Study of Instantaneous Variation of OFDM Sub-carrier Spectrum Towards Symbol-by-symbol Quality Control

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1. INTRODUCTION

According to the development of high-speed wireless access systems with speeds of over 10 Mbps, various studies on indoor multipath propagation characteristics in a 5-GHz band have been conducted in terms of the time or frequency domain. In particular, dynamic frequency-domain variation affects link adaptation techniques that improve the transmission performance by alternating the data rate of each sub-carrier in the spectrum of the Orthogonal Frequency Division Multiplexing (OFDM) system [1]. Therefore, detailed and instantaneous broadband frequency-domain propagation characteristics are required to develop a higher performance OFDMA system [2]. For example, frequency-domain representations such as a correlation (coherence) bandwidth lead us to understand the multipath effect on transmission performance [3-5]. Furthermore, the multipath effect influences the dynamic characteristics in the time domain when a terminal is moving. Parameters such as the coherence time or coherence length represent the duration of the same receiving conditions in time or in space. Instantaneous variations of a wideband spectrum contain multipath-effect information in both the frequency and time domains. The information is useful for some applications such as in the designing the optimum sub-carrier diversity or an interleaving scheme for an OFDM system. However, it is difficult to acquire experimental data on the instantaneous broadband (in the range of megahertz) frequency-domain characteristics because there are performance limitations to conventional measurement systems.

This paper presents a method for measuring the instantaneous broadband frequency-domain characteristics using an OFDM technique [6]. This method enables measurement of the instantaneous variation of each sub-carrier amplitude over the range of 20 MHz. Experimental results exhibit dynamic variations in the spectrum shape by means of cross correlation coefficients between 20-MHz spectra in both small and large rooms. A ray trace simulation was also conducted for these rooms to evaluate the measured result.

2. MEASUREMENT OF INSTANTANEOUS BROADBAND FREQUENCY-DOMAIN CHARACTERISTICS

We newly adopted an OFDM technique to acquire data in a fast-fading environment. Acquiring the instantaneous broadband frequency-domain amplitude is now possible by observing the magnitude of OFDM sub-carriers. These OFDM sub-carriers can be divided without interference between sub-carriers by frequency-orthogonality even if the frequency intervals between the sub-carriers are short. The data set of the magnitudes of OFDM sub-carriers can be acquired using each timing signal that corresponds to a usual OFDM symbol. The parameters of this measurement system are shown in Table I. The signal received by the reception antenna is converted to an IF signal, split into the In-phase component (I-ch) and Quadrature-phase component (Q-ch), and then stored in a storage device by 20-MHz (generated from a rubidium oscillator) A/D sampling. The stored data are converted to complex sub-carrier magnitude by an off-line FFT. This process achieves an observation time resolution of 3.2 μ sec in obtaining a shot of a wideband spectrum.

The measurements were carried out in two environments, a meeting room (Room-A;

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13.5 m × 7 m) and an auditorium (Room-B; 28 m × 18 m) in the same office building. The instantaneous complex magnitudes of the OFDM sub-carriers were acquired continuously every 3.2 μsec while the terminal station was moving along a straight measurement course at a slow walking speed (approximately 1 m/sec). An example of the acquired data is shown in Fig. 1(a) and 1(b). In this study, a data set of the frequency-domain complex amplitudes of OFDM sub-carriers was acquired every 3.2 μsec. The total of 31,252 data sets were acquired at 100 msec (= 3.2 μsec × 31252) intervals while the terminal station was moving along each measurement course. This time period of 100 msec is equivalent to the terminal station moving a distance of 10 cm.

3. SIMULATION OF CROSS CORRELATION CHARACTERISTICS BETWEEN SPECTRA

Ray trace simulations for the rooms, Room-A and Room-B, were carried out assuming a simple box-type room. The room environment comprises smooth metal walls and both the floor and ceiling are constructed of smooth dielectric materials with the relative permittivity of six. Direct wave and reflected waves with at most four-time reflection are considered. The Fresnel reflection coefficient is used to calculate the reflection level of the dielectric surfaces. Figure 2 shows an antenna configuration in a simple rectangular room for Room-B. A base station antenna is located near one of the walls and the terminal antenna moved around the center of the room. In a simulation, it is easy to obtain instantaneous spectrum shots because there is no need to consider the time delay caused by the technical limits of the measurement equipment. In a frequency range from 5.2 GHz to 5.225 GHz, each spectrum has 51 frequency points for received level calculations.

In order to evaluate the dynamic variation in a wideband spectrum, cross correlation characteristics are studied. The cross correlation coefficient can be obtained from the relationship between two spectra, i.e., those that have a time- or space-separation of Δt or Δd. This coefficient indicates the lifetime of the condition in which the spectrum and transmission quality are considered to be the same. Since Δt and Δd are linked together by the moving speed, Δd is used as a parameter in this simulation. Figure 3 is an example of the simulated spectra when Δd equals 5 cm for Room-B.

One hundred cross correlation coefficients are calculated at random positions in a 1 m × 1 m area located around the center of the room for each different Δd. Figure 4 shows the cumulative probability of the cross correlation coefficients in Room-B for four cases of Δd. These Δd values are normalized by wavelength λ. When Δd is small, most of the cross correlation coefficients nearly equal one. Along with the increase in Δd, the median values and standard deviations of the coefficient approach zero and 0.4 respectively.

Figure 5 shows the dependencies of both the median and standard deviation of the cross correlation coefficients on $\Delta d/\lambda$. The circle and triangle symbols correspond to Room-A and Room-B, respectively. When the coherence length is defined as the $\Delta d/\lambda$ at which the median of the correlation coefficient becomes 0.5 after taking the maximum value, it is about 0.25 in both Room-A and Room-B. After this $\Delta d/\lambda$ value, standard deviations are saturated to around 0.4. The solid line represents the calculated values of the space correlation coefficient obtained from the following equation, which is well known in the field of narrow band mobile propagation [7].

$$\rho = \left| J_0\left(2\pi \frac{\Delta d}{\lambda}\right) \right|^2$$

where ρ is the space correlation coefficient and J_0 is the zero-order Bessel function of the first kind.

4. MEASUREMENT RESULTS AND DISCUSSION

The cumulative probability of the cross correlation coefficient measured in Room-B is shown in Fig. 6 with four measurement cases as well as Fig. 4. Figure 7 shows dependencies of both the median and standard deviation of the measured cross correlation coefficients for $\Delta d/\lambda$ in Room-B. The results in both the figures show the same tendencies with those obtained from the above simulations. The following results were derived from Fig. 4 to Fig. 7.

(1) The coherence length defined as the $\Delta d/\lambda$ at which the median of the cross correlation coefficient becomes 0.5 is about 0.25 in both large and small rooms. This result indicates that the lifetime of the spectrum can be considered to be $0.25\lambda/v$, where v is the terminal moving speed.

(2) The distribution of the cross correlation coefficients between spectra appears to be normal when $\Delta d/\lambda$ becomes larger than the coherence length.

(3) Once the $\Delta d/\lambda$ exceeds 0.25, the standard deviation is saturated to around 0.5.

(4) The space correlation characteristics for narrow band mobile systems agree well with the correlation characteristics of the wideband spectrum variation.

5. CONCLUSION

A new method for measuring the instantaneous broadband frequency-domain characteristics using an OFDM technique was introduced and its effectiveness was verified based on indoor measurements. Dynamic variations of the spectrum for selected conditions pertaining to the room size were studied by both ray trace simulation and measurement at 5.2 GHz. The results showed that area size dependencies on dynamic variation of the spectrum were not remarkable. The instantaneous variation of the frequency characteristics over the range of 20 MHz enabled the analysis of the dynamic variations in a frequency spectrum and an evaluation of the multipath characteristics that is more detailed than before.

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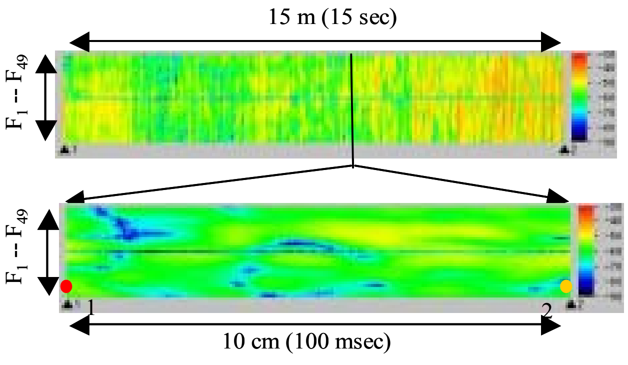
Table I. Measurement System Parameters

Center frequency	5.2 GHz
Number of OFDM sub-carriers	64
Frequency interval between OFDM sub-carriers	312.5 kHz
Modulation of each sub-carrier	Non-modulated (CW)
Time resolution	3.2 μ sec
Transmission (terminal station) antenna	V-pol sleeve dipole (omni-directional)
Reception (base station) antenna	Same type as transmission antenna



(Enlarged view of segment of acquired data)

Fig.1 (a) Example of acquired data

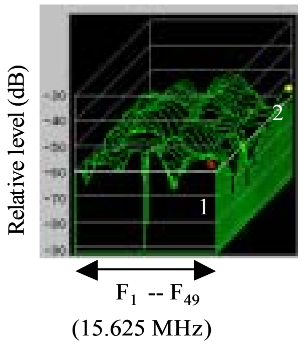


Fig.1 (b) 3D view of acquired data (Same data with as (a))

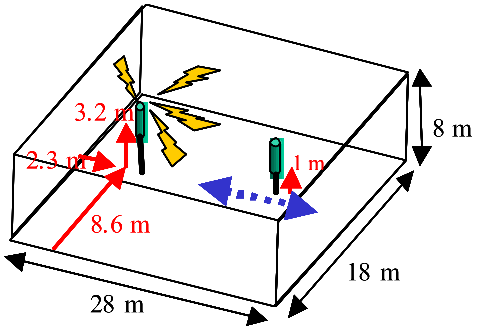


Fig.2 Model of Room-B for simulation

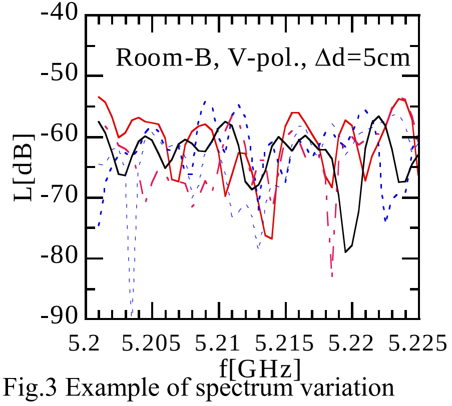


Fig.3 Example of spectrum variation obtained from ray trace simulation

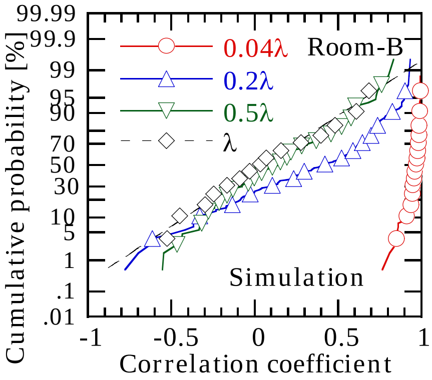


Fig.4 Cumulative probability of cross correlation coefficient (Simulated results in Room-B)

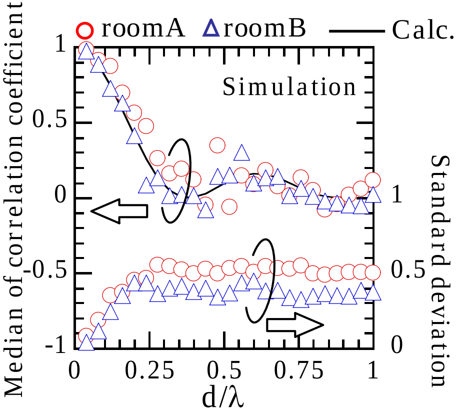


Fig.5 Median and standard deviation dependencies on d/λ (Simulated results)

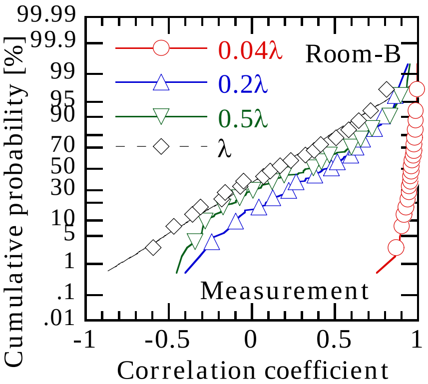


Fig.6 Cumulative probability of cross correlation coefficient (Measured results in Room-B)

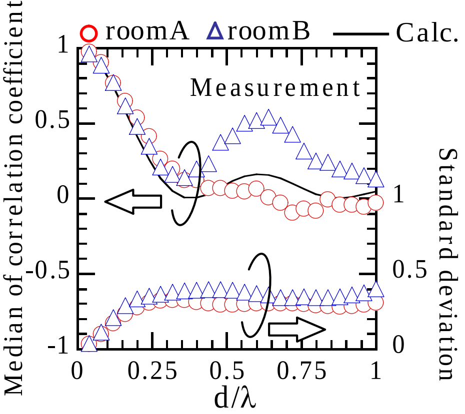


Fig.7 Median and standard deviation dependencies on d/λ (Measured results)