate of packet loss, path loss, fault tolerant, propagation, link variations, packet reception rate, signal quality, landslide monitoring.**

I. Introduction

Wireless sensor networks have allured the public's attention since it plays an inevitable part in environmental monitoring, landslide detection, disaster management etc. The networks meant to monitor any environment disasters are substantially deployed in an outside domain. These outdoor deployments of wireless sensor network endure sporadic loss of link due to rainfall, foliage, fading and shadowing which will affect the constancy of the network due to reduction in the packet reception rate. Hence outdoor wireless sensor networks entail a coherent fault tolerant mechanism habile to tackle with the dynamic environment changes.

For the design and development of a fault tolerant network it is awfully necessary to envisage the reckoned dynamic changes in the environment and its effects on the network. Dynamic changes occur in an outdoor environment due to rainfall rate, fog, vegetation, reflection, diffraction, shadowing, scattering etc. Due to these engenders we cannot clinch a line of sight path in every scenario. A non line of sight path induces the transmitted signal to deteriorate which result in a low quality transmission. To stabilize the link quality, this paper sets to explore the causes for link variation, and the network parameters that get affected due to environment changes. Relevant empirical models for rainfall, foliage, shadowing and fading are used to analyze the cause and effect relation of different network parameters using Qualnet software simulator. These analyzed results will be used for developing an adaptive routing protocol that will increase the reliability of the system by determining the route with the link quality value.

To discover how the environmental factors are altering the signal quality, a simulation model was done in Qualnet. By integrating the models in the Qualnet simulator the impact on different rate of packet transmissions were analyzed with respect to path loss and packet reception rate variations. It is observed that rainfall rate and propagation distance through foliage above a particular value affects the signal quality drastically than any other propagation parameters.

To evaluate the precision of the simulated model, data from the real-time wireless sensor network system for landslide monitoring, deployed at Munnar, India was collected. The data was then correlated with the simulated result and it showed about 93% similarity.

This research paper is organized into six sections. The first section offers an introduction and explains the purpose of the research. The second section discusses related work in that field. The third section explains in depth the challenges faced in Wireless Sensor Networks. The fourth section deals with the architecture details. The fifth section is organized with the obtained simulation results. The paper concludes at the sixth section by proposing the future work.

II. Related Works:

In [1] Margham et al. the effect of rainfall rate on the link quality was analyzed and the result shown that there is a negative impact on the link quality. But the authors did not consider any effect of path loss, shadowing and fading effects. In [2] Boccur et al. a statistical analyzing on the link quality estimation is done by using a software benchmarking tool called RadialE. But the authors failed to discuss the effect of dynamic environmental changes on the link quality. In [12] Yang et al. the authors discussed the accuracy of the existing path loss model with linear regression method on the measured data. Then concluded that a site specific information is necessary for the deployment of the wireless sensor networks. In [3] Ren et al. by using a packet oriented simulation tool, OPNET, the authors realized the effect of Rayleigh fading and shadowing fading. The effect of path loss was also optimized through adapting the path loss exponent values. In [6] Irfan et al. have presented the signal strength measurement results for path loss, shadowing and fading models. The authors used a simulator, InSSIDer, to take different signal strength values on outdoor and indoor environments at different locations. In [9] Erceg et al. a path loss and a path loss exponent model based determination of signal strength was done for the outdoor sensor deployment. In [15] Putra et al. explains that a signal can even be affected with the effect of vegetation and wind. To prove it, the authors had done a statistical analyzing. The linearity relationship between the received signal strength and link quality is calculated in Ekka [4] et al. In [7] Nose et al. a signal strength based route construction is done to tolerate fault in the network. In most of the existing works the network performance was discussed through a single propagation effect, a combined analyzing was not done so far. This paper analyzed the combined effect of the propagation factors in the network quality.

III. Propagation challenges:

The wireless sensor network deployed in the outdoor can be affected by various propagational challenges such as path loss, fading, shadowing etc. Most of these propagational effects are mainly due to the environmental factors such as rainfall, foliage, fog, wind etc.

The effects of fading, shadowing, path loss, rain and foliage in WSN are studied in this work which is discussed in below sections.

A. Foliage model selection:

Most of the empirical foliage loss models for the propagation path are exponential decay models, such as Weissberger model , ITU Recommendation(ITU-R) model, COST235 model, Maximum attenuation (MA) model, Nonzero gradient (NZG) model, and Dual Gradient (DG) model [5].

In general, the exponential decay model has the following form [5]:

$$L\,(dB) = Af^{B}d^{c} \qquad (1)$$

Where A, B, and C are the parameters from different experiments with regression techniques.

The gradient models, the NZG model [5] was proposed by Seville to rectify the zero gradient problem associated with the MA model [5]. However the NZG and MA model are not taking the frequency information as inputs. Hence by these models, we cannot analyze the propagation effects of different frequencies. Subsequently, the DG model is proposed with the antenna beam width and the operating frequency as the input parameters, since there is no frequency information in both the NZG model and MA model [5].

The different models based on horizontal path propagation with its empirical formula are as follows:

Weissberger model [5]:

$$Lw(dB) = 1.33 * f^{0.284} * d^{0.588} \qquad (2)$$

where f is the frequency in GHz, and d is the distance of propagation through foliage it should be between 14 meter and 400 meter.

ITU-R model [5]:

$$L_{ITUR}(dB) = 0.2 * f^{0.3} * d^{0.6} \qquad (3)$$

Where f is the frequency in MHz, and d is the tree depth in meter.

MA model [5]:

$$L_{MA}(dB) = A_m \left[1 - e^{\frac{-R_0 * d}{A_m}} \right] \qquad (4)$$

Where A_m is the maximum attenuation, R_0 is the initial gradient of the attenuation rate curve, and d is the distance of propagation through the foliage.

Since most of the wireless sensor networks use GHz frequency range for communication, the weissberger model for determining the path loss effects in WSN is selected.

B. Rainfall model:

The rainfall model is used to study attenuation in the transmited signal due to rain fall. Many scattering models exist to find the signal degradation due to rainfall. But all those scattering models require the complex calculation of the distance between the scattering object and the receiver and the transmitter.

The rainfall attenuation model's applied equation is [1]:

$$A = \alpha R^{\beta} \tag{5}$$

Where, R is the rainfall rate in millimeter per hour.

$$\alpha = e^{(1.58\ln(f) - 6.23)} \tag{6}$$

$$\beta = e^{(0.029\ln(f) + 0.031)} \tag{7}$$

C. Fading Model:

Fading is one of the major propagation effects in all wireless communication systems. The fading may differ with time, geographical position and radio frequency, and is modeled as a random process. A fading channel is a communication channel that experience fading. In any wireless systems, fading may either due to multipath propagation, known as multipath induced fading, or due to shadowing from obstacles affecting the wave propagation, sometimes referred to as shadow fading. The Rayleigh fading model is used to model the fading in a non line of sight path, which is used in this work.

Rayleigh fading distribution is as follows [14]:

$$P_r(r) = \frac{2r}{\sigma^2} e^{\frac{-r^2}{\sigma^2}} \tag{8}$$

Where r is the rms value of the voltage of the signal and sigma is the standard deviation from the expected mean value.

D. Log Normal Shadowing Model:

The large scale signal power strength model is used for predicting the average signal strength as a function of distance between the Transmitter and Receiver which may include antenna gains, height, and frequency of operation. The path loss model does not discriminate between two locations which are at the same distance from the base station, but are at two distinct directions. This is due to the fact that the path loss model is not considering the effect of local clutter. In reality if we consider two locations then the local mean of the path losses will vary. The Path loss model only conveys an average value of path loss of the transmitted signal in a region or area. The local mean is a random value and its effect is calculated through the shadowing model. Thus the Path loss formula is extended in order to taken care the local mean variation as well. Hence the combined effect of the path loss and the shadowing are considered to calculate the received signal strength at a distance'd' [7]:

$$P_r(dB) = P_t\left(\log(K) - 10\gamma\frac{d}{d_0} - \Psi\right) \tag{9}$$

Where:
K is a constant which depends on the antenna characteristics.
γ is the path loss exponent.
Ψ is the Gaussian distributed random variable.

The above mentioned propagation models are used to analyze the characteristics of the degrading signal such as received signal strength and the packet loss due to poor link quality.

IV. Software Architecture:

The architecture is designed in such a way to study the characteristics of the output signal with the different effects of the propagation parameters. In the figure 1, the propagation models module includes the fading model, shadowing model, rainfall attenuation model and vegetation attenuation model.

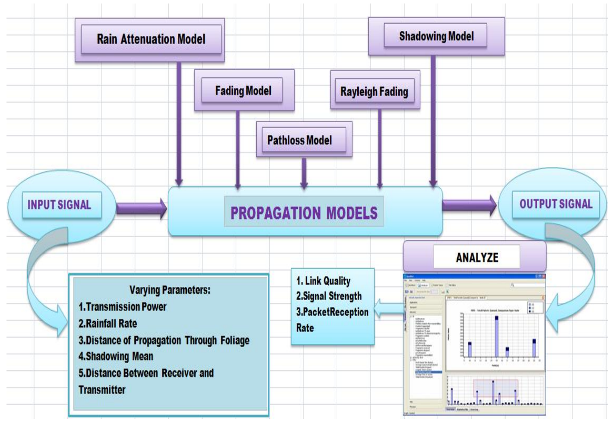

Figure 1: Architecture used for the simulation

The output signal is analyzed with link quality, received signal strength and the packet reception rate. The link quality is the ratio in the received signal strength to the noise power. Signal strength is the received signal strength received at the receiver. Packet loss is the number of packets received out of the total packet sent. It can also be inferred as the packet reception rate.

V. Simulation and Results:

A.Simulation modeling for rainfall attenuation model:

According to equations (6), (7) and (8) we created different simulation scenarios in Qualnet to obtain a series of data with the link quality and received signal strength. The simulation results obtained using Qualnet GUI interface are shown in figure 5 and figure 6.

B. Simulation of path loss:

In Qualnet simulator a sensor network scenario is created where the sender node is sending a total of 100 packets. This scenario is used to infer the effect of path loss in the transmitted signal with combined effect of the environmental parameters such as the rainfall rate and the distance of propagation through foliage. Then at different transmitter-receiver distance, the path loss is calculated and plotted the graph in Matlab.

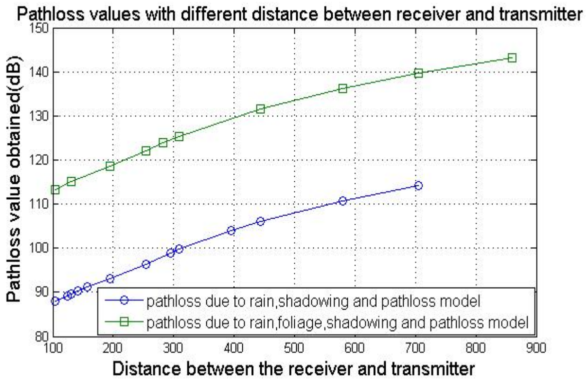

Figure 2: Path loss obtained by varying the distance between transmitter and receiver

From the analysis of the graph shown in figure 2, a 40 dB difference in the signal path loss is estimated without the effect of the environmental factors than with the effect of the environmental factors.

C. Effect of shadowing mean in the transmitted signal:

The shadowing mean is varied and analyzed the packet loss with the variation.

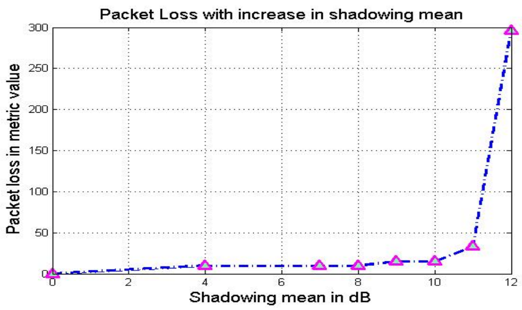

Figure 3: Packet loss with increase in shadowing mean

From the analysis of the simulation result, it is clear that the packet loss started when the shadowing mean is above 4dB. All the packets are lost when the shadowing mean is above 11dB.

D.Effect of Rainfall rate in the transmitted signal:

In a multi hop network, the rain fall rate approximately above 350mm/hr is affecting the signal quality. No packet loss is observed within the range of 50-350mm/hr. In a single hop network, the packet loss has occurred even at 325mm/hr.

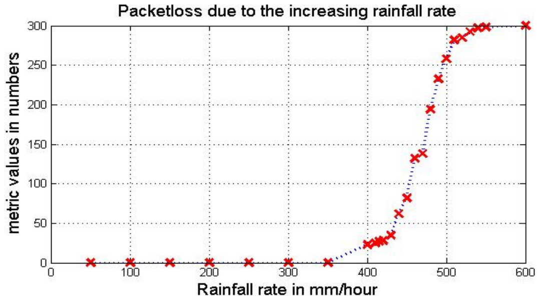

Figure 4: Packet loss with increase in rainfall rate for multi hop wireless sensor network

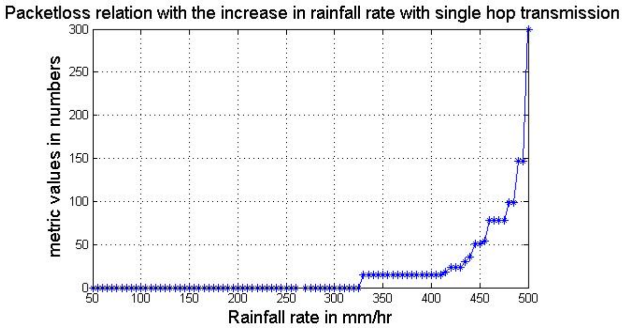

Figure 5: Packet loss with increase in rainfall rate for single hop wireless sensor network

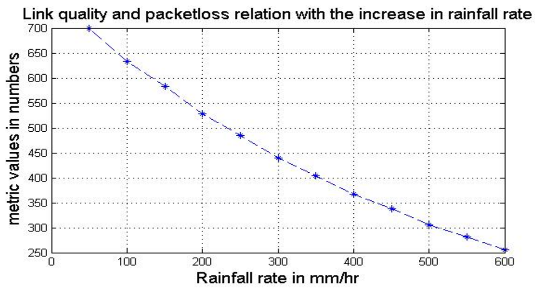

Figure 6: Link quality variation with the effect of rainfall rate

The link quality is observed to be decreasing with increase in rainfall rate.

E. Effect of foliage in the transmitted signal:

The distance of propagation through the foliage affects the signal quality. Even the movement of vegetation can degrade the signal quality which is not investigated in this paper.

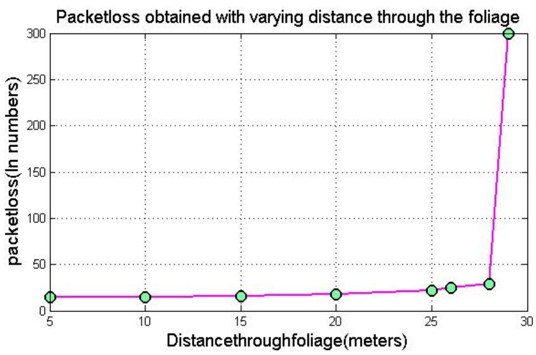

Figure 7: Packet loss with increase in distance through foliage in a multi hop wireless sensor network

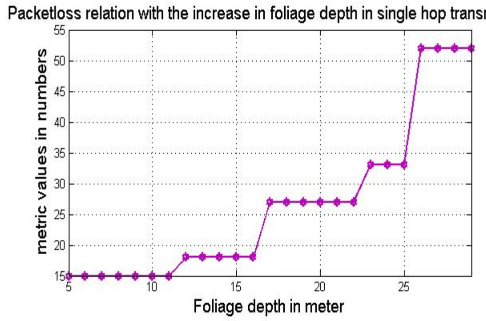

Figure 8: Packet loss with increase in distance through foliage in a single hop wireless sensor network

In figure 7 and 8, the simulation result of foliage model is shown. If the distance through foliage is more than 10 meters, it will affect the packet reception rate both in single and multi hop networks. The link quality is also analyzed with the variation in the distance through foliage.

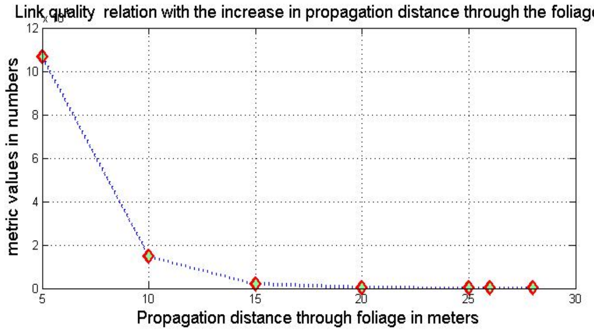

Figure 9: Link quality variation with increase in propagation distance through foliage

The result from graph in figure 9 shows if the distance through propagation is above 10 meters can affect the signal quality drastically.

F. Effect of transmission power in the packet loss:

With the result obtained using the different rain fall rates which are shown in figure 10, it is clear that when rainfall rate is above 5.833 mm per minute packet loss is observed. So assuming the rainfall rate to be 5.833 mm per minute the distance through foliage is varied and analyzed.

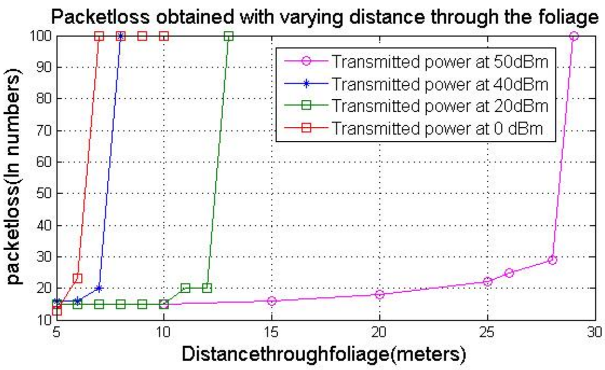

Figure 10: Packet loss with different power levels

In figure 11, the variation of link quality with different power levels is verified. The analyzed graph implies that at much lower power levels the degradation on the signal quality is at high rate.

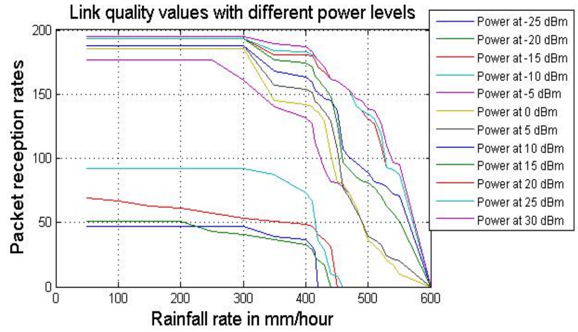

Figure 11: Link quality variation with different power levels

In figure 12, the packet reception rate with different power levels is verified. The simulated graph conveys that the packet reception rate is also showing large variation with the varying power levels.

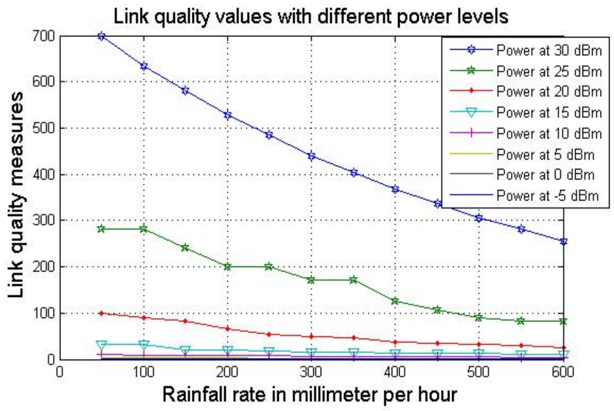

Figure 12: Packet reception rate variation with different power levels

H. Real Data Analysis:

The real data is received from the real-time wireless sensor network system for landslide monitoring, deployed at Munnar, India. 93% match with simulated result and real data from munnar is obtained in the real data analysis result shown in figure 13.

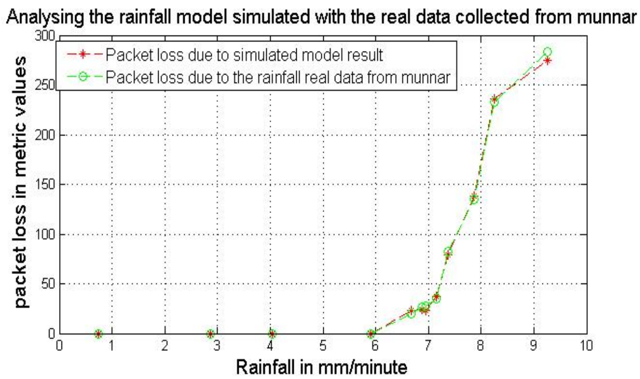

Figure 13: Real data analyzed with simulated results

For analyzing the most influential factor that causes the degradation in the transmitted signal a box plot analyzing is done in the mat lab. The minimum the size of the box plot, the minimum is the difference between the parameters compared. The analyzed box plot implies that the combined effect of the rainfall rate and distance of propagation through foliage is mostly affecting the signal degradation.

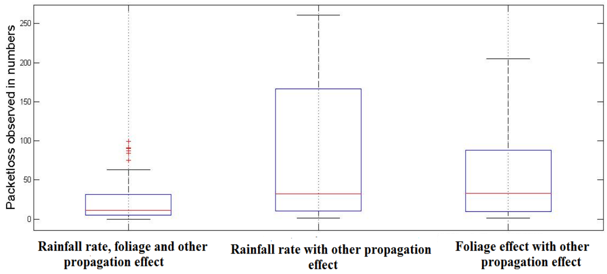

Figure 14: Comparison of propagation effect with real data from munnar

The real data from landslide monitoring system is analyzed with the simulated result in the Qualnet with the combined effect of the environmental parameters like the rainfall rate, foliage, shadowing and fading. The result holds the fact that the models were showing similar results as in theoretical models.

VI. Conclusion and Future works:

To analyze the effect of propagation and environmental factors on the signal quality we implemented simulation of these models in the Qualnet. Simulation result shows the rainfall rate and the distance of propagation through foliage have a non-negligible impact on the performance of the network especially on the link quality and packet reception rate. Then the simulated result is analyzed with real time wireless sensor network system for landslide monitoring deployed at munnar.

In future from these analyzed results we are planning to design an adaptive routing protocol that adapts its path with the best available link quality.

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VIII. References

[1] Markham, Andrew; Trigoni, N.; Ellwood, Stephen, "Effect of rainfall on link quality in an outdoor forest deployment," *Wireless Information Networks and Systems (WINSYS), Proceedings of the 2010 International Conference on* , vol., no., pp.1,6, 26-28 July 2010

[2] Baccour, N.; Ben Jama□a, M.; do Rosário, D.; Koubaa, A.; Youssef, H.; Alves, M.; Becker, L.B., "A testbed for the evaluation of link quality estimators in wireless sensor networks," *Computer Systems and Applications (AICCSA), 2010 IEEE/ACS International Conference on* , vol., no., pp.1,8, 16-19 May 2010

[3] Zhi Ren, Guangyu Wang, Qianbin Chen, Hongbin Li, Modelling and simulation of Rayleigh fading, path loss, and shadowing fading for wireless mobile networks, *Simulation Modelling Practice and Theory*, Volume 19, Issue 2, February 2011, Pages 626-637

[4] Ekka, Ashish *Pathloss Determination Using Okumura-hata Model for Rourkela,* [Online], Available: http://ethesis.nitrkl.ac.in.

[5] Y. S. Meng and Y. H. Lee, "Investigations of foliage effect on modern wireless communication systems: a review," *Progress In Electromagnetics Research*, Vol. 105, 313-332, 2010.

[6] Irfan Ahmed, Sara Orfali, Tamer Khattab, Amr Mohamed, "Characterization of the Indoor-Outdoor RadioPropagation Channel at 2.4 GHz", 2011 *IEEE GCC Conference and Exhibition (GCC).*

[7] Asuhiro Nose, Akimitsu Kanzaki, Takahiro Hara, Shojiro Nishio, "Route construction based on Measured characteristics of radio propagation in wireless sensor networks", *International Conference on Advanced Information Networking and Applications 2009.*

[8] V.Dasarathan,M.Muthukumar,K.N.Elamkumaran, "Outdoor channel measurement pathloss modelling and system simulation of 2.4 GHz WLAN IEEE802.11g in Indian rural environments", 2011 17th *Asia-Pacific Conference on Communications (APCC)*, On page(s): 339 – 343.

[9] Vinko Erceg, Larry J. Greenstein, Sony Y. Tjandra,Seth R. Parkoff, "An empirical based pathloss model for wireless channels in suburban environments", *Wireless Communications and Networking Conference*, 2004. WCNC. 2004 IEEE, On page(s): 1105 - 1108 Vol.2 Volume: 2, 21-25 March 2004.

[10] Syed Idris Syed Hassan, Seri Ampangan, Nibong Tebal,"Link empairment due to rain and other climatic factors", 2009, http://www.aprsaf.org.

[11] T. S. Rappaport, "Wireless communication Principles and Practice", 2nd Edition, Prentice Hall, pp.70-130, 2001.

[12] Yang Yang, Jing Hu, Tiecheng Song, Lianfeng Shen, "A Study of Near Ground Channel Model for 2.4GHz IEEE802.15.4 Signal in Outdoor Environment", Information Science and Engineering (ICISE), 2009, 1st International Conference on, On page(s): 2508-2513, 26-28 Dec 2009.

[13] Fabio Belloni, "Fading Models", 2004, [Online], Available: http://www.comlab.hut.fi

[14] Mark.D.Casciato, "Radio Wave Diffraction and Scattering Models for Wireless Channel Simulation", 2001, http://www.eecs.umich.edu

[15] Praditio Putra, "Stastistical modelling of wind effects on signal propagation for wireless sensor networks", 2011, http://eprints.qut.edu.au

[16] Fanimokun A.;Frolik, J.,"Effects of natural propagation environments on wireless sensor network coverage area," System Theory, 2003. Proceedings of the 35th Southeastern Symposium on , vol.,no.,pp.16,20,16 18March2003doi:,10.1109/SSST.2003.1194521

[17] Qualnet Simulator, [Online], Available: http://web.scalable-networcks.om