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EXPERIMENTAL INVESTIGATION OF CONTROLLING COVERAGE OF WIRELESS LAN BY USING PARTITIONS WITH ABSORBING BOARD

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Abstract: For a wireless communication system to work effectively without electromagnetic interferences, the electromagnetic environment needs to be controlled. We experimentally investigated methods for controlling the electrical field strength and the delay spread so as to achieve communications without electromagnetic interference in selected regions for a 2.4-GHz-ISM-band wireless LAN system. Several indoor environments in which partitions with electromagnetic absorbing board were placed around desks were used. The transmission loss and delay spread were investigated experimentally, and the BER and throughput characteristics were measured. We found that the coverage of a wireless LAN could be controlled by using partitions with absorbing boards. We identified several requirements for controlling the coverage that should be useful in designing indoor wireless communication systems.

INTRODUCTION

Wireless communication systems in the microwave band are now used in many offices. These systems include 2.4-GHz industrial, scientific, and medical (ISM) band wireless local area networks (LANs) [1],[2] and 1.9-GHz-band (in Japan) cordless phones. However, if the system is large, electromagnetic interference with other systems may occur [3]-[5]. For example, a shortage of channels may lead to channel collisions and strongly reflected waves may lead to bit errors. Therefore, the indoor electromagnetic environment must be controlled for a wireless communication system to work effectively.

Improvement in the antenna system [6] and the signal processing system [7] have helped to control the coverage of wireless systems. Choosing appropriate building materials has been shown to help control the electromagnetic environment [8],[9]. The 2.4-GHz-ISM-band wireless LANs are manufactured by many companies, and these LANs have non-directional antennas, so users can easily install them. Therefore, controlling the electromagnetic environment by selecting appropriate building materials is more effective than improving the antenna system for actual implementations.

We have experimentally investigated a method for controlling the coverage of a 2.4-GHz-ISM-band wireless LAN system with monopole antennas by using electromagnetic absorbing boards [10] as partitions. We used an electromagnetic environment evaluation booth [8] whose wall material could be changed. We set the covered and uncovered regions in the booth beforehand and investigated methods for achieving the best communication conditions in the coverage region. The propagation characteristics, including the transmission loss and delay spread, were measured for four indoor environments. The bit error rate (BER) and throughput characteristics of a conventional wireless LAN system were also investigated and several requirements for controlling the coverage were identified.

EXPERIMENTAL SETUP

The configuration of the electromagnetic environment evaluation booth is shown in Fig. 1. The booth was completely covered with electromagnetic absorbers to prevent radio waves with the same frequency bands used in our investigations from entering the booth. The absorbers had above-20-dB absorbing characteristic for radio waves above 1.5 GHz. The booth was 9.1 m long, 4.45 m wide, and 2.8 m high. It had a raised access floor constructed of metallic plates, 0.5 x 0.5 m. It had a suspended ceiling constructed of 0.9 x 0.9 x 0.02 m acoustical squares made of rock wool. The walls were either metallic plates or metallic plates lined with electromagnetic absorbers. These absorbers had the same absorbing characteristics as those on the outside of the booth.

Eight desks and chairs were placed in the booth, with partitions around the desks. The desks were constructed of steel panels and the chairs were constructed of a cushion and plastic parts. Two groups of four desks were placed symmetrically in the booth to simulate a typical office, as shown in Fig. 1. An antenna as an antenna of personal station (PS) was placed symmetrically on each desk. They were 0.7 m high and placed 0.1 m from the partitions. Another antenna as an antenna of center station (CS) was placed on the center line (2.225 m from the x walls, and 0.3 m from one y wall). It was 1.5 m high. The PS and CS antennas were monopole antennas, like those in an ac-

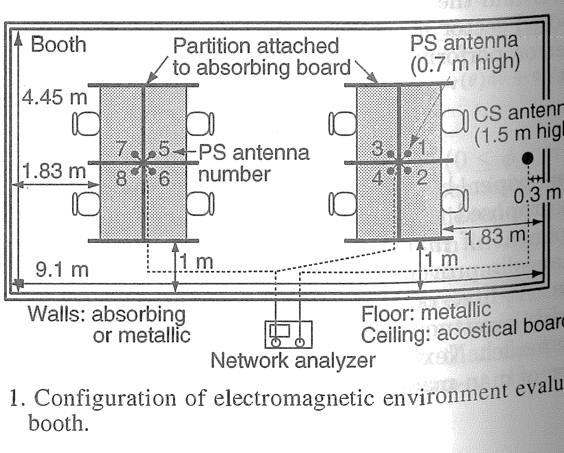
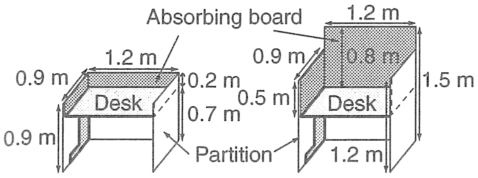


Fig. 1. Configuration of electromagnetic environment evaluation booth.



(a) Partition No. 1 (b) Partition No. 2

Fig. 2. Structure of partitions attached to absorbing board and desk.

ual wireless LAN. They had vertical polarization.

Electromagnetic absorbing boards [10] were attached to the partitions, as shown in Fig. 2. Partitions with two different structures were used. Partition 1 (Fig. 2(a)) is the shortest partition that comes on the market; it is 0.9 m high. Partition 2 (Fig. 2(b)) is the tallest partition generally installed around a desk. It was either 1.2 m or 1.5 m high. These partitions were made from wood panels and plastic parts. Absorbing boards were installed around each desk, extending from the desk top to a height of 0.2, 0.5, or 0.8 m. They were made of silicic calcium and ferrite powder; their absorption characteristics were about 20 dB at 2.484 GHz. They were 8 mm thick and backed with aluminum sheets.

We determined beforehand that the antenna at positions 1, 2, 5, and 6 were to be in the coverage region, while the other antennas were not. We then investigated ways to achieve coverage for the antennas to be covered.

We tested coverage in four environments: (1) absorbing walls and partition 1, (2) absorbing walls and partition 2, (3) metallic walls and partition 1, and (4) metallic walls and partition 2. In all environments, the direct wave from the transmitting antenna reached only antennas 1 and 2. In environments 1 and 3, it also reached antennas 5 and 6.

PROPAGATION CHARACTERISTICS

A network analyzer placed outside the booth was connected to the CS and PS antennas by coaxial cables laid under the floor, as shown by the dotted lines in Fig. 1. It was used to measure the transmission loss and delay spread from the CS antenna to each PS antenna.

TRANSMISSION LOSS

The measured transmission loss for the four tested environments is shown in Fig. 3. The loss is the average transmission loss for 401 frequencies between 2.471 and 2.497 GHz, the bandwidth of the wireless LAN. We used the average because the transmission loss varied widely between frequencies. The horizontal axis shows the PS antenna positions shown in Fig. 1. The vertical axis shows the transmission loss normalized by the transmission loss at position 1 in environment 1.

Although antenna pairs 1 and 2, 3 and 4, 5 and 6, and 7 and 8 were placed symmetrically with respect to the CS antenna, the transmission loss differed by several dB within each pair because it was impossible to install the antennas, desks, and partitions in perfectly symmetrical positions.

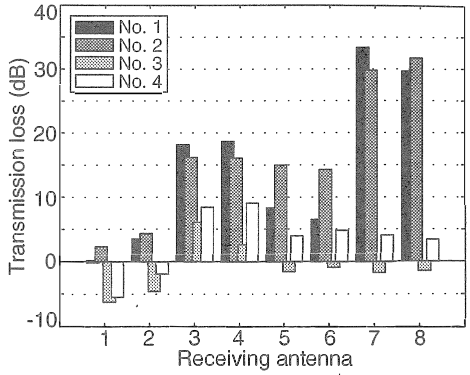


Fig. 3. Measured average transmission loss from 2.471 to 2.497 GHz at receiving positions 1 to 8 for four tested environments.

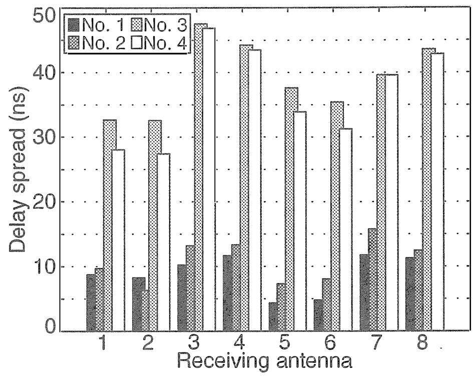


Fig. 4. Measured delay spreads at receiving positions 1 to 8 for four tested environments.

The transmission loss was about 18 dB at antennas 3 and 4 and about 30 dB at antennas 7 and 8 when we used absorbing walls (environments 1 and 2) because the reflections from the walls were small. Based on the transmission loss at antennas 1, 2, 3, 4, we estimated that the partitions had at least 15-dB attenuation characteristics. The difference between environments 1 and 2 was especially clear at positions of 5 and 6: the transmission loss was about 8 dB when a direct wave was received (environment 1) and about 15 dB when the antennas were in a shadowed region (environment 2).

When we used the metallic walls (environments 3 and 4), the transmission loss was greater near the center of the booth (antennas 3 to 6), and although antennas 7 and 8 were in shadowed regions, the transmission loss for these antennas was below 4 dB because the reflections from the metallic walls were strong. These results show that using partitions with absorbing boards effectively controls the transmission loss if the walls are made of low-reflection-coefficient materials, like absorbing walls, but the partitions were not effective when the reflections from the walls were strong.

DELAY SPREAD

The root mean-square (rms) delay spread is an important parameter [11] in evaluating wireless systems. The measured de-

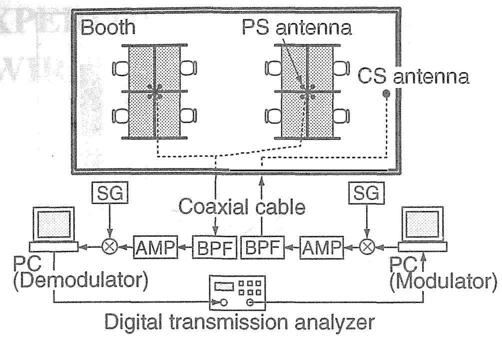


Fig. 5. BER characteristics measurement system.

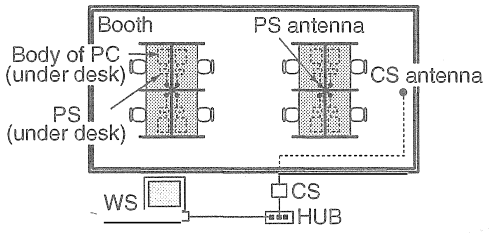


Fig. 6. Throughput characteristics measurement system. Throughput from WS to PCs was measured using a file transfer protocol.

lay spreads for our four environments are shown in Fig. 4. The horizontal axis shows the position of the PS antennas, and the vertical axis shows the delay spread.

The figure shows that the delay spread varied greatly with the wall material. The delay spread for environments 1 and 2 was less than about 15 ns at all receiving positions, while that for environments 3 and 4 was greater than 25 ns at all receiving positions. Moreover, the variation in delay spread between partition types was within several nanoseconds. Comparing the measured transmission loss with the delay spread when the walls were made of the same material (environments 1 and 2 or 3 and 4), when the transmission loss was large, the delay spread was large.

PERFORMANCE OF WIRELESS LAN

MEASUREMENT METHOD

To measure the BER characteristics, we used the setup shown in Fig. 5. A wireless system board, which used the direct sequence spread spectrum (DSSS) system, was installed in each personal computer to measure the BER because it is difficult to measure the BER of an actual wireless LAN. The operating frequency band was set at 2.471 to 2.497 GHz, the same as that specified in IEEE 802.11 for a wireless LAN [1]. All antennas were monopole antennas and were placed at the same positions as for the propagation characteristic measurements.

The setup we used to measure the throughput characteristics is shown in Fig. 6. We used an actual wireless LAN that used a DSSS system with a data rate of 2 Mbps. Each PS was connected to a PC by a twisted pair cable, and the PCs and PSs were placed under the desks. The workstation (WS) and CS of the LAN were connected to a hub by 10BASE-T cable. They were placed outside the booth. A CS antenna was connected to the CS by a coaxial cable, and a PS antenna was connected to each PS by a coaxial cable. Both types of antennas were monopole antennas and were placed at the same positions as for the BER characteristic measurements. The throughput was measured by using the file transfer protocol to transfer a 5-MB text file from the WS to four PCs through the CS and PSs.

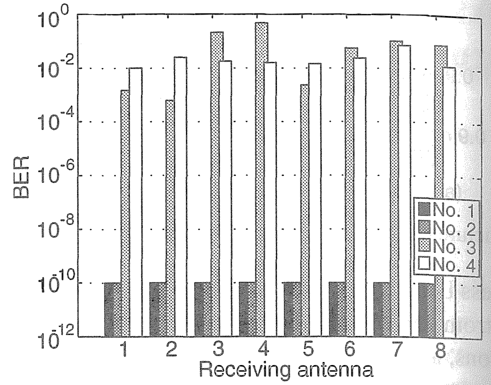


Fig. 7. Measured BER characteristics at receiving positions 1 to 8 for four tested environments.

BER CHARACTERISTICS

The measured BER characteristics at each receiving position for each environment are shown in Fig. 7. We found that the BER was greatly dependent on the wall material. When the walls were made of low-reflection-coefficient material (environments 1 and 2), the BER was below 10^{-10} at all positions. When the walls were made of high-reflection-coefficient material (environments 3 and 4), it was above 10^{-4} at all positions. In contrast, the BER was little dependent on the partitions. Comparing these results and the measured delay spreads, the BER was below 10^{-10} when the delay spread was below about 15 ns, and it was above 10^{-4} when the delay spread was above about 25 ns.

THROUGHPUT CHARACTERISTICS

The measured throughput characteristics are summarized in Table 1. The measurements were done when the wireless LAN system was used to communicate between the CS and four PSs (1 to 4 or 5 to 8), at the same time. The throughput for each PS was measured.

The measured throughput was normalized by the throughput measured when the CS was directly connected to a PS by coaxial cable. In this case, there was no interference and the throughput for each PS was 0.25. However, in this study, antennas 1, 2, 5, and 6 were in the coverage area, and the other antennas were not. Therefore, the best throughput was 0.5 at positions 1, 2, 5, and 6 and 0.0 at the other positions. The results shown in Table 1 were estimated based on the deviation from the best throughput at each position.

We measured the throughput when the received signal was

Table 1. Measured throughput characteristics evaluated by deviations from 0.5 for antennas 1, 2, 5, and 6 in the coverage area and from 0.0 for the other antennas.

Environment \ Antenna	1	2	3	4	5	6	7	8
1	○	○	○	○	○	○	○	○
2	◎	◎	◎	◎	◎	◎	◎	◎
3	×	×	◎	◎	×	△	◎	○
4	×	×	◎	◎	×	×	×	◎

◎ Deviation = 0
○ 0 < Deviation ≤ ±0.25
△ ±0.25 < Deviation < ±0.5
× Deviation ≥ 0.5

attenuated 10 dB because the electric field radiating from the wireless LAN was too strong to control the coverage in our measurement environments. As a result, the received-signal level at antenna 1 in environment 1, for example, was about -60 dBm.

As shown in Table 1, for environment 1, communication was achieved at all positions. The throughput at positions 1 and 2, where direct waves were received, was about 0.35. That at positions 3 and 4, where no direct wave was received, was about 0.15. Therefore, the regions where the throughput was high were marked by the partitions. From Fig. 3, there was a deviation of about 15 dB in the transmission loss between positions 1, 2 and 3, 4. In general, the received signal level for a 2.4-GHz-ISM-band wireless LAN should be -85 to -75 dBm [12]. Therefore, the received-signal levels at positions 3 and 4 were almost at the limit for wireless LANs, so the throughput was decreased. Furthermore, the throughputs for positions 5 to 8 in environment 1 were almost the same as those for positions 1 to 4.

The regions where the throughput was high in environment 2 were marked by the partitions more clearly than in environment 1 because the throughput at positions 1, 2, 5, and 6 in environment 2 was 0.5, while that at the other positions was 0.0. The reason for this is probably because the delay spreads at positions 1, 2, 5, and 6 were smaller than those at the other positions and strong reflected waves decreased because the partitions were taller than those in environment 1. Moreover, we found that it was possible to control the coverage at points there was no direct wave.

In contrast, there was no uniformity in the throughput for environments 3 and 4 (metallic walls). The throughput at one position was 1.0, and that at the other positions was 0.0 because the reflected waves were very strong and were transmitted for a long time. Moreover, the same result was achieved when the received signal was attenuated above 10 dB. These results show that it is difficult to support simultaneous communication in environments where the delay spread is above 25 ns and the BER is above 10^{-4}. In any case, it is difficult to control the coverage when the walls are made of high-reflection-coefficient materials.

CONCLUSIONS

A method for controlling the coverage so as to achieve sufficient performance of a wireless LAN system in selected regions by using partitions with absorbing boards was investigated for several indoor environments by using an electromagnetic environment evaluation booth. As the results, three requirements were identified:

(1) Low-reflection-coefficient material should be used for the walls, and the delay spread should be below 15 ns.
(2) The covered and uncovered regions should be separated by partitions with absorbing boards, and the electric field in the covered one should be at least 15 dB stronger than it the other.
(3) The received signal level in the uncovered regions should be below -75 dBm.

We plan to investigate how large the delay spread can be while still achieving coverage control and to create software tool for designing wireless LANs. We will also investigate coverage control in an actual large office.

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