Characterization of Radio Path Loss in Seaport Environment for WiMAX Applications

Ming-Tuo Zhou [1], Joe Jurianto [2], Jaya Shankar [2], M. Fujise [1]
[1]Wireless Communications Laboratory, National Institute of Information and
Communication Technology (NICT), Singapore,
20 Science Park Road, #01-08A/10 TeleTech Park, Singapore 117674, mingtuo@nict.com.sg
[2]Institute for Infocomm Research, 21 Heng Mui Keng Terrace Singapore 119613

Abstract

Experimental results of radio path loss measured at 5.8 GHz in seaport are presented. Results show that within a range of more than 10km, the radio signal attenuates at a rate close to that of the free space and when higher base antenna is used, the attenuation rate approaches that of the free space more. Based on the measured data, a simple path loss model is developed. This study is helpful to deploy WiMAX systems for seaport users.

1. INTRODUCTION

Due to the rapid development of the Internet and various information systems, users in anchored or moving ships in seaports desire the access to broadband information services. Although the current seaport users may access the Internet via General Pack Radio Service (GPRS) or satellite links, the access has relatively low speed. WiMAX based on IEEE 802.16 standards can be a good candidate mainly due to its high-speed (several Mbps or tens Mbps) and relatively long-distance access range (more than ten kilometers [1]). In order to build IEEE 802.16-based networks in seaports, it is necessary to study the wireless channel in seaport environments. Path loss is one of the main channel properties that needs to be characterized. However, to our knowledge, the path loss characteristics discussed so far for IEEE 802.16 applications are limited to urban and suburban environments [2][3]. Studies in seaport environments are rarely carried out.

In this paper, we present experimental results of radio path loss at 5.8 GHz measured in the seaport environment. The frequency that we selected is within the frequency range defined in the IEEE802.16d-2004 standards. Two important parameters, path loss exponent and standard deviation are characterized. The first parameter describes the attenuation rate of the radio signal power along the base and the receiver distance; the second indicates the severity of the shadowing effect. We found that, with a base antenna height of several to over hundred meters (4m to 185m in experiments) above the average sea surface, radio signals attenuates with a rate slightly faster than the square of the distance, which is the case in the free space. When higher base antenna is used, the path loss exponent is closer to the free space case. The path loss standard deviation decreases when antenna height is increased; this shows that with higher antenna, the radio signals experiences clearer propagation path and the shadowing effect is less serious. Based on the measured data, we developed a simple model. Other than 5.8 GHz, the model should also be applicable to other popular frequencies, e.g., 3.5 GHz.

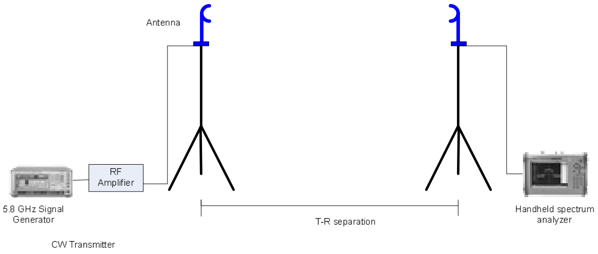

Fig. 1: Equipment setup for path loss measurements

2. TESTING ENVIRONMENT AND DATA COLLECTION METHOD

The path loss measurement was carried out in Singapore Port, which is one of the busiest ports in the world. It has a typical seaport environment with many ships anchored or moving in the port and a sea wave height of about 1 m in good weather. A view of Singapore Port can be found in [3].

In the experiment, the transmitter was fixed on the shore or on top of a tall building. The receiver antenna was amounted on a ship. During the measurements, the receiver ship moved and stopped at different locations to change the transmitter-receiver distance. Global Position System (GPS) was used to keep track of the separation distance between the transmitter and receiver. As the transmitter was at a fixed location in one measurement scenario, only the receiver was required to read the GPS position during the test. The GPS at the receiver ship was collected at one second interval by a laptop and was

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* *The results in this paper are derived from a joint collaboration project between NICT and Institute for Infocomm Research.*

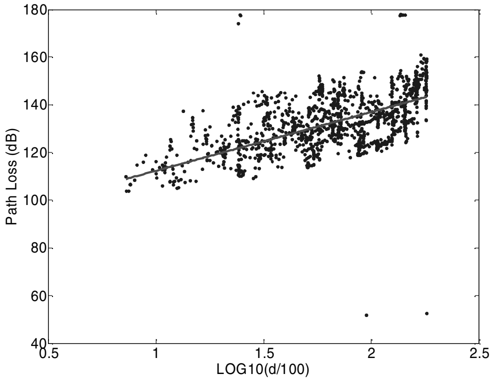

Fig. 1: Scatter plot for path loss measurement at frequency 5.8 GHz in the Singapore Port with base station antenna height of 4 m. The path loss exponent is analyzed to be γ=2.462, and the standard deviation of s is σ=10.084 [dB]

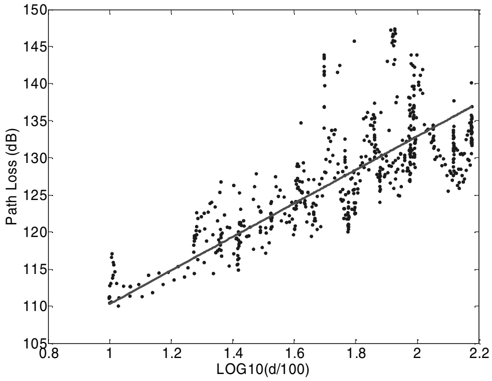

Fig. 2: Scatter plot for path loss measurement at frequency 5.8 GHz in the Singapore Port with base station antenna height of 76 m. The path loss exponent is analyzed to be γ=2.259, and the standard deviation of s is σ=5.111 [dB]

time-stamped automatically. The resolution of the GPS is 10 m. In the measurements, the farthest separation between the transmitter and the receiver can be 18 km.

Three experiment scenarios were implemented: two in the east side of Singapore Port and one in the West Coast of Singapore Port. In the three experiments, the base station antenna heights were 4 m, 76 m and 185 m (to the mean sea surface), respectively. The receiver antenna height was about 8 m (to the mean sea surface).

Figure 1 shows the experimental setup. At the transmitter side, a Continuous Wave (CW) signal generator is used as a source. The signal generator is set at 5.8 GHz with 0 dBm output. A 30 dB power amplifier is connected between the signal generator and the antenna. The antenna is omnidirectional in the horizontal plane and has a 9 degree beam width in the vertical plane. The gain of the antenna is 12 dB. The same antenna is used at the receiver. The receiver antenna was connected to a portable spectrum analyzer. For continuous data acquisition, the spectrum analyzer was connected through Ethernet cable to a laptop. The laptop records the peak power reading from the spectrum analyzer with time stamp.

The measured data were averaged every 30 seconds to eliminate the effect of the fast fading due to multipath and estimate the local mean power.

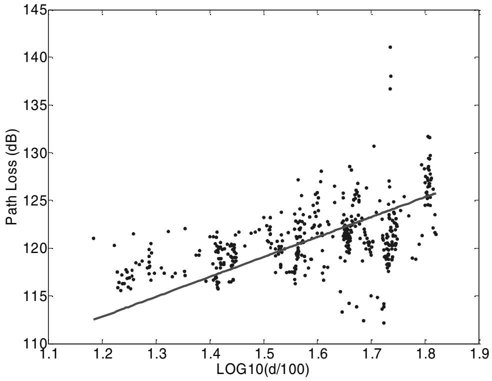

Fig. 3: Scatter plot for path loss measurement at frequency 5.8 GHz in the Singapore Port with base station antenna height of 185 m. The path loss exponent is analyzed to be γ=2.090, and the standard deviation of s is σ=3.362 [dB]

3. SCATTER PLOTS AND PATH LOSS CHARACTERS

Generally the path loss in a macro-cellular environment shows an increasing trend with distance from the base station. Using the decibel (dB) representation, the path loss can be modelled as a Gaussian random variation with a mean as power γ of distance and a standard deviation σ characterizing the effect of shadow fading [4]. At distance zero, the path loss in dB is minus infinite and this value makes no sense. For this reason, a close-in distance d_0 is selected and the free space propagation loss at d_0 is set as a reference value. Hence, the decibel path loss beyond d_0 can be written as

$$PL = A + 10\gamma\log10(d/d_0) + s \quad \text{for } d > d_0, \tag{1}$$

where A=20log10($4\pi d_0/\lambda$) (λ is the radio wavelength in m) is the free space path loss at d_0, γ is the path loss exponent, d is the distance from the base, and s is a zero-mean Gaussian random variation representing the shadow fading effect.

Based on Eq. (1), linear regression with minimum mean square error (MMSE) can be applied to find the path loss exponent γ and the deviation σ for each experiment scenario. In the data processing, d_0 was chosen to be typically 100 m

TABLE I. RESULTS OF THE LINEAR REGRESSION WITH MMSE CONSTRAINT FOR SEAPORT PATH LOSS MEASUREMENTS.

base antenna height (m)	4	76	185
γ	2.462	2.259	2.090
σ	10.084	5.111	3.362

for macrocell with radius of more than 10 km. The scatter plots for the three experiment scenarios are shown in Fig. 2, Fig. 3, and Fig. 4, respectively. The analyzed path loss exponent γ and the standard deviation σ are listed in Table I.

From the analyzed results, it is clear that both the power-law exponent γ and the standard deviation σ decreases with the base antenna height. This is true since with higher base antenna height, the radio signal experiences less blockage and better sea-surface clearance. In all the three scenarios, the path loss exponents are close to free space propagation with a power exponent of 2. When the antenna height is 185 m, the difference from the free space propagation is only 0.09, by which a line-of-sight propagation is well indicated. Compared to the land environments (urban and suburban) with typical γ more than 3.5 [4], the seaport environment has smaller propagation loss. When the base antenna height is set to 76 m, the characteristics of the channel is closest to a flat terrain with light tree density (γ=3.483) found in land environment. As for the standard deviation, it is generally smaller in seaport environments than in land environments. In suburban environments the standard deviation is generally between 8.2 and 10.6 dB [2]. In our measurements, only the case with base antenna height of 4 m shows a large deviation. Such a phenomenon was observed because in the experiment (h_b=4m), there were many instances of ships being anchored or moved between the base and the receiver. When this happens, there is a loss in line-of-sight and the receiver power drops by more than 20 dB.

4. DISCUSSION AND MODELLING

The path loss exponent γ in land environments resembles a Gaussian random variable over the population of macrocells and for a given terrain category the mean of γ is characterized as a function of the base antenna height h_b [4]. This also applies to the seaport environments. As observed in the measurements, in a wide range of base antenna heights (4m to 185m) in seaport environments, the path loss exponents has a relatively small range between 2 and 2.5. It indicates that the statistical deviation of γ in seaports is relatively small and the measured exponent values may roughly stand for the mean exponent values at the corresponding base antenna heights. It can be shown that this approximation introduces small deviation in the estimation of the path loss. For example, by using Eq. (1) we know the difference in path loss between γ=2.5 and 2.75 at 10 km is about 5 dB; this value is less than the standard deviation of the path loss measured at h_b=4m (10.084dB) and just close to the value measured at h_b=76m (5.111dB); the difference is even smaller when d<10km. Based on this finding and approximation, as shown in Fig. 5, the path loss exponent in seaports can be represented by a function of h_b given as $\gamma=2.358-0.00145h_b+0.45/h_b$. Thus, for a given base antenna height, the exponent γ can be estimated, and then by using $PL_{mean} = A+10\gamma\log10(d/d_0)$, the mean value of the ratio path loss at 5.8 GHz can be obtained. In order to apply this estimation to other WiMAX frequencies, like 3.5 GHz, a frequency correction term should be included. It has been shown that radio path loss changes with frequency by $f^{2.6}$ [6], hence, the frequency correction term is given by

$$\Delta PL_f = 6\log10(f/5800), \qquad (2)$$

where f is the frequency in MHz.

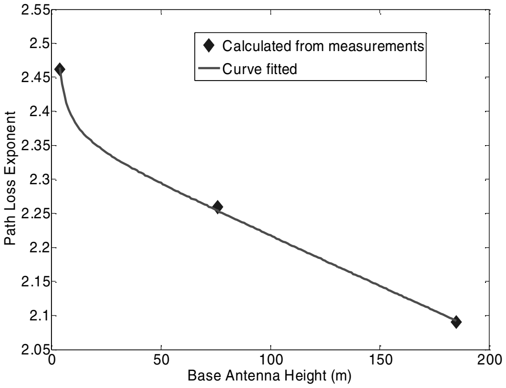

Fig. 5: Path loss exponent as function of the base antenna height in a typical seaport environment

5. CONCLUSION

Radio path loss at 5.8 GHz in seaports was measured and the results show that the path loss properties are close to the free space. With higher base antenna height this properties are clearer. A simple model is derived from the measured data, which can also be applied to other WiMAX frequencies.

ACKNOWLEDGEMENT

The first author would like to thank S.K. Hazra, S.H. Toh, W.M. Tan, P.Y. Kong, H.G. Wang, Ge Yu, Chee Wei, Derek Leong, and V.D. Hoang for support. We would also like to thank the Maritime Port Authority of Singapore (MPA) for their support in the sea-port tests.

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