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# Fading Characteristics for Indoor Wireless Channels at 5GHz Unlicensed Bands

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**Abstract: The paper reports on the experiments undertaken at the University of Wollongong to characterise fading profiles of an indoor wireless channels at 5GHz bands. The measurements were undertaken at different locations around the campus with results recorded for a post-processing to calculate the Rician k-factor, the level crossing rate and the average fade duration.**

## 1. Introduction

Development of high-speed wireless LANs (WLANs) has changed the philosophy for potential bandwidth demanding multimedia applications. They no longer need to rely on an access to the high-speed wired networks but can be easily accessed in locations where every user having a compatible wireless modem can use the network. An example of such a scenario can be a lecture theatre, where not only the teaching material is distributed to students' notebook PCs via wireless network but also their class test solutions are submitted via the same way. A popular type of the high-speed WLANs currently being deployed is one complying with IEEE 802.11a [1] (or HYPERLAN2 [2]) standard. In contrary to their predecessors, these WLANs operate in the 5 GHz band and use OFDM signalling.

Small scale fading is a term that is used to describe the rapid fluctuations in amplitude and phase of a radio signal over a short period of time or travel distance. Fading is caused by interference between two of more versions of transmitted signal, which arrive at the receiver at slightly different times. The results of fading in radio propagation can be loss of signal temporarily, or incorrect signals being interpreted at the receiver end. In the case of data transmission, it can severely reduce throughput if packets that suffer fading have to be constantly retransmitted. Several techniques to help to reduce these problems have been devised, including using multiple receive/transmit antennas, or application of special modulation schemes.

Some research has been done into fading in both the 2.4 GHz and 5 GHz bands [3, 4, 5, 6, 7]. It has been found that the Rician distribution is a suitable approximation for the results obtained in practice [3, 4].

The aim of the reported study was to measure the main characteristics of fading, e.g. the Rician k-factor, the level crossing rate and the average fade duration in typical operational environments where 802.11a networks are being deployed. To do that, we took the measurements at four locations at the University of Wollongong main campus. The chosen locations were a small size clattered laboratory room, a hallway, a large lecture theatre, and a stairwell. At each of these locations we measured the temporal variations in the received signal strength with three people moving around the receive antenna. The results were stored for future processing to calculate characteristics of fades. Apart from fading parameters, the delay profile characteristics were measured at the same locations. The results of those measurements can be found in [9].

The rest of this paper is organised as follows. Section 2 gives a short introduction to the measured quantities. In section 3, we describe the measuring equipment and the measurement locations. Section 4 presents characteristics of fades at different locations, while section 5 concludes the paper.

## 2. Characteristics of fades

When there is a dominant stationary signal component, such as a line-of-sight propagation path, the small-scale fading envelope distribution is Rician. In such a situation, random multipath components arriving at different angles are superimposed on a stationary dominant signal. At the output of an envelope detector, this has the effect of adding a dc component to the random multipath.

The effect of a dominant signal arriving with many weaker multipath signals gives rise to the Rician distribution. As the dominant signal becomes weaker, the composite signal resembles a noise signal, which has an envelope that is described by Rayleigh distribution. Thus, the Rician distribution degenerates to a Rayleigh distribution when the dominant component fades away.

Let A denote the direct waves peak amplitude, and $\sigma$ the standard deviation of the overall received signal envelope R, then the Rician k-factor is given as

$$k = \frac{A^2}{2\sigma^2}$$

The Rician cumulative distribution function (CDF) is dependent on the value of $k$, and for $k$=0 it degenerates into that of a Rayleigh distribution. The Rician CDF is calculated as follows

$$C_{rice}(R) = 1 - \overline{C_{rice}(R)},$$

where

$$C_{rice}(R) = \exp[-(k + \frac{R^2}{2\sigma^2})] \sum_{m=0}^{\infty} (\frac{\sigma\sqrt{2k}}{R})^m I_m(\frac{R\sqrt{2k}}{\sigma})$$

and $I_m()$ is the modified $m$th order Bessel function of the first kind. Although the computation of the Rician CDF appears difficult because of the summation of an infinite number of terms, in practice the summation of $m$=50 terms is sufficient to reduce the remaining terms contribution to a negligible level [8].

The level crossing rate ($N_L$) and average fade duration ($t_L$) are also useful statistics in describing fading distributions. Level crossing rate is defined by:

$$N_L = \frac{N}{T}$$

where $N$= Number of crossings of the specified signal level $L$, $T$= Time in seconds of fading record.

Average fade duration is given by:

$$t_L = \frac{1}{N} \sum_{i=1}^{N} t_i$$

where $t_i$= Time duration of each individual fade.

## 3. Measurements

The measurements were performed using a Rhode & Schwarz Vector Network Analyser, model ZVC with a frequency range of 300 kHz to 8 GHz. A pair of identical quarter-wave monopole antennas optimised for the 5 GHz band was used for all measurements. The antennas were donated by a Sydney based company, Argus Technologies Pty. Ltd. The chosen frequency range for the measurements was the range of 5.15 GHz to 5.35 GHz , as this is the majority of the spectrum allocated for use in Australia.

Approximately 8 points at each location were chosen, which are shown in Figures 1, 2, 3 and 4. At each location, the receive antenna remained fixed, while the transmit antenna was moved to various positions.

The topology of the small room consisted of one doorway, a wall with several large windows, and was approximately square with dimensions 5.8m by 5.7m. It had a three-metre ceiling, and was situated on the second floor of a two-storey building. The walls and ceiling were made of normal plasterboard, and the floor was carpeted. The environment consisted of several rows of benches, cluttered with various types of computer equipment.

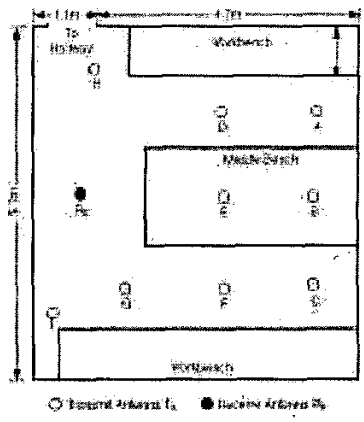

**Figure 1. Floor plan and antenna placements for the small room.**

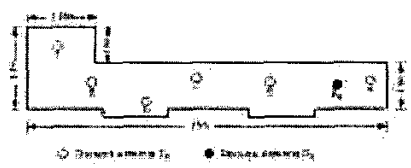

**Figure 2. Floor plan and antenna placements for the hallway.**

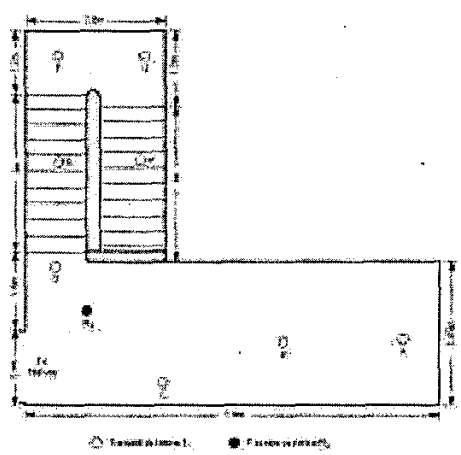

**Figure 3. Floor plan and antenna placements for the stairwell.**

The hallway was situated directly next to the small room, and contained several doorways along its walls. All of these doorways were closed for the duration of the experiments. The hallway had dimensions of 15m by 1.8m, but opened out at one end to be 3.4m wide.

Ceiling height remained at 3m, and all walls and ceiling were made of standard plasterboard. The floor was carpeted, and the area was free of any obstructions.

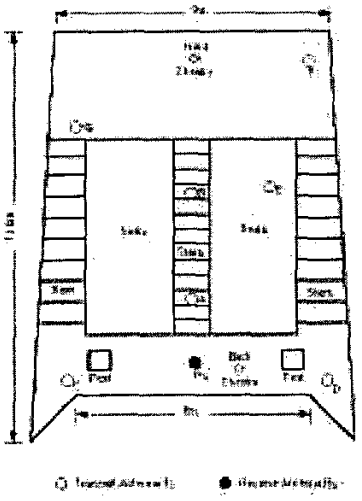

**Figure 4. Floor plan and antenna placements for the lecture theatre.**

The stairwell location consisted of a level top section with one doorway and two walls made of large windows and a stairwell with two sets of stairs going downward. The top section had dimensions of 2.85m by 5.4m, and each stair section was 1.2m by 3m. Each step had a height of 16.5cm giving a height drop of 1.65m for each row of stairs. The floor was carpeted concrete, while the walls were solid concrete in the stairwell. The environment was free from any clutter.

The topology of the lecture theatre consisted of a top section with two large pillars, a centre section with several hundred seats sloping downward, and a bottom section with some benches. The entire theatre was approximately square, with dimensions 13.6m by 9m. The height difference between the top and bottom sections was 5m. Ceiling height form the bottom section was approximately 8m, and was made of solid concrete, with walls being made of carpeted timber.

## 4. Measurement results

The transmitting and identical receiving antennas were mounted on two separate identical PVC pipes, of heights adjustable in the range 1.0 to 1.8m. Both antennas were connected to the Vector Network Analyser, which was used as signal generator and signal analyser. To determine impairments caused by sources from outside the laboratory, all motion in the room was initially kept to zero. The variations in received signal amplitude over a 20 second period at each location were less than ± 1 dB and can be regarded as insignificant. Measurements were then collected at various different transmit antenna positions, outlined in Figures 1, 2, 3 and 4. During each measurement, three people moved around the receive antenna only, keeping within a two metre radius.

Each measurement was stored as an ASCII text file on a floppy disk for post-processing. The Network Analyser has the facility to output the results as a bitmap image, but ASCII values were chosen to assist in the various data analysis and manipulation required. Each 20 second measurement consisted of 401 points stored in a single file. Each point consisted of a time component (in seconds) and a power component (in [dB]). These points were used to reproduce the original graphs in Matlab. An example of such a plot is shown in Fig. 5.

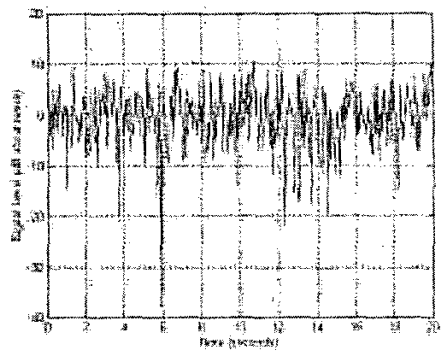

**Figure 5. Fading pattern for transmit antenna at position E in lecture theatre.**

Based on the measured results, we calculated the Rician k-factors for every antenna placement at all four locations. The results are presented in Table 1.

**Table 1. Ricean K-factors (in [dB]) at various antenna placements at the four locations**

| Placement | Small Room | Hallway | Stairs | Lecture theatre |
|---|---|---|---|---|
| A | 2.5 | 2.5 | 2.8 | 2.2 |
| B | 3.2 | 2.7 | 2.4 | 2.6 |
| C | 3.2 | 2.1 | 2.4 | 2.2 |
| D | 2.7 | 2.6 | 1.8 | 2.2 |
| E | 4.7 | 2.3 | 2.6 | 2.4 |
| F | 2.8 | 2.4 | 2.7 | 2.7 |
| G | 2.7 | | 3.2 | 2.6 |
| H | 2.7 | | 3.4 | |
| I | 2.1 | | | |

The recorded measurement results were also used to calculate the level crossing rate and average fade duration. These characteristics were calculated for each location and antenna placement. At each location, it was noticed fades as deep as -24 dB below the median were common. Also, peaks as high as 9 dB above the median were also frequent in all scenarios. Across all results, a common feature that can be seen is that deeper fades

generally last slightly longer than shallow fades. This holds true for peaks as well, with most deviations of more than 9dB above the median lasting more than one second. Also, it can be seen that the received power crosses the median level of 0 dB between 3 and 6 times per second for most scenarios. For all scenarios, the degree of motion in the environment is an important factor in influencing fading. More motion increases the level crossing rate at $L$=0, and the levels at which crosses actually occur are scattered over a larger range. Example results for the position A in the lecture theatre are listed in Table 2.

**Table 2. Level crossing rate and average fade duration for position A in the lecture theatre.**

| $L$ [dB] | $N_L$ [sec$^{-1}$] | $t_L$ [sec] |
|---|---|---|
| 9 | 0.250 | 3.940 |
| 6 | 1.500 | 0.598 |
| 3 | 2.700 | 0.275 |
| 0 | 4.100 | 0.122 |
| -3 | 3.400 | 0.081 |
| -6 | 2.350 | 0.068 |
| -9 | 1.500 | 0.057 |
| -12 | 0.850 | 0.055 |
| -15 | 0.550 | 0.054 |
| -18 | 0.350 | 0.054 |
| -21 | 0.100 | 0.050 |
| -24 | 0.100 | 0.050 |

## 5. Conclusions

The paper provides information that may be useful in design and deployment of communication systems operating in the 5 GHz band, like those compliant with IEEE 802.11a and HIPERLAN2 wireless standards. The obtained results closely follow what would be expected of radio propagation at any frequency. We expect to use the results in developing a Markov chain model of the indoor wireless channel where probabilities for transitions between the states will be determined based on the applied modulation scheme, and the measured channel characteristics.

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**Tadeusz A Wysocki** received the MEngSc degree with the highest distinction in telecommunications from the Academy of technology and Agriculture, Bydgoszcz, Poland, in 1981. In 1984, he received his PhD degree, and in 1990, was awarded a DSc degree (habilitation) in telecommunications from the Warsaw University of Technology. Since December 1998 he has been working as an Associate Professor at the University of Wollongong, within the School of Electrical, Computer and Telecommunications Engineering. The main areas of Dr Wysocki's research interest include: indoor propagation of microwaves, code division multiple access (CDMA), digital modulation and coding schemes, space-time-coding, as well as routing protocols for ad-hoc networks. He is the author or co-author of four books, over 100 research publications and nine patents. He also chaired three International Symposia on DSP for Communication Systems, in 1996, 1999, and 2002, respectively, and is a Senior Member of IEEE