Delay Characteristics for an IEEE 802.11a Indoor Wireless Channel

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Abstract: The paper reports on the experiments undertaken at the University of Wollongong to characterise delay parameters of an indoor wireless channel at 5GHz bandwidth. The measurements were undertaken at different locations around the campus with results recorded for a post-processing to calculate mean excess delay, r.m.s. delay spread, and the coherence bandwidth of the channel.

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. Because of the nature of the OFDM, the utilised wireless channel needs to satisfy certain characteristics, which are more stringent than those required for a proper operation of DS SS based WLANs, like 802.11 and 802.11b. In particular, for the OFDM scheme applied in the 802.11a standard to achieve its maximum performance, the coherence bandwidth of the channel must be greater than 300 kHz, which is bandwidth of each sub-carrier channel.

The aim of the reported study was to measure if this condition is satisfied 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 delay spread by recording the received power of a transmitted impulse and the time of this transmission. Then we computed the mean excess delay and r.m.s. delay spread with respect to a reasonable threshold for the multipath noise floor [3,4].

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 the measured delay profiles at different locations, the calculated mean excess delays and r.m.s. delay spread as well as the corresponding coherence bandwidth, while section 5 concludes the paper.

2. Delay spread

The *mean excess delay*, *rms delay spread,* and *excess delay spread* (X dB) are multipath channel parameters that can be determined from a power delay profile. Mean excess delay (τ) and rms delay spread (σ) are the time dispersive properties of wide band multipath channels that most commonly quantify these channels [3,4].

Maximum delay time spread is the total time interval during which reflections with significant energy arrive. R.m.s. delay spread is the standard deviation value of the delay of reflections, weighted proportional to the energy in the reflected waves.

The mean excess delay is the first moment of the power delay profile and is defined as [3]:

$$\bar{\tau} = \frac{\sum_k P(\tau_k)\tau_k}{\sum_k P(\tau_k)}$$

The r.m.s. delay spread is the square root of the second central moment of the power delay profile and is defined as [3]:

$$\sigma_{\tau} = \sqrt{\overline{\tau^2} - (\bar{\tau})^2}$$

where

$$\overline{\tau^2} = \frac{\sum_k P(\tau_k)\tau_k^2}{\sum_k P(\tau_k)}$$

These delays are measured relative to the first detectable signal arriving at the receiver at $\tau_0 = 0$.

The maximum excess delay (X dB) of the power delay profile is defined to be the time delay during which multipath energy falls to X dB below the maximum. In other words, the maximum excess delay is defined as $\tau_X - \tau_0$, where τ_0 is the first arriving signal and τ_X is the maximum delay at which a multipath component is within X dB of the strongest arriving multipath signal. [4]

Some research has been conducted into power delay profiles in the 5 GHZ band [5,6]. It has been found that the profiles have an approximately exponentially decaying shape. Additional spikes have been observed, particularly in the line of sight (LOS) conditions for zero excess delay [5].

The coherence bandwidth, B_c , is a defined relation derived from the r.m.s. delay spread. Coherence bandwidth is a statistical measure of the range of frequencies over which the channel can be considered “flat” (i.e. a channel which passes all spectral components with approximately equal gain and linear phase). In other words, coherence bandwidth is the range of frequencies over which two frequency components have a strong potential for amplitude correlation. If the coherence bandwidth is defined as the bandwidth over which the frequency correlation function is above 0.9, then the coherence bandwidth is approximately

$$B_c = \frac{1}{50\sigma_t}$$

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 use at 5 GHz 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.

Next, the timeframe for measurements of delay spread needed to be selected. Choosing a value too small would probably result in not recording significant signal components. Alternately, it must be remembered that the larger the sample period, the lower the resolution of the recorded graph. A sample period of 200ns was selected for the small room, hallway and stairwell. For the much larger lecture theatre, a 300ns sample period was chosen. These values were determined from the fact that propagation time for a signal is given by:

$$t = \frac{d}{c}$$

where t = time in seconds, d = distance in metres, c = 300,000,000 m/s.

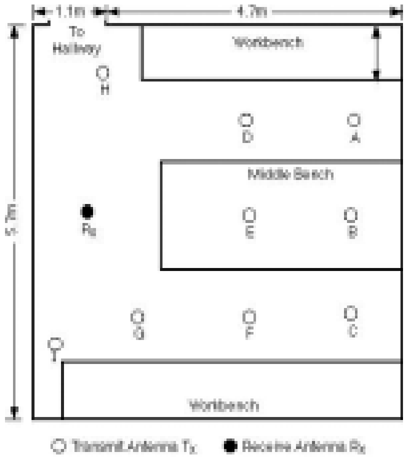

Figure 1. Floor plan and antenna placements for the small room.

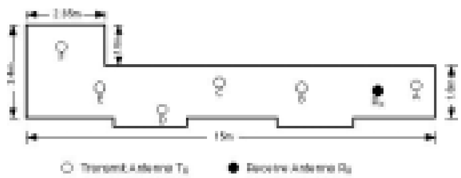

Figure 2. Floor plan and antenna placements for the hallway.

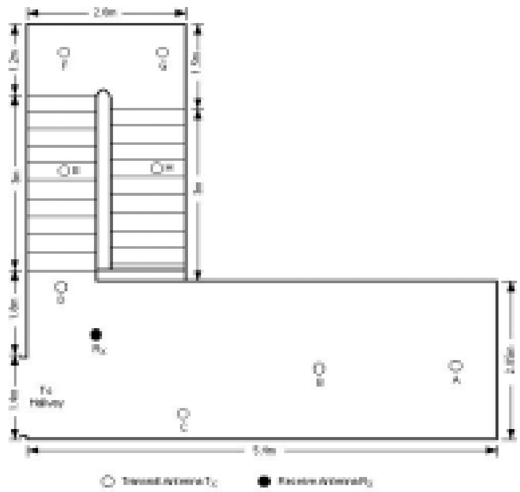

Figure 3. Floor plan and antenna placements for the stairwell.

200ns allows for sufficient reflections to arrive, while still retaining a high resolution. For the larger, more open lecture theatre, more time for reflections to arrive was allowed, hence the 300ns sample period.

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

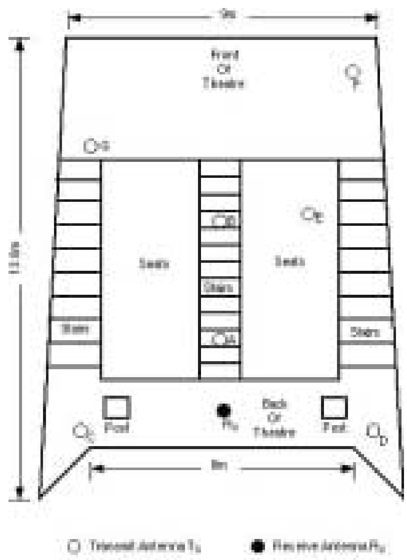

Figure 4. Floor plan and antenna placements for the lecture theatre.

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 is 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.

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.

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 graph in Matlab. Values for the delay spread at each location were collected and normalised to 0 dB.

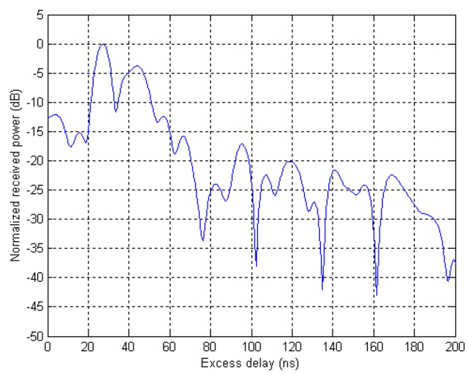

Figure 5. Power delay profile for transmit position A in the small room

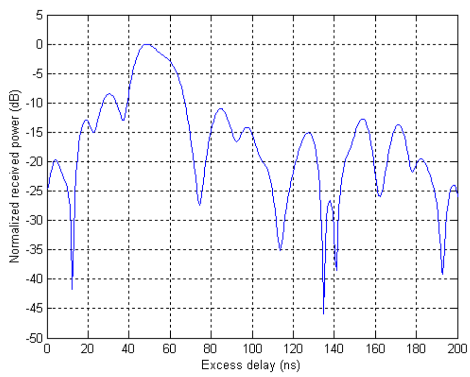

Figure 6. Power delay profile for transmit position E in the hallway

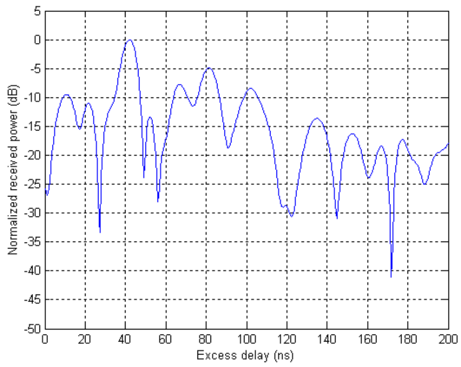

Figure 7. Power delay profile for transmit position F in the stairwell

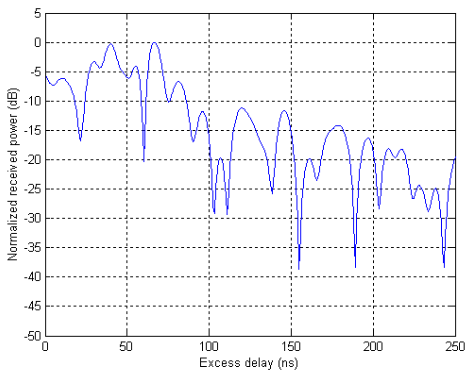

Figure 8. Power delay profile for transmit transmit position E in the lecture theatre

It can be seen from these power delay profile plots that the layout of each location has a noticeable effect on radio propagation at 5 GHz. The small room has a very large line-of-sight component compared to the various reflections arriving at later times. This line-of-sight component arrives in a relatively small time (approximately 25ns) which corresponds to the small separation between transmit and receive antennas. In the hallway and stairwell situations, the initial line-of-sight peak in power arrives much later than in the small room. Also, various significant peaks in received power can be seen at later times. These peaks are caused by the extra scattering produced from the walls in these confined locations. In the case of the hallway, these secondary peaks occur as late as 130ns after the line-of-sight component.

Finally, in the lecture theatre location, the effects of the greatly increased dimensions of the room are demonstrated. As expected, significant reflections arrive over a large time period (up to 250ns), while the line-of-sight component still appears at a time proportional to the distance between the transmit and receive antennas.

In the currently deployed standards, HIPERLAN2 and 802.11a, delay spreads of this magnitude are considered acceptable. Both standards have a guard interval between subcarriers of 800ns, which is sufficient to enable good performance on channels with delay spread of up to 250ns. An optional shorter guard interval of 400ns may be used when delay spread values are particularly small.

The location of the transmit antenna also has a significant effect on the power delay profile. Examples of this are shown in Figures 9 and 10.

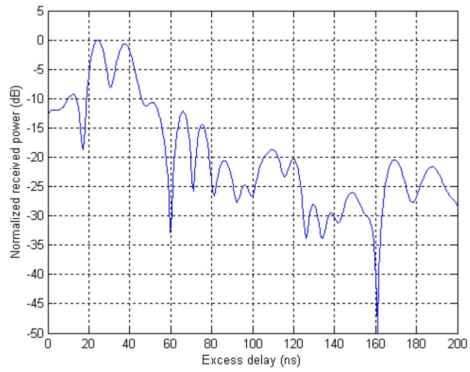

Figure 9. Power delay profile for transmit position C in the small room

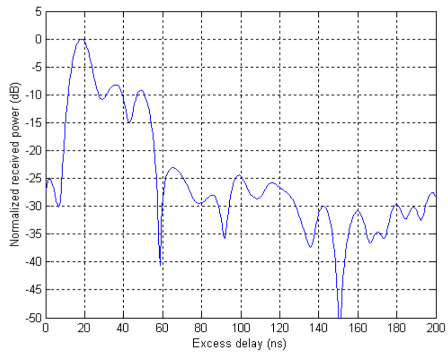

Figure 10. Power delay profile for transmit position E in the small room

As it can be seen, position C has two significant peaks very close to each other. This is explained by the corner location of the transmit antenna, with the signal reflecting almost immediately from the corner back to the receive antenna. Alternatively, the delay profile of position E shows only a single significant component, and small subsequent peaks. This is due to the central location of that transmit antenna, which is in line with expectations.

As mentioned earlier, important time dispersion parameters that help describe a radio channel are mean excess delay and r.m.s. delay. The mean excess delay and r.m.s. delay spread have to be computed with respect to a reasonable threshold for the multipath noise floor. If this threshold were set too low, it would result in too high values for these dispersion parameters. A common rule of thumb used to select this threshold is to set it to four times the noise standard deviation. Numerically, the noise threshold was set to -22 dB with respect to the normalised received power. Table 1 shows values of mean excess delay (in ns) tabulated for each location. Table 2 shows values for the r.m.s. delay spread (in ns) for each location.

Table 1. Mean excess delay (in ns) for the various locations with -22 dB threshold

Pos.	Room	Hallway	Stairs	Theatre
A	61.61	47.37	116.00	133.07
B	77.33	50.55	115.83	167.86
C	81.47	96.06	93.58	148.93
D	53.13	82.58	63.16	76.57
E	36.95	104.61	103.19	174.30
F	56.85	102.23	109.01	171.26
G	78.17		113.25	169.06
H	83.40		81.03	
I	105.97			

Table 2. r.m.s. delay spread (in ns) for the various locations with -22 dB threshold

Pos.	Room	Hallway	Stairs	Theatre
A	41.57	16.87	59.72	80.75
B	49.43	25.90	58.61	73.57
C	52.46	56.82	60.02	70.17
D	28.94	52.56	30.27	58.83
E	13.95	55.71	55.10	77.59
F	30.41	57.96	60.21	80.62
G	41.54		59.60	76.57
H	55.07		43.51	
I	56.92			

Interesting results to note from the values for mean excess delay are the relatively high values, as expected, for the lecture theatre location. Antenna positions A, F and G for the stairwell also produced relatively high values for the mean excess delay. Smaller values were obtained in at the hallway and small room locations, which is again in line with expectations. The hallway scenario provides a clear example of the effect that line-of-sight distance has on the delay spread, with mean excess delay increasing proportionally with distance.

The calculations of mean excess delay and r.m.s. delay were also conducted using a smaller threshold (18 dB), with results slightly smaller in magnitude but retaining approximately the same ranking.

The results for r.m.s delay spread follow a similar pattern to those for mean excess delay. The values for the lecture theatre location are significantly higher than for the other locations, as to be expected from the larger distances involved. The smallest values were again obtained in the small room, with approximately increasing delays observed in the hallway. Interestingly, the results for positions F, G and H for the stairwell location were in the same order of magnitude to these at antenna placements A, B and C. This indicates that this type of uneven environment has no real adverse effects on delay spread.

Following directly from the results for delay spread are estimates for the coherence bandwidth. As mentioned earlier, the coherence bandwidth is a statistical measure of the range of frequencies over which the channel can be considered "flat" (i.e. a channel which passes all spectral components with approximately equal gain and linear phase). Table 3 shows the values of the coherence bandwidth at each location.

Table 3. Coherence bandwidth (in kHz) for the various locations

Pos.	Room	Hallway	Stairs	Theatre
A	733.47	1319.40	321.71	842.90
B	628.75	781.51	317.41	285.71
C	775.12	570.88	337.15	444.79
D	818.92	475.24	1034.60	1381.80
E	1554.10	398.36	566.65	247.56
F	829.14	485.74	374.43	306.92
G	514.94		335.43	238.36
H	423.49		473.30	
I	509.96			

As can be seen from Table 3, the coherence bandwidth takes values in the range 238 kHz to 1554 kHz. In the two main 5 GHz standards (HIPERLAN2 and 802.11a), each subcarrier channel is 300 kHz wide. This means that positions B, E and G in the lecture theatre location could possibly have trouble operating successfully with these systems. For all other positions in all locations, the coherence bandwidth exceeds the minimum requirements for the HIPERLAN2 and 802.11a standards.

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. The delay spread of the signal was seen to increase with the distance, and also increase with the size of surroundings. The measurements performed were undertaken at various locations to provide a number of useful results in different environments. The locations such as hallways and stairwells are places, which could commonly be encountered in many real-world applications of indoor radio transmission. The small room and large theatre scenarios also help to demonstrate the effects that dimension and layout have on radio communication. Fro the analysis of the measurements it is noticeable that in some instances the coherence bandwidth of the channel is smaller that the requirement for a proper operation of the IEEE 802.11 or HYPERLAN2. Hence, in locations like a large lecture theatre an attention need to be taken when choosing placement for the wireless access point.

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