

Chapter 2

Wireless Channels

2.1 Introduction

The wireless channel environment governs the performance of wireless communication systems, since the environment is unpredictable and dynamic. This will make the analysis of the wireless communication system difficult. To that end we classify the wireless channel model as illustrated in Fig. 2.1. The channel is one of the essential elements of the transmission chain. Generally, it acts as a disruptive factor that can alter the issued signal. This chapter will focus on wireless channel classification then, the channel will be introduced in information theory.

2.2 Wireless Channel Models

2.2.1 Fading Channels

In wireless communications, obstacles, such as houses, buildings, trees and mountains cause reflection, diffraction, scattering and shadowing of the transmitted signals and multipath propagation. Due to the multipath the transmitted signals arrive in different phase angles, amplitude and time interval. The fading is the amplitude fluctuation of the received signal caused by the frequency selective or time variant of the multipath channel.

The fading process can follow Rayleigh probability distribution or Rician probability distribution, this will depend on the strength of scattering components during transmission. As illustrated in Fig. 2.2, the Rician probability distribution will be considered for strength of scattering (LOS) and the Rayleigh probability distribution will be considered for the strength less scattering (NLOS).

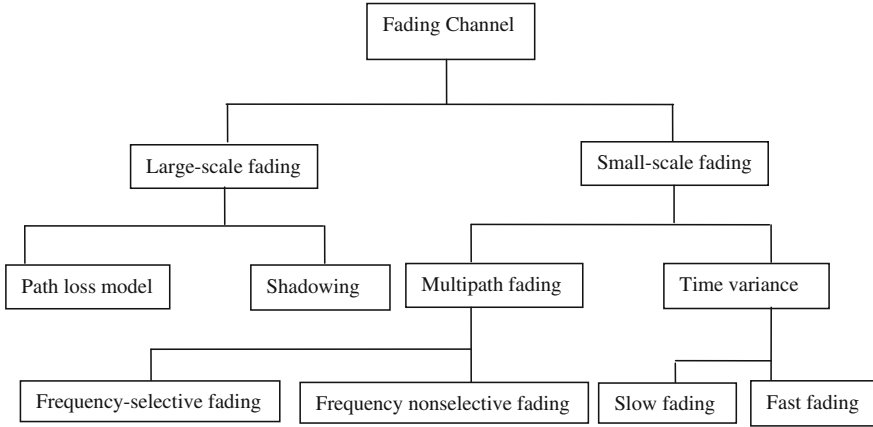


Fig. 2.1 Wireless channel model

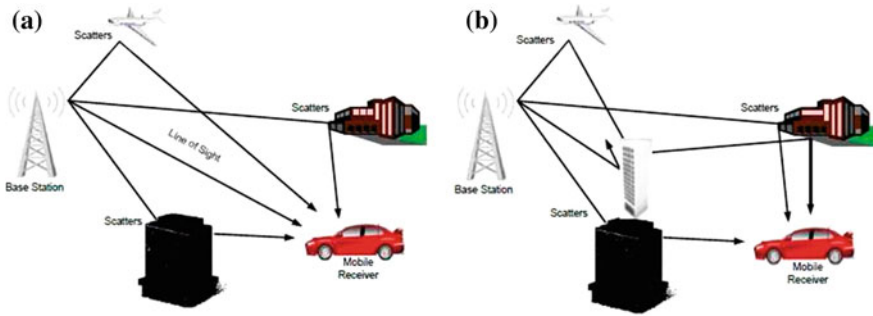


Fig. 2.2 Radio propagation environment

2.2.2 Frequency Non Selective Channel

The Multipath time delay spread or phenomenon can affect the transmitted wireless signal.

Frequency non selective channel or frequency selective channel are two categories of Multipath channels with time delay spread. When the channel bandwidth is much larger than the bandwidth of the transmitted signal, the received signals are called frequency non selective known as flat fading.

Figure 2.3 illustrates the flat fading characteristics, it can be seen that symbol period T_s is greater than the delay spread of channel τ . In this case the inter-symbol interference (ISI), is not caused. In conclusion a signal is affected by a flat fading channel if:

$$B_s \ll B_c \quad (2.1)$$

$$T_s \gg \sigma_\tau \quad (2.2)$$

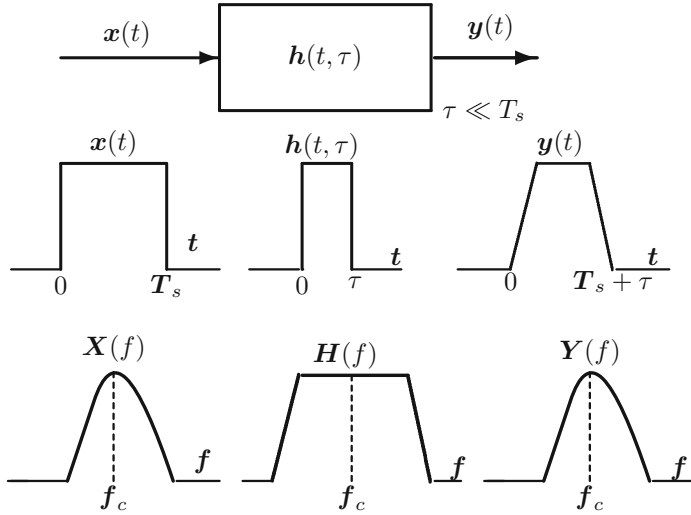


Fig. 2.3 Frequency-non-selective fading channel

where B_s and T_s represent respectively the bandwidth and symbol period of the transmitted signal, and B_c and σ_τ represent the coherence bandwidth and root mean square (rms) delay spread of the channel respectively.

2.2.3 Frequency Selective Channel

Frequency selectivity occurs when the constant amplitude and linear phase response of the wireless channel is narrower than the signal bandwidth. In such condition the symbol period of the transmitted signal is smaller than the channel impulse response

The transmitted symbols have a short duration, compared to the multipath delay spread, this can cause a multiple attenuated and time delayed versions of the transmitted signal, which results in inter-symbol interference. As opposed to the frequency-flat nature of the frequency non-selective fading channel, the amplitude of the frequency response of the transmitted signal varies with frequency. Figure 2.4 shows the characteristics of a frequency selective fading channel. In this figure both the time and the frequency domain are illustrated to show how wide is the frequency channel window compared to the original transmitted signal up converted to frequency domain.

Frequency selective fading channels are called a wideband channels as the channel τ is much greater than the symbol period T_s of the transmitted signal.

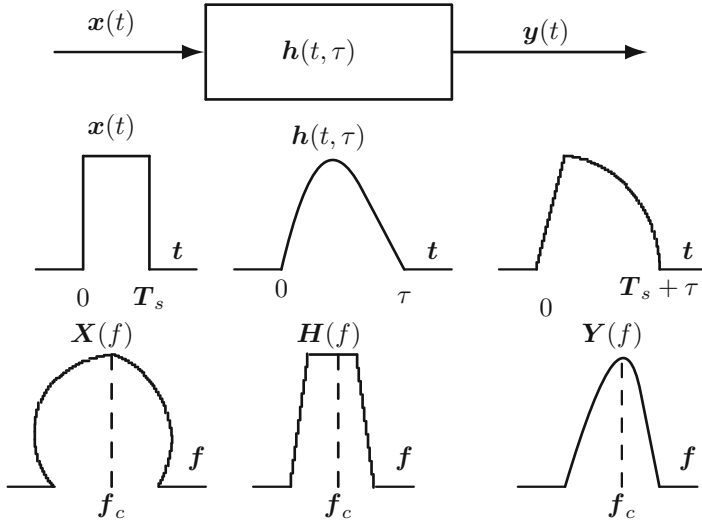


Fig. 2.4 Frequency-selective fading channel

In conclusion a signal is affected by a frequency selective channel if:

$$B_s \geq B_c \quad (2.3)$$

$$T_s \leq \sigma_\tau \quad (2.4)$$

We can consider a channel is frequency selective when $\sigma_\tau = 0.1T_s$

2.2.4 Doppler Shift

The propagation in the frequency domain due to a variation in the time domain, is caused by the movement of the transmitter or receiver. This variation in time domain is called Doppler Shift. Let f_d denote the Doppler shift of the received signal, where θ is the angle of arrival of the transmitted signal with respect to the direction of the vehicle. Given that f_c is the carrier frequency of the transmitted signal, the of the received signal is defined as:

$$f_d = \frac{v f_c}{c} \cos \theta \quad (2.5)$$

where v is the vehicle speed and c is the speed of light.

2.2.5 Rayleigh Channel Model

In 1968, Clarke [1] developed a model for writing the mobile radio channel by a random process. He assumes that the received signal is the sum of L plane waves. Due to the Doppler effect, the signal frequency is shifted (Fig. 2.5), the shift which depends on the speed of the mobile. The shift will follow the Eq. (2.5).

The electric field can then be expressed in terms of its components in phase and quadrature as follows:

$$E_y(t) = E^I(t) \cos(2\pi f_c t) - E^Q(t) \sin(2\pi f_c t) \quad (2.6)$$

where

$$E^I(t) = E_0 \sum_{n=0}^L \cos(2\pi f_n + \phi_n) \quad (2.7)$$

$$E^Q(t) = E_0 \sum_{n=0}^L \sin(2\pi f_n + \phi_n) \quad (2.8)$$

where E_0 is the amplitude of the transmitted field supposed constant. f_c is the carrier frequency and f_n, ϕ_n are the shifted frequency and the phase of the wave number n

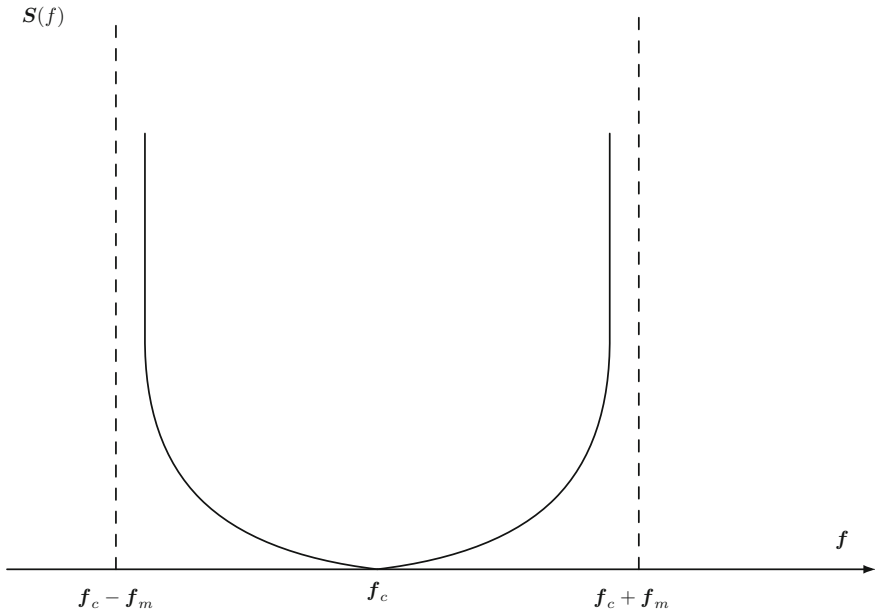


Fig. 2.5 Doppler spectrum

respectively. If the number of path L is large, ($L > 6$), according to the limit central theorem, $E^I(t)$ and $E^Q(t)$ are two random, Gaussian, and independent variable [2].

Thus, the channel coefficient $h_{n,k}$ could be considered as complex random Gaussian process. In an urban environment where the direct path is stopped by obstacles, the average of $h_{n,k}$ is null, and its variance is equal to $\sigma_h^2 = \frac{E_0^2}{2}$.

Let $h_{n,k}^I$ and $h_{n,k}^Q$ are the phase and the quadrature of $h_{n,k}$, The function of probability distribution of $h_{n,k}$ is:

$$f_H(h_{n,k}) = f_{H^I}(h_{n,k}^I) f_{H^Q}(h_{n,k}^Q) \quad (2.9)$$

$$= \frac{1}{2\pi\sigma_h^2} \exp \left[-\frac{(h_{n,k}^I)^2 + (h_{n,k}^Q)^2}{2\sigma_h^2} \right] \quad (2.10)$$

Then, the amplitude will follow the Rayleigh law. Assuming that all the reflectors have uniform distribution, Clarke showcases that the spectral density function will have the following shape: The autocorrelation function of $h_{n,k}$ is

$$\rho = E \{ \mathbf{h}_k [\mathbf{h}_{k-l}]^* \} \quad (2.11)$$

$$= \sigma_h^2 \exp(j2\pi f_c l) J_0(2\pi f_m l T_s) \quad (2.12)$$

where J_0 is the Bessel function of 0 order.

2.2.6 Correlated Rayleigh Channel Generation

The most used method to generate the Rayleigh channel is that proposed by Clarke [1] in 1968. It consists in generating two identical, independent Gaussian process distribution and then filter them by identical two low pass filters with Frequency response $\mathbf{H}(f) = \sqrt{S(f)}$. This allows to filter correlated signals. The output of each filter is then injected in the inverse fast Fourier transform (IFFT) modules. The channel impulse response is then obtained as the sum of the two signals issued from the IFFT modules.

2.3 Transmission Channel in Information Theory

Messages, symbols, code words, signals, and electric waves Electromagnetic or optical used often in telecommunications, those are but a carriers to handle more fundamental and invariant entity called *information*. The information theory, introduced by Shannon in 1948, offers a basic mathematical tool to quantify this entity. The information produced by a source remains invariant with respect to messages and forms which serve as support transmission. Then it is obvious that the choice of

adequate message to present the good information is a critical element. The channel coding's role is to seek this adequate message to preserve the information quantity produced by a source. We present in this section, some notions and definitions of information theory and the famous fundamental theorem of Shannon.

2.3.1 Information Quantity, Entropy and Mutual Information

The idea of quantifying information, states that it is useless to send message if known by the receiver. This idea, however trivial, has totally defined the information quantity of a message, as a measure of its uncertainty. Thus, we can conclude that to be sure, the information quantity should be null, and uncertain event is more informative than a certain event.

Let $\mathbf{x}$ is the realization of an event with probability $Pr(\mathbf{x})$. The intrinsic information quantity $\mathbf{h}(\mathbf{x})$ of this event will then, an increasing function of its improbability $1/Pr(\mathbf{x})$, namely:

$$\mathbf{h}(\mathbf{x}) = f[1/Pr(\mathbf{x})] \quad (2.13)$$

where $f(\cdot)$ is a croissant function which satisfy the following condition:

$$\lim_{Pr(\mathbf{x}) \rightarrow 1} f[1/Pr(\mathbf{x})] = 0 \quad (2.14)$$

In addition, we hope that the joint observation of two independent events lead to an information equals to the sum of information obtained by observing individual of these two events as:

$$f(\mathbf{x}, \mathbf{y}) = f(\mathbf{x}) + f(\mathbf{y}) \quad (2.15)$$

where $\mathbf{x}$ and $\mathbf{y}$ are two events. The logarithm function well verify the conditions mentioned above. So, the Shannon defined the intrinsic information quantity of an event $\mathbf{x}$ by:

$$\mathbf{h}(\mathbf{x}) = \log_2[1/Pr(\mathbf{x})] \quad (2.16)$$

$$= -\log_2[Pr(\mathbf{x})] \quad (2.17)$$

This quantity is always positive (it is zero only if $\mathbf{x}$ is true). it tends to infinity if $Pr(\mathbf{x})$ tends to zero. We note in Eq. (2.16), the base of the logarithmic function is 2, so we can use any base for the logarithm. However, the choice suggested by Shannon was the base 2 and the unit of the information quantity is the Shannon (Sh).

The intrinsic information by pairs of two event $\mathbf{x}$ and $\mathbf{y}$ of joint probability $Pr(\mathbf{x}, \mathbf{y})$ is given by:

$$h(\mathbf{x}, \mathbf{y}) = -\log_2[Pr(\mathbf{x}, \mathbf{y})] \quad (2.18)$$

By the same way, the conditional information of $\mathbf{x}$ given $\mathbf{y}$, which accounts for the information quantity, remaining $\mathbf{x}$ subsequent to the observation $\mathbf{y}$, is defined by:

$$h(\mathbf{x}|\mathbf{y}) = -\log_2[Pr(\mathbf{x}|\mathbf{y})] \quad (2.19)$$

We define the mutual information of two events $\mathbf{x}$ and $\mathbf{y}$ by:

$$i(\mathbf{x}, \mathbf{y}) = \log_2 \left[\frac{Pr(\mathbf{x}|\mathbf{y})}{Pr(\mathbf{y})} \right] \quad (2.20)$$

This function accounts the average information quantity, how big the knowledge of an event $\mathbf{y}$ can apport to an event $\mathbf{x}$. This quantity is also symmetric since it measures the information that knowledge the event $\mathbf{x}$ how can yield on the information contained in $\mathbf{y}$.

Let S be a source, emitting symbols from the alphabet $s_1, s_2, \dots, s_n$, having each a probability $Pr(s_i)$. When the source is stationary, we can define the mean produced by this source, also called *entropy*. The entropy is then given by:

$$H(S) = E\{h(s_i)\} \quad (2.21)$$

$$= -\sum_{i=1}^n Pr(s_i) \log_2[Pr(s_i)] \quad (2.22)$$

2.3.2 Shannon Paradigm

In order to study a system of communication in information theory Shannon adopts the simplified chain, as in Fig. 2.6. This figure presents the Shannon paradigm [3]. The source transmit unknown messages through a disturbed channel. The receiver, who has only the disturbed message at the output of the channel, He try to take a decision

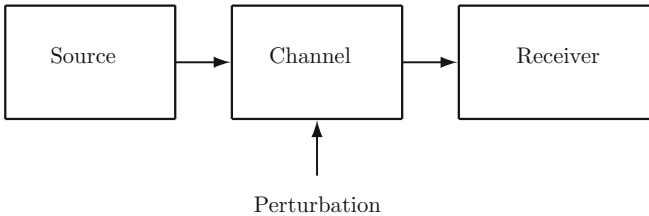


Fig. 2.6 Shannon paradigm

of the issued signal. He then makes “*Assumptions*” about the message issued and chooses the most likelihood. Let denote by X and Y random variables taking values in $\{x_1, x_2, \dots, x_n\}$ and $\{y_1, y_2, \dots, y_m\}$ which represent respectively the message transmitted by the source and the message received. An important quantity associated to this pair of random variables is the average mutual information defined by:

$$I(X, Y) = E\{i(x_k, y_l)\} \quad (2.23)$$

$$= - \sum_{k=1}^n \sum_{l=1}^m Pr(x_k, y_m) \log_2 \frac{Pr(x_k, y_m)}{Pr(x_k)Pr(y_l)} \quad (2.24)$$

The average can also be written as

$$I(X, Y) = H(X) - H(X|Y) \quad (2.25)$$

$$= H(Y) - H(Y|X) \quad (2.26)$$

$$= H(X) + H(Y) - H(X, Y) \quad (2.27)$$

We could interpret the above equation as: The average is equal to the transmitted “information”, reduced by the remaining indetermination between the transmitted and issued symbol.

2.3.3 Channel Capacity

There is a tool to measure the ability of a channel to transmit information. The capacity C of a channel is defined as the maximum of the average mutual information $I(X, Y)$ associated with its input and its output, namely:

$$C = \max_{Pr(x)} I(X, Y) \quad (2.28)$$

The channel capacity represents the maximum information that can be transferred through a channel. According to the Eq. (2.28), this maximum is defined with respect to the distribution probability of the transmitted messages. A “good” choice of this

distribution and messages carrying the information will be an important factor in achieving or approaching this capability. Thus, it was proposed to interpose a “module” between the source and the channel to define the best forms of messages conveying information. This module is said encoder of the emitted information and the mechanism is called channel coding.

2.4 Conclusion

The Channel is an important element of the transmission chain. It often acts as a disturbing element which changes the transmitted signal. In digital communication, we are interested in studying and “fixing” the channel effects on the statistics and the shape of the issued signal. This requires channel modeling of its variations in time and frequency. Several studies have proposed mathematical models and statistics to characterize and simulate mobile radio channels. The first section of this chapter has been devoted to the description of mobile radio channel in digital communication.

In information theory, the notion of the channel takes on another meaning. In fact, this theory concerned with the amount of information carried by the issued message. Thus, the transmission channel is seen as a factor that degrades the amount of transmitted information. The quantification of information was introduced by in [3]. We saw, in this chapter, a channel is characterized in information theory by its capacity, which represents the maximum information that can be transmitted via this channel. To be in edge of the theoretical limit, the channel coding is often required. This will be the focus of the next chapter by introducing the channel coding in MIMO-OFDM systems.

References

1. Clarke R (1968) A statistical theory of mobile radio reception. *Bell Syst Tech J* 47:957–1000
2. Jakes WC (1974) *Microwave mobile communications*. Wiley, New York
3. Battail G (1997) *Theorie de l’information: application aux techniques de communication*. Masson, Paris

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