Journal of Engineering and Applied Sciences 15 (2): 444-451, 2020
ISSN: 1816-949X

Fading Characteristics over Wireless Channels

Siriaksorn Jakborvornphan
Department of Engineering, Thai-Nichi Institute of Technology, 1771/1 Pattanakarn Road,
Suan Luang, 10250 Bangkok, Thailand

Abstract: Multipath fading is phenomena that may cause attenuation and distortion to the transmitted signal. The signal transmitted may be diffracted, refracted or reflected over a spread of times from obstacles such as ground, hills, building that are located in the transmission path between the transmitter and receiver sides. Multipath fading, therefore, needs to be taken into consideration when designing wireless radio communication systems. This study presents the key characteristics and simulation modelling for various types of fading channels in the wireless transmission system. Besides, an effort has been made to illustrate the performance comparison of different types of small-scale fading that are subjected to due to multipath delay spread in time and a movement of mobility. The simulations of small-scale fading over the wireless channel that are dependent on Doppler spread and delay spread were determined using communication toolbox in MATLAB.

Key words: Mobile radio propagation, small-scale fading, multipath delay spread, frequency selective fading, fast fading, communication

INTRODUCTION

Wireless propagation can be served in distinct size of service areas. The focuses here in this study are on the propagation of transmitted signal over the wireless radio channel through different types of fading. The propagation over open areas that are free from obstacles is the simplest model to treat. On the other hand, the propagation in urban areas is quite complex because there are a number of obstacles on the way of transmission. A signal propagating through a mobile radio channel depends on the nature of the transmitted signal with respect to the characteristics of the channel (Sklar, 2001). Also, a Line-of-Sight (LOS) transmission path between the transmitter and the receiver is rarely found over the wireless communication systems. The propagation conditions over the wireless link are in general difficult to characterise because electromagnetic waves generated at either ends will encounter obstacles during transmission. Due to reflection, diffraction and scattering from various obstacle objects, the signal can take many different paths from transmitter to receiver. The transmitted signal often reaches the receiver by more than one path, resulting in the phenomenon known as multipath fading. The received signals compose of signals from indirect paths and a direct path (if exists) at the receiver to give a distorted transmitted signal. As a mobile terminal moves, signal amplitude will fluctuate randomly and the interaction between the electromagnetic waves results in a so-called multipath fading of signal.

The rate of fading is related to the relative speed of the mobile with respect to the base station and wavelength of the signal that is being transmitted. This means that the strengths of the signal decrease with the distance between the transmitter and receiver. One of the difficulties in wireless propagation is maintaining good communications since, the field pattern of the transmitting signals are disturbed and thereby diminishing the received signal for a long period of time (Rappaport, 2002).

Mobile radio propagations: As a mobile terminal moves away from the transmitter over much larger distances, the local average received signal will gradually decrease. The mean signal strength for an arbitrary Transmission Reception (T-R) separation distance is predicted by slower large-scale propagation models. There are basically two major types of fading in the wireless communication systems, namely, small-scale and large-scale fading. The two models are useful in estimating the coverage area of a transmission over large T-R separation distance (typically on the order of hundreds of kilometres).

The rapid fluctuations of the received signal strength over very short distances (a few wavelength) or short duration of time (on the order of seconds) can be characterised by small-scale fading model. The received signal power is a sum of many contributions coming from different directions. On the other hand, large-scale fading represents the average signal power attenuation over large areas caused by terrain contours such as hills, forests or building, located in the transmission path between the transmitter and the receiver. Large-scale fading caused by path loss and shadowing provides a way of estimating the path loss as a function of propagation distance (Goldsmith, 2005).

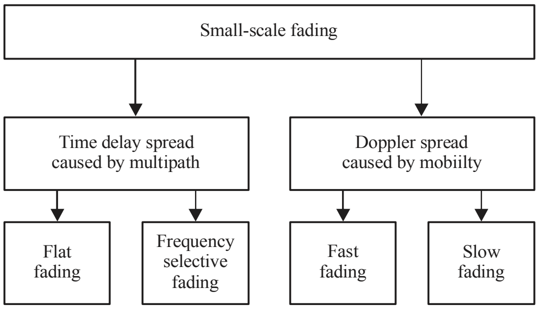


Fig. 1: Types of small-scale fading

MATERIALS AND METHODS

Small-scale fading: Multipath in the radio channel creates small-scale fading effects. The three most important effects in small-scale multipath propagation are fading, random frequency modulation and time dispersion. The mobile receives the signals from different directions, paths with different propagation delays. Each of the multipath components have randomly distributed amplitudes, phases and angles of arrival. They are combined at the receiver antenna and cause the signal received by the mobile to be distorted.

A radio wave propagation can be dispersed either in time or in frequency domain for any mobile radio channel. A small-scale fading leads to four distinct effects, as shown in Fig. 1. Fading effects due to multipath time delay spread leads to "time dispersion" and "frequency selective fading" whereas Doppler spread leads to "frequency dispersion" and "time selective fading". Time dispersion due to multipath causes the transmitted signal to undergo either flat fading or frequency selective fading. On the other hand, a channel may be classified either as a fast fading or slow fading channels, depending on how rapidly the transmitted baseband signal changes as compared to the rate of change of the channel (Molisch, 2011).

Types of small-scale fading

Frequency selective fading: If the channel possesses a constant gain and linear phase response over a bandwidth that is smaller than the bandwidth of the transmitted signal, then the channel creates frequency selective fading on the received signal. The spectrum s(f) of the transmitted signal has a bandwidth which is greater than the coherence bandwidth B_C of the channel in frequency selective fading. Frequency selective fading is caused by multipath delays which approach or exceed the symbol period of the transmitted symbol. A multipath delay spread (σ_τ) is greater than the reciprocal bandwidth of the transmitted signal (T_S). A common rule of thumb is that a channel is frequency selective if $T_S \leq 10\sigma_\tau$.

The received signal is distorted because multiple versions of the transmitted waveform are attenuated (faded) and delayed in time. Frequency selective fading is due to time dispersion and hence induces the Inter Symbol Interference (ISI). Frequency selective fading channels are known as "wideband channels" since, the bandwidth of the signal is wider than the bandwidth of the channel impulse response (Rappaport, 2002). A signal is considered to be frequency selective fading if:

- $B_s > B_c$
- $T_S < \sigma_\tau$
- Inter Symbol Interference (ISI) and irreducible BER

Flat fading: If a mobile radio channel has a constant gain and linear phase response over a bandwidth is greater than the bandwidth of the transmitted signal, then the received signal will undergo flat fading. The spectrum characteristics of the transmitted signal are preserved at the receiver. The strength of the received signal changes with time due to fluctuation in the gain caused by multipath. The reciprocal bandwidth of the transmitted signal (T_S) is much greater than the multipath time delay spread of the channel (σ_τ). Flat fading channels are known as "amplitude varying channels" or "narrowband channels" because the bandwidth of applied signal is narrower than the channel flat fading bandwidth (Molisch, 2005). A signal is considered to be flat fading if:

- $B_s < B_c$
- $T_S > \sigma_\tau$
- Signal fits easily within the bandwidth of the channel
- Loss in SNR

Slow fading: The channel impulse response changes at a rate much slower than the transmitted baseband signal. The rate of change of the channel characteristics is much smaller than the rate of change of the transmitted signal. The doppler spread of the channel B_D is much less than the bandwidth of the baseband signal B_S. A signal is considered to be slow fading if:

- $T_S < T_c$
- $B_S > B_d$
- Low doppler spread and loss in SNR

Fast fading: The channel impulse response changes rapidly with the symbol duration. Fast fading deals with the rate of change of the channel due to motion. The rate of change of the channel characteristics is larger than the rate of change of the transmitted signal. The channel changes during a symbol period because of receiver motion. The coherent Time of the channel (T_c) is smaller than the symbol period of the Transmitted signal (T_s) causing "frequency dispersion" or "time selective fading" due to doppler spreading which leads to signal distortion. The effects of small-scale fading due to multipath delay spread in time and frequency domains are summarised clearly in Fig. 2.

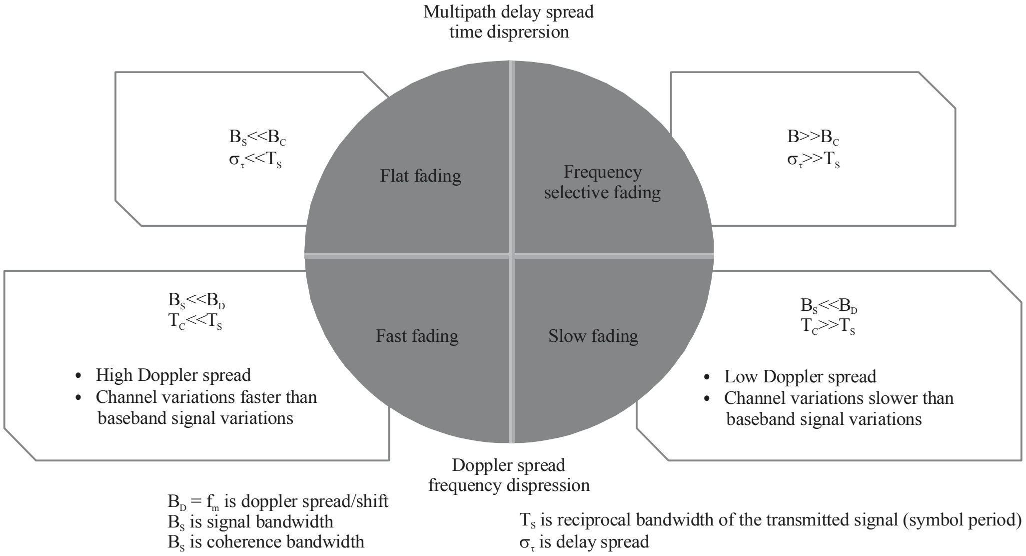


Fig. 2: Condition of small-scale fading for multipath delay spread in time and frequency domains

A signal is considered to be fast fading if:

- $T_s>T_c$
- $B_s<B_d$
- High Doppler spread and irreducible in BER

RESULTS AND DISCUSSION

Parameters setting

RMS delay spread: The RMS delay spread is the square root of the second central moment of the power delay profile and is defined as:

$$\sigma_\tau = \sqrt{\overline{\tau^2} - \left(\bar{\tau}\right)^2} \quad (1)$$

where, the mean excess delay or the first moment of the power delay profile is given by:

$$\bar{\tau} = \frac{\sum_k a_k^2 \tau_k}{\sum_k a_k^2} = \frac{\sum_k P(\tau_k)\tau_k}{\sum_k P(\tau_k)} \quad (2)$$

and the second central moment of the power delay profile is defined as:

$$\overline{\tau^2} = \frac{\sum_k a_k^2 \tau^2_k}{\sum_k a_k^2} = \frac{\sum_k P(\tau_k)\tau^2_k}{\sum_k P(\tau_k)} \quad (3)$$

These delays are measured relative to the first detectable signal arriving at the receiver at the value of $\tau_0 = 0$. Typical values of RMS delay spread I Table 1 are on the order of microseconds (μsec) in outdoor mobile radio channels and on the order of nanoseconds (nsec) in indoor radio channels.

Coherent bandwidth: Coherent bandwidth is derived from the RMS delay spread. It occurred because of a natural phenomenon caused by reflected and scattered propagation paths in the radio channel. Also, it is possible to obtain an equivalent description of the channel in the frequency domain using its frequency response characteristics. If the delay spread parameters is used to characterise in the time domain, then coherence bandwidth is used to characterise the channel in the frequency domain. Coherent Bandwidth (B_c) is a statistical measure of the range of frequencies over which the channel can be considered “flat”.

The RMS delay spread and coherence bandwidth are inversely proportional to one another. If the coherent bandwidth is defined as the bandwidth over which the frequency correlation function is above 0.9, then the coherent bandwidth is approximately equivalent to:

$$B_C \approx \frac{1}{50\sigma_\tau} \quad (4)$$

If the frequency correlation function is above 0.5, then the coherent bandwidth is approximately equivalent to:

$$B_C \approx \frac{1}{5\sigma_\tau} \quad (5)$$

Table 1: Typical measured values of RMS delay spread (Rappaport, 2002)

Environment	Frequency (MHz)	RMS delay spread (σ_τ)	Notes
Urban	910	1300 nsec average 600 ns SD 3500 ns max	New York City
Urban	892	10-25 μsec	Worst case San Francisco
Suburban	910	200-310 nsec	Averaged typical case
Suburban	910	1960-2110 nsec	Averaged extreme case
Indoor	1500	10-50 nsec 25 nsec median	Office building
Indoor	850	270 nsec max	Office building.
Indoor	1900	70-94 nsec average 1470 nsec max	Three San Francisco buildings

Table 2: Calculations for different types of fading

Type of fading	No. of paths	Symbol period (T_s) (sec)	Signal bandwidth (B_s) (Hz)	RMS delay spread (σ_τ)	Coherence bandwidth (B_c)
Frequency Selective Fading	4	0.0001	10000	0 msec	0 Hz
				0.2 msec	5 kHz
				0.3 msec	333 Hz
				0.4 msec	250 Hz
Flat fading	4	0.1	10	0 msec	0 Hz
				0.2 msec	5 kHz
				0.3 msec	333 Hz
				0.4 msec	250 Hz
Slow fading	4	0.001	1000	2 sec	0.5 Hz
Fast fading	4	0.001	1000	0.01 sec	100 Hz

Doppler spread: Doppler spread (B_d) is a measure of the spectral broadening caused by the time rate of change of the mobile radio channel. It is defined as the range of frequencies over which the received Doppler spectrum is essentially, non-zero and is defined as:

$$B_D = f_m = \frac{v}{\lambda} = \frac{vf_c}{c} \tag{6}$$

where, f_m is the maximum Doppler shift and is given by:

$$f_m = \frac{v}{\lambda}$$

Coherent time: Coherence Time (T_c) is the time domain dual of Doppler spread and is used to characterise the time varying nature of frequency in the time domain. It is a statistically measure of the time duration over which the channel response is invariant and quantifies the similarity of the channel response at different times. The Doppler spread and coherence time are inversely proportional to one another and is expressed as:

$$T_C \approx \frac{1}{f_m} \tag{7}$$

Calculations and simulation results

Simulation set up: A simple model was constructed using a Simulink in MATLAB in order to generate data Source, Binary PSK (BPSK) modulator and fading channel blocks. We use a random integer generator from the communications blockset, BPSK modulator from communications blockset/modulation and the multipath rayleigh fading channel from the communications blockset/channels libraries in order to perform both frequency selective and flat fading as shown in Fig. 3.

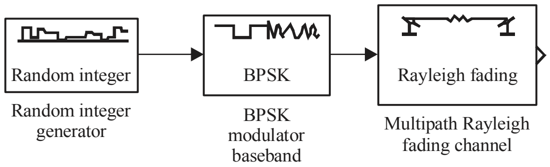


Fig. 3: Simulation setup model for fading channel

The path of the block for a random integer generator is set as follow (Fig. 4 and 5):

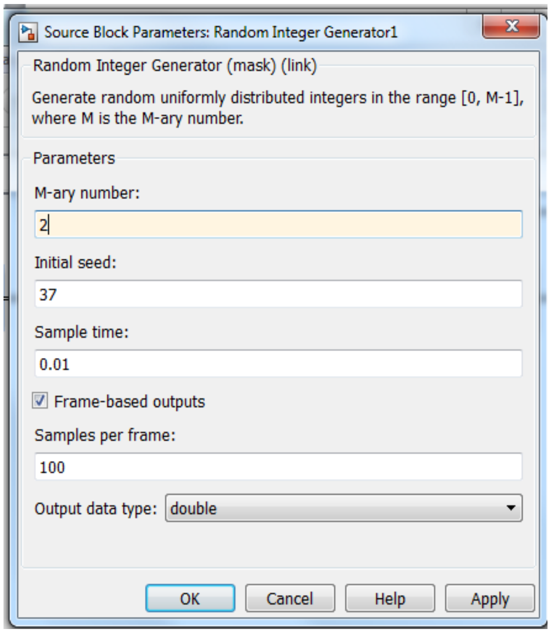
- Communications blockset»comm sources»random data sources»random integer generator

The path of the block for multipath Rayleigh fading channel is set as follow (Fig. 6 and 7):

- Communications blockset»channels»multipath Rayleigh fading channel

Calculations: For a signal propagating over a wireless channel, symbol duration, system bandwidth, sampling period and the channel characteristics such as Doppler spread, RMS delay spread, coherent bandwidth and coherent time determine the type of fading that the signal can experience. Table 2 indicates the lists of parameters used for the simulation of various types of fading. Frequency dispersion and time dispersion mechanism in a wireless communication channel have an influence on the four different ways of small-scale fading depending upon the channel characteristics, the velocity and the signal parameters (Tang and Tang, 2005).

Simulation results: The channel impulse response for frequency selective fading and flat fading are shown in Fig. 8a and 9a, respectively. It can be seen that the channel impulse response changed greatly compared to the flat fading. A multipath delay spread and different



Random Integer Generator (mask) (link)

Generate random uniformly distributed integers in the range [0, M-1], where M is the M-ary number.

Parameters

M-ary number: 2

Initial seed: 37

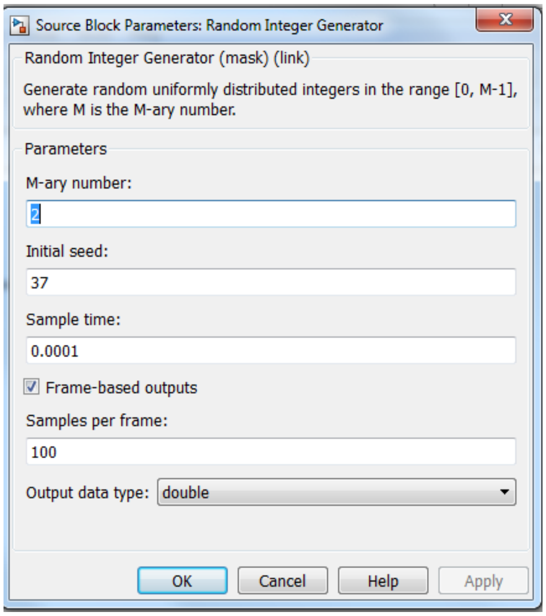
Sample time: 0.01

☑ Frame-based outputs

Samples per frame: 100

Output data type: double

Fig. 4: Sampling period for flat fading (T_s = 0.1sec)



Random Integer Generator (mask) (link)

Generate random uniformly distributed integers in the range [0, M-1], where M is the M-ary number.

Parameters

M-ary number: 2

Initial seed: 37

Sample time: 0.0001

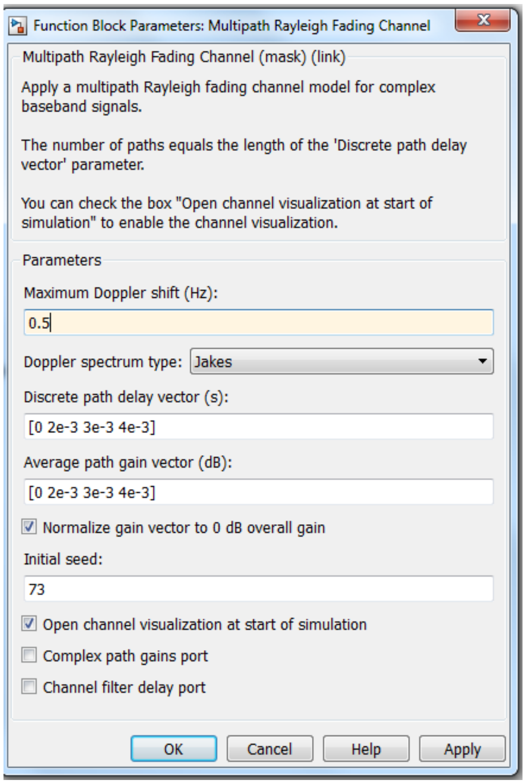
☑ Frame-based outputs

Samples per frame: 100

Output data type: double

Fig. 5: Sampling period for frequency selective fading (T_s = 0.0001sec)

frequency components can be easily seen in the case of frequency selective fading. As a result, the received signal is attenuated and distorted. Moreover, the frequency responses shown in Fig. 8b and 9b show that frequency selective fading is worse than that of the flat fading. Therefore, an equalisation technique needs to be introduced in the process in order to compensate for the unwanted signal.



Multipath Rayleigh Fading Channel (mask) (link)

Apply a multipath Rayleigh fading channel model for complex baseband signals.

The number of paths equals the length of the 'Discrete path delay vector' parameter.

You can check the box "Open channel visualization at start of simulation" to enable the channel visualization.

Parameters

Maximum Doppler shift (Hz): 0.5

Doppler spectrum type: Jakes

Discrete path delay vector (s): [0 2e-3 3e-3 4e-3]

Average path gain vector (dB): [0 2e-3 3e-3 4e-3]

☑ Normalize gain vector to 0 dB overall gain

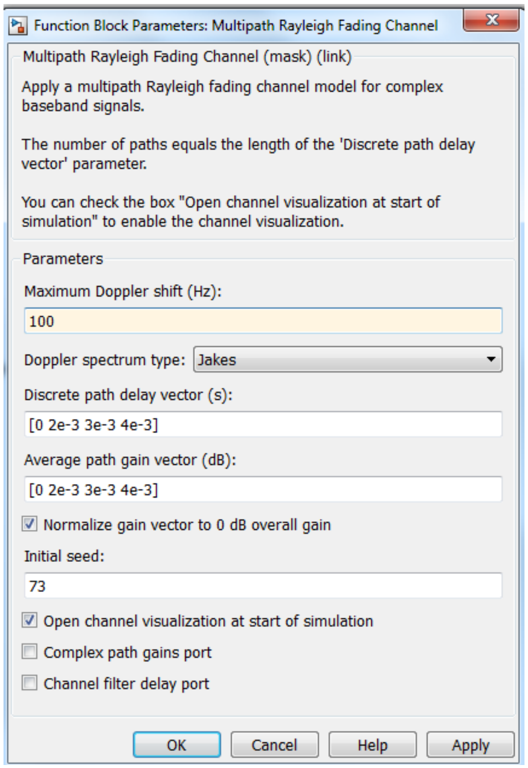
Initial seed: 73

☑ Open channel visualization at start of simulation

☐ Complex path gains port

☐ Channel filter delay port

Fig. 6: Maximum Doppler spread for slow fading (0.5Hz)



Multipath Rayleigh Fading Channel (mask) (link)

Apply a multipath Rayleigh fading channel model for complex baseband signals.

The number of paths equals the length of the 'Discrete path delay vector' parameter.

You can check the box "Open channel visualization at start of simulation" to enable the channel visualization.

Parameters

Maximum Doppler shift (Hz): 100

Doppler spectrum type: Jakes

Discrete path delay vector (s): [0 2e-3 3e-3 4e-3]

Average path gain vector (dB): [0 2e-3 3e-3 4e-3]

☑ Normalize gain vector to 0 dB overall gain

Initial seed: 73

☑ Open channel visualization at start of simulation

☐ Complex path gains port

☐ Channel filter delay port

Fig. 7: Maximum Doppler spread for fast fading (100 Hz)

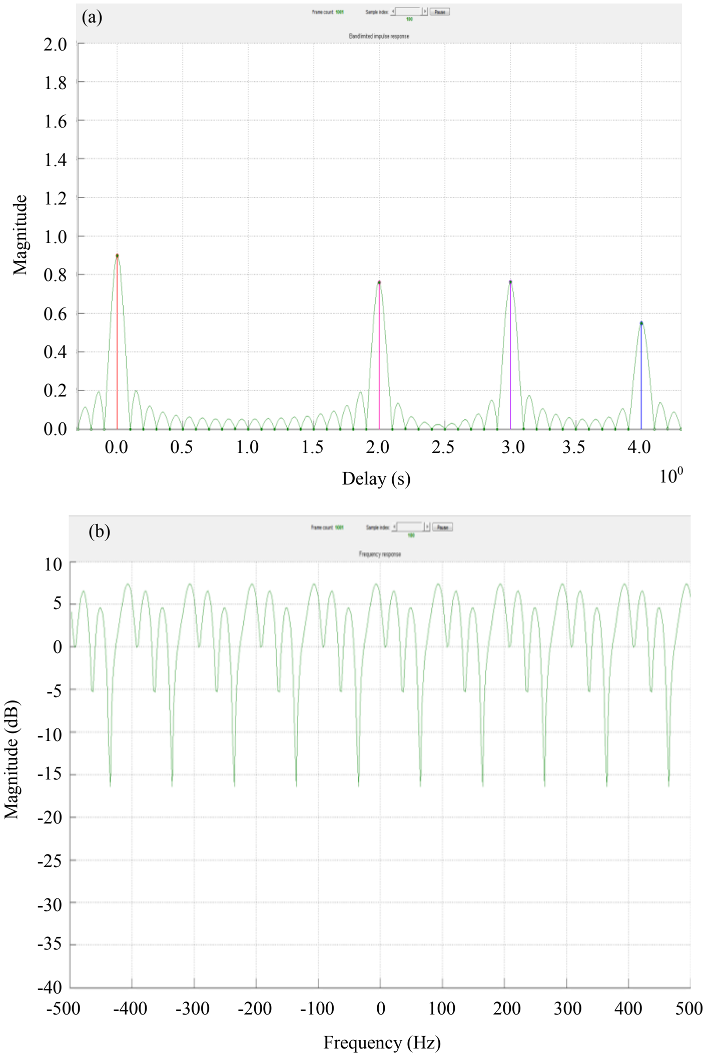


Fig. 8 (a-b): (a) Impulse response and (b) Frequency response of frequency selective fading

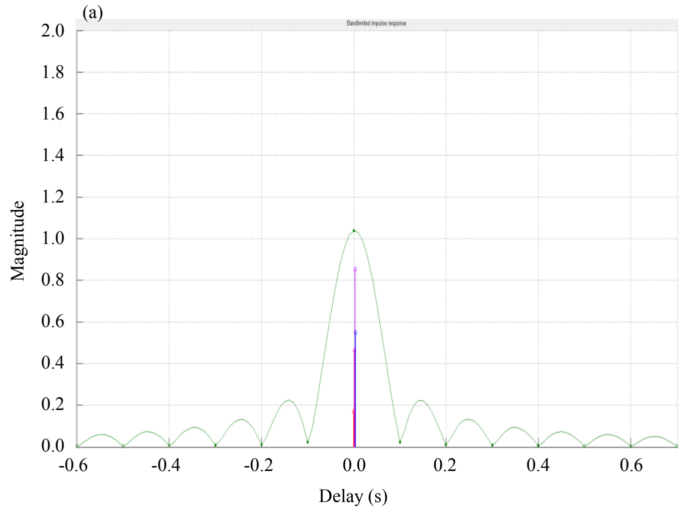


Fig. 9 (a, b): Continue

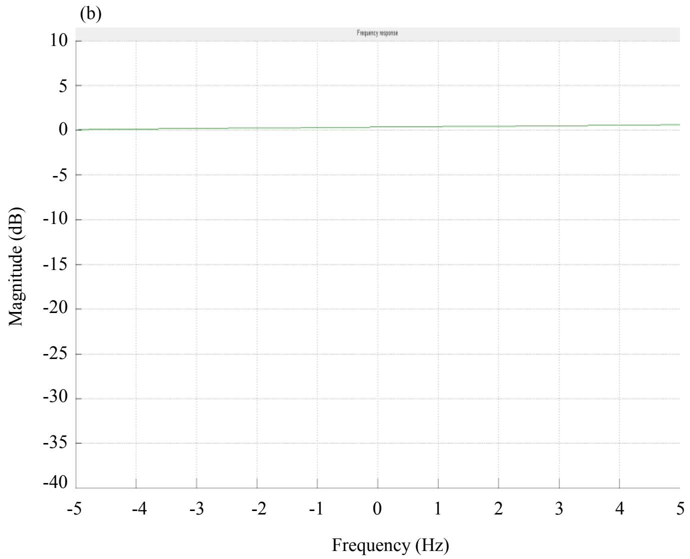


Fig. 9 (a, b): (a) Impulse response and (b) Frequency response of flat fading

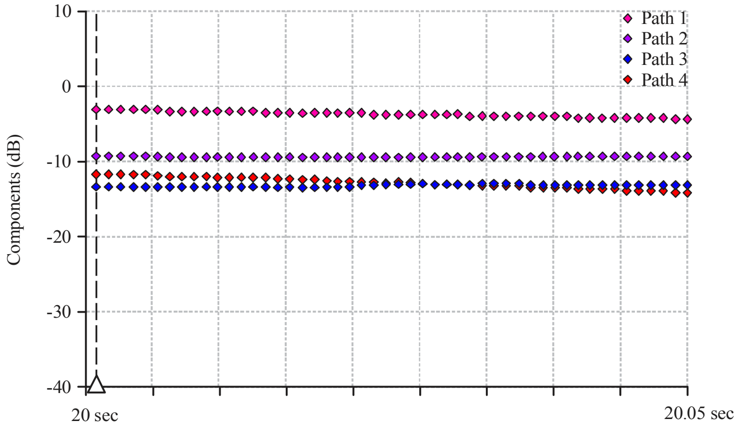


Fig. 10: Multipath fading components of slow fading for four different paths

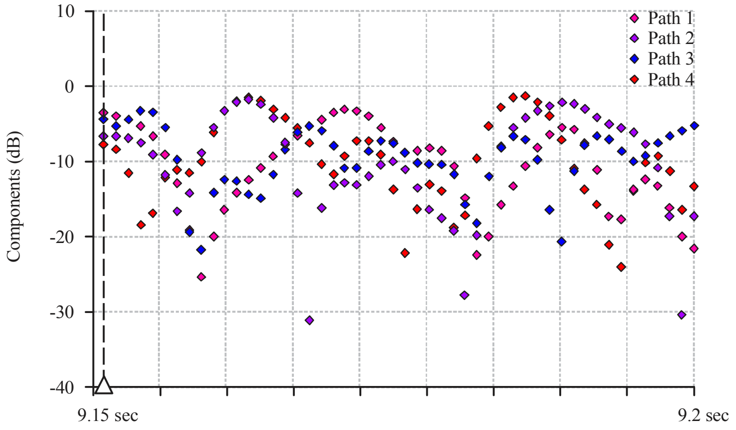


Fig. 11: Multipath fading components of fast fading for four different paths

The multipath fading curves for slow fading and fast fading channels are shown in Fig. 10 and 11, respectively. It is clearly seen from the figures that the signal strength changes slowly over a period of time in that of the slow fading. This is because of a higher Doppler spread. The channel variations move faster than baseband signal variations. In contrast, the channel impulse response changes at a rate much faster that the slow fading over the period of time. The reason for this is because the rate of change of the channel characteristics is much smaller than the rate of change of the transmitted signal.

CONCLUSION

Multipath fading is seen to be an issue in many instances since the transmitted signals can take multiple paths to travel and as a result the received signal strengths at the receiving end decreases. In this study, we have characterised several factors that contribute to small-scale fading models in wireless communication channels. The comparative study of small-scale fading was done under various channel fading conditions. Two major manifestations (dispersion and fading rapidity) of small-scale fading were studied in this work. The respective channel impulse responses were studied and compared between frequency selective fading and flat fading conditions. All the simulations of small-scale fading channels are based on BPSK modulation format and were performed in MATLAB. We found that the simulation results revealed a close agreement to the theoretical frameworks. The fading caused by high speed of movement of the mobility shows much greater distortion of the received signal than the slow fading. The impulse responses obtained showed that the different frequency components affected differently in that of a frequency selective fading.

ACKNOWLEDGEMENT

The researcher wishes to express her sincere thanks to the Department of Engineering, Thai-Nichi Institute of Technology for providing the MATLAB program to perform this study.

REFERENCES

Goldsmith, A., 2005. Wireless Communications. Cambridge University Press, Cambridge, UK., ISBN-13:978-0-511-13315-2, Pages: 644.

Molisch, A.F., 2011. Wireless Communications. 2nd Edn., John Wiley & Sons Ltd, Chichester, England, UK., ISBN:9780470741870, Pages: 884.

Rappaport, T.S., 2002. Wireless Communications: Principles and Practice. 2nd Edn., Prentice Hall, Upper Saddle River, New Jersey, USA., ISBN-13:978-0130422323, Pages: 736.

Sklar, B., 2001. Digital Communications: Fundamentals and Applications. 2nd Edn., Prentice Hall, Upper Saddle River, New Jersey, USA., Pages: 1079.

Tang, K.W. and W.K.S. Tang, 2005. A chaos-based secure voice communication system. Proceedings of the 2005 IEEE International Conference on Industrial Technology, December 14-17, 2005, IEEE, Hong Kong, China, pp: 571-576.