Interference Characteristics between 2.4-GHz-band Middle-speed Wireless LANs using Direct Sequence and Frequency Hopping

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Abstract - Middle-speed (1-to-2-Mbit/sec) 2.4-GHz-band wireless LAN systems are widely used throughout the world. As they occupy the same frequency range, electromagnetic interference will occur between them. We investigated interference characteristics between wireless LAN systems that use Direct Sequence (DS) and Frequency Hopping (FH).

Experimental results showed that varying the modulation parameters changed the interference characteristics of the throughputs of wireless LAN systems. Calculated throughput characteristics for the interference agreed with experimental results. Calculating of the DS and FH system performance when $E_b/N_0 = 20$ dB showed that the D/U ratio required for the FH system was smaller than those required for the DS systems. However, when the D/U ratio was above 8 dB, the throughputs of the DS systems were higher than that of those FH system. These results clarified the interference characteristics, and will be useful in the prediction of communications performance in environments where DS and FH systems are intermixed.

Introduction

Wireless LAN systems based on the spread spectrum (SS) in the 2.4-GHz-band are widely used throughout the world [1]. In Japan, all of these systems occupy the same frequency range; thus interference can occur between them[1][2]. This should be considered an electromagnetic compatibility (EMC) problem, because transmitters of other systems, which are not covered by the standard governing these LANs, act as a kind of disturbance source.

Interference between radio communication systems and disturbance sources, such as devices (e.g., microwave ovens) or Gaussian noise, has been studied[3][4], but the interference characteristics between communication systems have not been investigated. Knowledge of these characteristics is important in designing wireless LAN networks for buildings or offices that will not suffer from the interference[5].

Here we present the interference characteristics measured and calculated between 2.4-GHz-band middle-speed wireless LAN systems that employ direct sequence (DS) and frequency hopping (FH).

Wireless LAN System

The wireless medium access control and physical specifications of the 2.4-GHz-band middle-speed wireless LAN are standardized in IEEE 802.11[1]. A wireless LAN system is composed of some base stations, called access points, and many personal stations. These systems use SS of DS or FH.

Generally, the coverage radius of an access point is about 50 m for indoor operation. As shown in Fig. 1, even if office walls are made of metal or absorbent material, the communications signal will leak out through chinks in the walls and reach neighboring offices. This will create an area in which these cov-

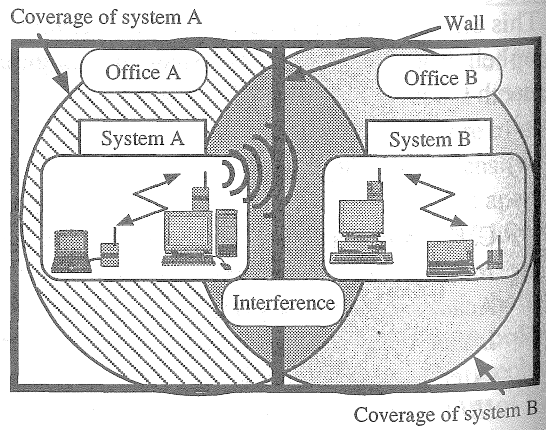

Fig. 1 Overlap of wireless LAN systems.

Table 1. Technical parameters of wireless LAN systems.

	DS1	DS2	DS3	FH1
Spreading	DS	DS	DS	FH
Modulation	DQPSK	DQPSK	DBPSK	4FSK
Spreading rate	11	11	13	
Hop number				23

Operating frequency of all systems: 2.471 to 2.497 GHz

erages overlap, i.e., where signals of both systems A and B can arrive, resulting in interference will occur between them. We investigated the interference characteristics experimentally and theoretically.

Measurement system

Our measurements used three types of DS systems and one type of FH system in our measurements. The technical parameters of these systems are summarized in Table 1. The experimental system for measuring the interference characteristics is shown in Fig. 2.

Optimally, interference should be evaluated in the actual communications environment. Our study, however, was conducted without the effect of the propagation characteristics. The objective system and the disturbance source were managed by the same workstation, and disturbance waves were added by means of a changeable attenuator. By this means we changed the ratio between desired and undesired signals (D/U ratio) at station 1 and measured the interference characteristics for several conditions (see Table 2). DS 1, 2, and 3 are DS systems, and FH 1 is an FH system. A 5-Mbite file was transmitted by file transfer protocol (FTP) from the workstation to computers 1 and 2, and throughput was measured.

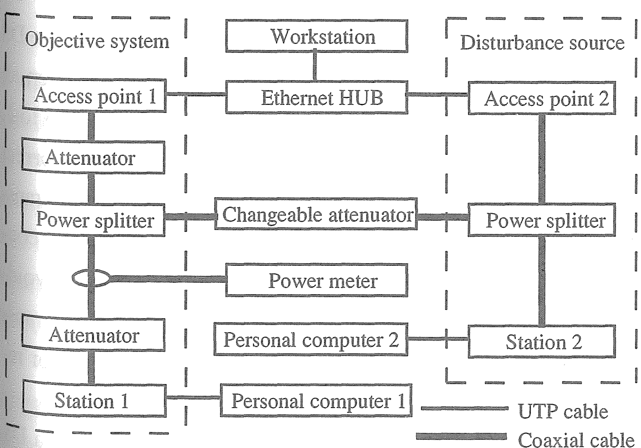

Fig. 2 Experimental system for our measurements.

Table 2. Measurement conditions.

	Objective system	Disturbance source
Case1	DS1	FH1
Case2	DS2	FH1
Case3	DS3	FH1
Case4	FH1	DS1
Case5	FH1	DS2
Case6	FH1	DS3

Simulation method

We calculated the interference characteristics to investigate the mechanism of the interference. The bit error rate (BER) P_b of DS 1 and 2 can be written as[5]

$$P_b = \exp\{-\gamma\cdot(1-\frac{1}{\sqrt{2}})\} \tag{1}$$

and P_b of DS 3 is written as[6]

$$P_b = \frac{1}{2}\cdot\exp(-\gamma) \tag{2}$$

where γ is the signal-to-noise (S/N) ratio. The S/N ratio γ is defined by the power of the desired signal after despreading P_d (W), the noise power P_n (W), and the power of the undesired signal after despreading P_u (W), as follows.

$$\gamma = P_d / (P_n + P_u) \tag{3}$$

When the source of disturbance is a FH system, the S/N ratio after despreading γ can be expressed as

$$\gamma = D\cdot R/(\sigma^2 + U/G_p) = 1/[1/\{(E_b/N_0)\cdot R\} + 1/\{(D/U)\cdot G_p\cdot R\}] \tag{4}$$

where D is the desired signal power and R is the cumulative distribution of the desired signal in the operating frequency. U is the power of the undesired signal and G_p is process gain. σ^2 is noise power. E_b represents the energy per bit. N_0 is the noise power spectral density. (D/U) is the D/U ratio.

Here, we also calculated the interference characteristics of the FH system. The P_b of FH 1 can be written as follows:[7]

$$P_b = \frac{M}{2\cdot(M-1)}\cdot\sum_{i=1}^{M-1}(-1)^{i-1}\cdot\binom{M-1}{i}\cdot\frac{1}{i+1}\cdot\exp\left(\frac{-i}{i+1}\cdot\gamma\right) \tag{5}$$

where M means the M-ary signal transmission, and γ can be expressed as follows:

$$\gamma = D/\{\sigma^2/K + U/(G_p\cdot W)\} = 1/[1/(K\cdot E_b/N_0) + 1/\{(D/U)\cdot G_p\cdot W\}] \tag{6}$$

where K is the number of information digits, and $M = 2^K$. W is the ratio of the operating frequency bandwidth to that of the main lobe in the interference signal.

These wireless LANs employed an error correction function called Go-Back N. In this error control, throughput S (bit/sec) is expressed by the average effective transmission time T_e (sec) and the length N (bit) of the transmission frame as

$$S = N / T_e \tag{7}$$

and T_e is written as follows:[9]

$$T_e = \sum_{i=1}^{\infty} \{i \cdot N/v + (i-1) \cdot C\} \cdot P_f^{i-1} \cdot (1-P_f)^i = (N - C \cdot v \cdot P_f)/\{v \cdot (1-P_f)\} \tag{8}$$

where v (bit/sec) is the maximum value of throughput, and C (sec) is the period from the time of causing error to the starting time of transmitting the correct frame. The frame error rate P_f is expressed by the BER P_b as follows:[9]

$$P_f = 1 - (1 - P_b)^N \tag{9}$$

Substituting Eqs. (1), (2) and (4) into Eq. (6) yields the interference characteristics of these DS and FH systems.

Interference characteristics

DS system

We evaluated the interference characteristics of DS systems in cases 1 to 3, using FH 1 as a disturbance source. The measured and calculated results of throughput versus D/U ratio in cases 1 to 3 are shown in Fig. 3; the throughput was normalized by the maximum value. The calculation used the parameters shown in Table 3.

As shown in Fig. 3, the throughputs of cases 1 and 2 had almost the same characteristics, because DS 1 and 2 had similar modulation parameters. These throughputs had a degradation of 5 dB compared to that of case 3 when all the throughputs were changed from 0 to 1. The value of the degradation was caused by the difference in comparison detection.

From our investigation, when an FH system was the disturbance source and $E_b/N_0 = 20$ dB, the D/U ratio should be above about 10 dB. The calculated results agreed well with measured results, differing by only about 2 dB. Therefore, our simulation method will be practical for the prediction of communication performance of DS systems.

Table 3 Sinulation parameters.

	E_b/N_0 (dB)	R	G_p	M	K	W	v (Mbit/sec)	C (msec)
Case 1	19	0.9	11				1.4	2
Case 2	20	0.9	11				1.5	3
Case 3	20	0.6	13				1	7
Case 4	12		23	4	2	26/22	0.6	30
Case 5	20		23	4	2	26/22	0.6	30
Case 6	20		23	4	2	26/26	0.6	30

N:1518×8bit

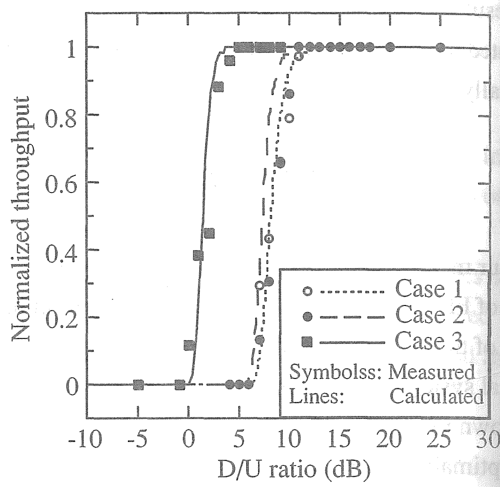

Fig. 3 Interference characteristics of DS systems.

FH system

Using the experimental system shown in Fig. 2, we also investigated the interference characteristics of the FH system in cases 4 through 6. For FH 1, we used DS 1, 2, and 3 as the disturbance sources. Figure 4 shows the measured and calculated throughputs versus D/U ratio for cases 4 through 6.

As shown in Fig. 4, cases 4 and 5 also had the similar characteristics, and the difference in D/U ratio between cases 4 and 6 was about 3 dB when all the throughputs were changed from 0 to 1. The difference was caused by the difference in the spreading rate between DS 1 and 3.

Compared with the interference characteristics of the DS systems, the throughput of FH 1 had two tendencies when all the throughputs were changed from 0 to 0.5 and from 0.5 to 1. This is because FH 1 took more time to transmit the correct frames when the errors were caused in the multiple frames transmitted based on the transmission control protocol (TCP) congestion avoidance algorithm[8]. Here, TCP congestion avoidance is the algorithm in which the number of frames being transmitted at any one time is increased until time frame error results.

We found that, when the disturbance source was a DS system and $E_b/N_0 = 12$ dB, the D/U ratio should be above 15 dB.

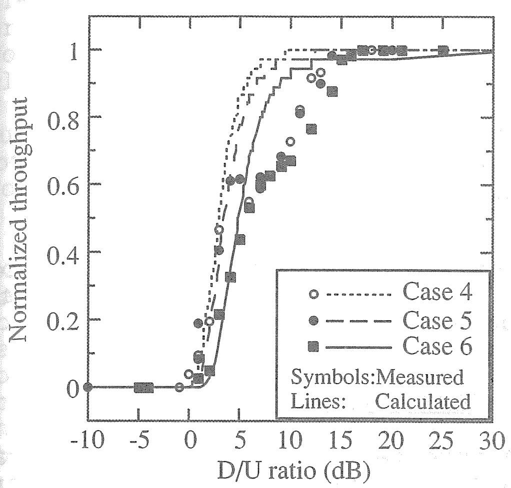

Fig. 4 Interference characteristics of FH system.

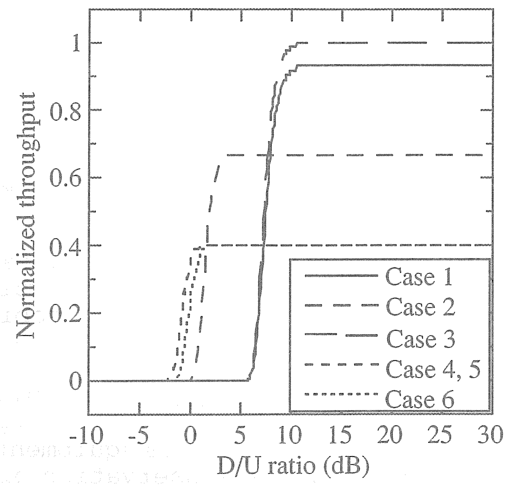

Fig. 5 Interference characteristics when $E_b/N_0 = 20$ dB.

The difference between the simulated and measured results was bigger when throughputs were above 0.5, showing a maximum difference of 6 dB. This difference might be caused by not considering the behavior of the TCP congestion avoidance algorithm; hence, we must investigate the effect of the algorithm.

As an example, we calculated the interference characteristics in cases 1 to 6 when $E_b/N_0 = 20$ dB; these are showed in Fig. 5. When the D/U was below 0 dB, FH 1 performed better than DS 1, 2 or 3. On the other hand, the DS systems performed better than FH 1 when the D/U was above 7 dB. To prevent interference, the D/U ratio should be above 8 dB when $E_b/N_0 = 20$ dB. This makes our simulation will be practical for predicting communications performance in an environment in which DS and FH systems are intermixed.

Conclusions

We investigated the interference characteristics between DS and FH wireless LAN systems. We found that varying the modulation parameters changed the interference characteristics of the throughputs of wireless systems. We simulated the interference and the calculated results agreed well with the measured results. This indicates that our simulation will be useful in the prediction of communications performance (in an environment in which DS and FH systems are intermingled).

In the future, we will investigate the effect of communications control on interference and performance in the fading environments.

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