PROCEEDINGS OF ISAP2005, SEOUL, KOREA

A STUDY ON SPATIAL CHARACTERISTICS OF AN INDOOR MULTI-ANTENNA CHANNEL

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1. INTRODUCTION

Multi-antenna techniques are highlighted in these days because they can provide a higher channel capacity than that can be provided by a single antenna system. So far, the most popular multi antenna technique is a diversity antenna technique and it can provide a diversity gain. But a new generation of a wireless communication needs higher capacity, so new multi-antenna techniques are widely studied. One of these techniques is a multi-input multi-output (MIMO) technique which utilizes a randomness of a channel fading and can provide a higher channel capacity than that of single or diversity antenna techniques. A system capacity of the multi-antenna technique depends on channel spatial correlation characteristics [1]-[6]. In many researches, it is known that a spatial correlation depends on a Ricean K factor so the channel capacity depends on a Ricean K factor [1]-[4]. But in indoor environments, a dependency between Ricean K factor and capacity has not been proven. So this paper has focused on relations of various channel characteristics such as Ricean K factor, correlation coefficients and capacity in indoor office room environments. They are measured in various environments and their experimental values are compared in a respect of capacity.

2. CHANNEL MODEL

2.1. MIMO channel model

The MIMO channel is modeled as M_T by M_R matrix and in a flat fading channel, the signal model is [1]

$$\mathbf{y}(l) = \sqrt{\frac{E_s}{M_T}}\mathbf{H}(l)\mathbf{s}(l) + \mathbf{n} \tag{1}$$

The E_s is a signal power, M_T and M_R is the number of transmitting and receiving antennas, respectively. The symbol l is a sample number. The $\mathbf{s}$ and $\mathbf{y}$ are vectors of transmitted and received signals, respectively. When M_T is equal to 2 and M_R is equal to 2, the channel matrix $\mathbf{H}(l)$ is $[h_{11}(l)\, h_{12}(l); h_{21}(l)\, h_{22}(l)]$. The channel should be normalized to remove a large scale fading characteristic. So a normalization coefficient A is defined as [5]

$$A = \sqrt{\frac{M_T M_R L}{\sum_{l=1}^{L} \| \mathbf{H}_{meas}(l) \|_F^2}} \tag{2}$$

$\| \cdot \|_F$ is a Frobenius norm and $\mathbf{H}_{meas}$ is a measured channel matrix, $\mathbf{H} = [\mathbf{H}(1), \mathbf{H}(2), \cdots, \mathbf{H}(L)]$. L is a total sample number.

ISBN: 89-86522-77-2 94460©KEES

A normalized channel matrix $\mathbf{H}$ is defined as

$$\mathbf{H}(l) = A\mathbf{H}_{meas}(l) \tag{3}$$

2.2. MIMO capacity

When the channel is unknown and its channel power is uniformly allocated, the channel capacity is defined as [1]

$$C(l) = \sum_{i=1}^{min(M_T,M_R)} log_2\left(1+\frac{E_s}{M_T N_0}\lambda_i(l)\right) \tag{4}$$

E_S/N_0 is a signal to noise ratio and $\lambda_i(l)$ is an eigenvalue of a $\mathbf{H}(l)(\mathbf{H}(l))^H$.
The ergodic capacity is defined as

$$C = E\{C(l)\} = \frac{1}{L}\sum_{l=1}^{L} C(l) \tag{5}$$

2.3. Ricean K factor

A Ricean K factor is a power ratio of a direct wave to indirect waves. With measurement results, the K factor can be estimated by using a moment method [4][7]. The Ricean K factor is estimated from the equation as

$$K = \frac{|V|^2}{|\sigma|^2} = \frac{\sqrt{G_a^2 - G_v^2}}{G_a - \sqrt{G_a^2 - G_v^2}} \tag{6}$$

when G_a is the average of a channel $\mathbf{H}$ and G_v is the RMS fluctuation of total channel elements $h_{mn}(l)$ of $\mathbf{H}$.

3. MEASUREMENT

3.1. Channel sounder and channel estimation

Various channel sounding techniques are developed in these days. Furthermore, MIMO channel sounding techniques are also developed, recently [6]. In this research, the MIMO channel sounder is constructed with an orthogonal code and channel estimation theory. The channel sounder has two transmitters and two receivers, so it can identify four channels with orthogonal 100 kcps/s codes. The MIMO channel sounder uses maximum likelihood estimation and estimates four independent channels [6][8]. Estimated channel matrix is used to evaluate a MIMO channel characteristic. While transmitted signal s and received signal y in Eq. (1) are known but channel matrix **H** is unknown, the unknown channel matrix **H** should be estimated from maximum likelihood estimation.

3.2. Measuring environment

Measuring environments are summarized in table 1. Two scenarios are supposed in measurements. One is a non-line of sight environment that a transmitter is placed in a corridor and a receiver is placed in a room. The other is a line of sight environment that a transmitter and receiver are placed in a room. In this case, the transmitter is placed in front of a door. So in these two cases, they have a similar propagation path but nevertheless each of them is on a line of sight and non-line of sight, respectively. A receiver is moved by 20λ long to measure multipath fading characteristics. Room conditions of an empty room and a conventional office room with a table, desk, etc. are used for this measurement.

Table 1. Classification of a measured environment

Index	environment	furniture density	Tx Position
1	Small office	Heavy	Outter (NLOS)
2		Middle	
3		Light	
4	Small office	Heavy	Inner (LOS)
5	Large office		
6	Small auditorium	Heavy	Inner (LOS)
7		Middle	
8		Light	
9	Large auditorium	Heavy	

4. RESULTS

In this section, channel characteristics are analyzed with a correlation coefficient, a capacity and a Ricean K factor. Those are analyzed in a respect of an environment variation. Channel correlation and capacity at 20 dB SNR are analyzed in a respect of an antenna spacing parameter.

4.1. Ricean K factor and capacity

It is known that a Ricean K factor is a measure of an angular spread and it is related with a capacity. Figure 2 shows a relation of Ricean K factor and capacity. A Ricean K factor and a channel capacity are analyzed with eq. 5 and eq. 6, respectively. A variation range of Ricean K factor is 2 ~ 28(linear scale) and a range of capacity is 8 ~ 9 bps/Hz at a 20 dB SNR case. As shown in a figure 2, in a line of sight case, a variation range ($K_{max} - K_{min}$) is wider than that of a non-line of sight. Furthermore the Ricean K factor and capacity have no dependency each other in an indoor environment. It is concluded that a Ricean K factor is varied according to circumstances and its variation is large, so it is not clear that the Ricean K factor is a measure of a line of sight in those environments. But its variation range is dependent on either a line of sight or not.

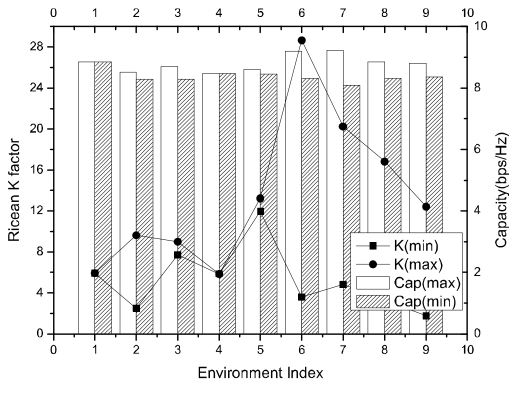
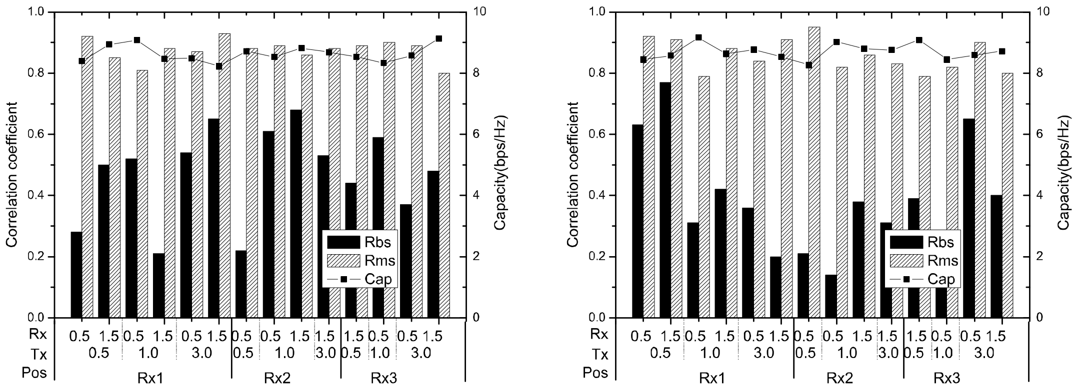


Figure 2. Common characteristics for an indoor MIMO channel capacity

4.2. Correlation coefficient and capacity

As shown in a figure 3, the complex correlation coefficients have no dependency on a Tx-Rx situation of line of sight or non-line of sight. The correlation at transmitter side(R_{bs}) has values of 0.75~0.92 and the correlation at a receiver side(R_{ms}) has values, 0.12~0.78. So the correlation coefficient at receiver side is varied according to a circumstance with wider range than the correlation coefficient at receiver side and the capacity is more dependent on the correlation coefficient of transmitter. As a result, a low correlation at transmitter side below about 0.75 causes higher channel capacity, but a relation of receiver side correlation coefficient and a capacity is not clear.



(a) NLOS (b) LOS

Figure 3. R_{bs}, R_{ms} and Capacity

5. CONCLUSION

This paper proves experimental characteristics and relations of Ricean K factor, correlation coefficients and capacity in indoor environments. Firstly, Ricean K factor is varies with a circumstance but its variation is large. So it cannot be a measure of a line of sight. Furthermore, it has no dependence with a capacity in indoor environments. Secondly, the correlation coefficient at receiver side is varied according to a circumstance with wider range than those values at transmitter. So it doesn't have a clear relation with a channel capacity. It is concluded that the correlation coefficient at receiver side is more affected by a circumstance around a receiver, and a low correlation coefficient at transmitter side is more advantage because it can get more channel capacity and is not sensitive to an environment.

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