Proceedings of ISAP2012, Nagoya, Japan

UHF Wireless Communication Channel in a Tree Canopy

#Pobsook Sooksumrarn [1] and Monai Krairiksh [2]
Faculty of Engineering, King Mongkut's Institute of Technology Ladkrabang
1 Chalongkrung rd, Ladkrabang Bangkok, Thailand 10520
s1060026@kmitl.ac.th[1], kkmonai@kmitl.ac.th [2]

1. Introduction

A wireless sensor network has played an important role in various applications [1] including agriculture where it is essential in quality control of fruit production. Microwave sensors have been installed on fruits to monitor their ripeness and signals corresponding to the level of ripeness were sent from the fruits on a tree to the tree node on that tree and then to the master node to warn growers to harvest at the appropriate time [2]. For an effective design of a wireless communication system in a tree canopy, channel characteristics are highly desirable. The works on propagation through foliages have been comprehensively reviewed [3] but none of them were for propagation channel in a tree canopy. Hence, a propagation channel in a tree canopy is presented experimentally in this paper.

2. Measurement Campaign

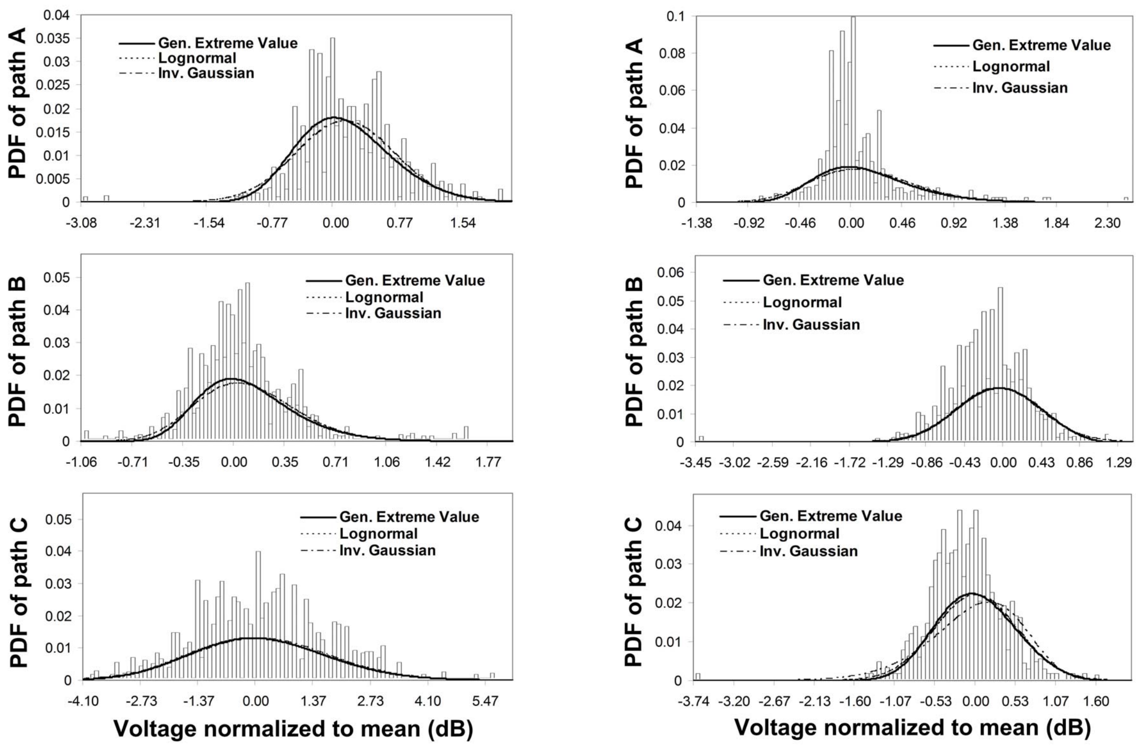
The frequencies of operation in this work were chosen to be at 433MHz and 915 MHz, which is an ISM band whose license is free and RF modules are readily available. This study performed channel measurement in a mango (Mangifera indica) tree canopy to exhibit probability density function (PDF) and path loss. It was approximately 5.2 m tall and an average trunk diameter was around 20 cm.

The measurements were carried out by using continuous-wave transmission. Monopole antennas with a typical gain of 2 dBi and 1.8 dBi at 433 MHz and 915 MHz, respectively, were used for transmission and reception at both frequencies. The positions of transmitting antennas were changed whereas the receiving antenna was fixed at a height of 1.4 m. Signal was transmitted from an Agilent N5182A signal generator with 0 dBm power was fed into the transmitting antenna. An Agilent E4403B spectrum analyzer was used for measuring the received power. Three measurement paths according to three different conditions depending on the amount of leaves and branches that directly affected the characteristics of the channel were setup.

Path A is a non-line-of-sight channel, the wave from the transmitter was blocked by foliage. Path B is a line-of-sight channel where some part of the path was slightly blocked by leaves and a few small branches. Path C is a non-line of sight channel. The wave from the transmitter was covered by foliage, big branches, and small branches.

3. Channel Characterization

Signal arrives at the receiving antenna is from direct and multipath propagations that result in signal fading. Channel can be characterized statistically and divided into line-of-sight or non-line-of-sight channel. The signals were measured with two thousand samples in each condition then the PDF, normalized to mean voltage, were plotted in Fig.1 (a) for 433 MHz and in Fig.1 (b) for 915 MHz. The PDF in Fig.1 (a) corresponding to path A, path B and path C were plotted with the General Extreme Value, Lognormal and Inverse Gaussian functions. We plotted these functions out since they provided the best match to the measured PDF. The root mean square error (Erms) between the sampled PDF and the known functions was estimated.



(a) (b)

Figure 1: PDF for each path (a) 433 MHz (b) 915 MHz

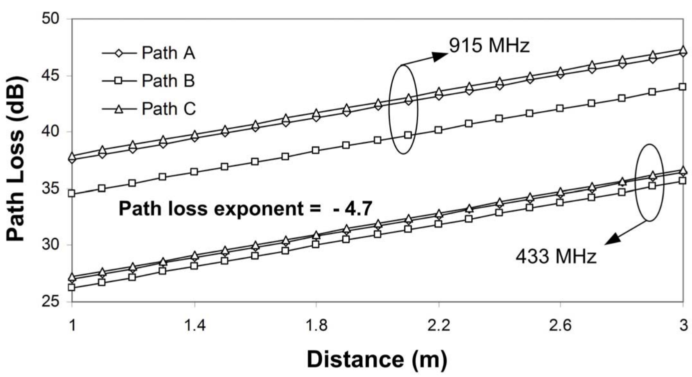


Figure 2: Path loss for each frequency

For the results of 915 MHz in Fig.1 (b), General Extreme Value, Lognormal and Inverse Gaussian functions were plotted with the sampled PDF as well. The Erms are listed in Table 1. For 433 MHz; General Extreme Value, General Extreme Value and Lognormal provided the best fit to the sampled PDF in path A, path B and path C, respectively. For 915 MHz, the best fit in all paths was the General Extreme Value function. Hence, the General Extreme Value function was chosen to model the channels in all paths and both frequencies. The Rician function was used to describe the proportion of the multipath signal to the direct signal. The k-factors for both frequencies of the three paths are listed in Table 2. The k-factors of path B were the highest due to the absence of obstacle along the path. Path C had the lowest k-factor since there was a branch between the transmitting and the receiving antennas. Those for 915 MHz had lower k-factors due to larger electrical size of leaves and branches than those for 433 MHz. In addition, these PDF models were used to calculate cumulative distribution function (CDF) that represented the probability of the signal being less than a specified level. This CDF was used in the estimation of the reliability of the wireless communication system.

To evaluate path loss, the signal levels at three positions along path A, B and C at both frequencies were measured. Then, they were converted to path loss and are illustrated in Fig.2. The path loss exponents for the three paths in Fig. 2 at both frequencies were -4.7. Note that the path loss exponents for path A and path C were high due to the foliage along the path.

Table 1: Average Erms for Each Distribution

Path A at 433 MHz		Path A at 915 MHz	
Model	ERMS	Model	ERMS
Gen.Ext.Value	0.043	Gen.Ext.Value	0.083
Lognormal	0.055	Lognormal	0.118
Inv.Gaussian	0.059	Inv.Gaussian	0.166
Path B at 433 MHz		**Path B at 915 MHz**	
Model	ERMS	Model	ERMS
Gen.Ext.Value	0.059	Gen.Ext.Value	0.039
Lognormal	0.088	Lognormal	0.045
Inv.Gaussian	0.064	Inv.Gaussian	0.048
Path C at 433 MHz		**Path C at 915 MHz**	
Model	ERMS	Model	ERMS
Lognormal	0.031	Gen.Ext.Value	0.040
Gen.Ext.Value	0.033	Lognormal	0.046
Inv.Gaussian	0.041	Inv.Gaussian	0.050

Table 2: k – Factors for Different Paths

Frequency / Path	433 MHz (dB)	915 MHz (dB)
A	22.55	14.25
B	28.65	19.55
C	13.75	10.15

4. Environmental Effects

The effect of strong wind was simulated by pulling branches at the central part of the tree with a rope. For light wind, a fan was used to blow leaves and an anemometer was used to measure the wind velocity. It was obvious that simulating strong wind along path A resulted in a loss of 0.2-0.4 dB at 433 MHz whereas it was 0.3-0.5 dB at 915 MHz. For path B, the corresponding loss at 433 MHz and 915 MHz were 0 dB and 0.2 dB respectively. Path C showed losses of 0.1-0.2 dB and 0.4 dB at 433 MHz and 915 MHz respectively. Light wind simulated by a fan affected leaves motion only. The average losses at both frequencies were less than those created by the simulation of strong wind, and the loss at 433 MHz was less than that at 915 MHz. A spray was used to simulate rain that covered branches and leaves with water mist. Signal strength was measured after water was sprayed on the canopy and attenuations due to rain were not observed at both frequencies. Table 3 summarizes the losses due to wind and rain at both frequencies and fade margins are listed.

Table 3: Attenuation Due to Wind and Rain

Frequency (MHz)	Path	Strong wind (dB)	Light wind (dB)	Rain (dB)	Fade margin (dB)
433	A	0.2-0.4	0	0	0.4
	B	0	0	0	0.0
	C	0.1-0.2	0	0	0.2
915	A	0.3-0.5	0.1	0	0.5
	B	0.2	0.1	0	0.2
	C	0.4	0.1	0	0.4

5. Conclusion

In the system design, knowing the antenna gain and the sensitivity of the receiver, path losses in Fig. 2 were used to calculate basically how much power was transmitted by each specific node. Then, channel models suitable for the specific path were selected in order to estimate the CDF to determine the reliability of the system, and the margin from environmental effects had to be taken into account. The results from this work enable one to design a reliable wireless communication system in a tree canopy which is essential in fruit's pre-harvesting control.

Acknowledgments

This work was supported by the Telecommunications Research and Industrial Development Institute, National Broadcasting and Telecommunications Commission Fund (Grant No.PHD002/2551) and the Thailand Research Fund (TRF) under the senior research scholar project (Grant No.RTA-518002).

References

[1] F. Akyildiz, W. Su, Y. Sankarasubramaniam, and E. Cayirci, "Wireless Sensor Network: Survey," Computer Network, vol.38, pp.393-422, 2002.

[2] M.Krairiksh, J.Varith, and A.Kanjanavapastit, "Wireless sensor network for monitoring maturity stage of fruit," Science Research/Wireless Sensor Network, vol.3, pp.318-321, 2011.

[3] Y.S.Meng and Y.H.Lee, "Investigations of foliage effect on modern wireless communication systems: A review," Progress In Electromagnetics Research, vol.105, pp.313-332, 2010.