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Title: Retransmission Probability and Throughput of SFH in Rayleigh Fading Indoor Channel of Multi-Cell Environment

Author:

Tomoaki Ishifuji

Central Research Laboratory, Hitachi, Ltd.
Tel :+81-423-23-1111
Fax:+81-423-27-7700
E-mail:ishifuji@crl.hitachi.co.jp

Abstract

The retransmission probability and throughput characteristics of Slow Frequency Hopping (SFH) in Rayleigh fading indoor channel of multi-cell environment is examined. Because signal strength in a Rayleigh fading indoor channel changes slowly[1], when retransmission unit length is shorter than the fading period, retransmission probability is little influenced by the retransmission unit length and error correction capability. With the 2.4GHz ISM band, QPSK can provide a throughput of nearly 1 Mbps when we use 4 cells, 100 frequency hops, a transmission power of 600 mW, and the transmission distance is 20 m.

1. Error Control Scheme

Figure 1 shows the structure of the error control block used in this analysis. Error control is accomplished in two steps, forward error correction, and stop-and-wait retransmission.

The error control scheme can be outlined as follows:

(a) A retransmission unit is composed of L blocks in which the error correction is achieved independently.
(b) An error correction block is composed of 2^k - 1 bits, with 2^k - 1 - kt information bits and kt correction bits that can correct t errored bits.
(c) More than one failure of error correction in L blocks caused a retransmission.
(d) The failure of error correction is found by CRCs in the information bits.

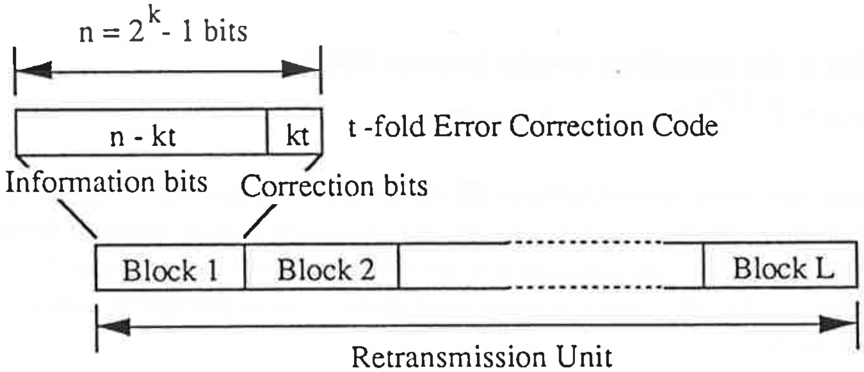

Fig. 1 Structure of Error Control Block

2. Retransmission Probability

In calculating the retransmission probability, the Rayleigh fading indoor channel and multi-cell environment is assumed. The frequency hopping patterns used satisfy the following conditions.

(a) In an m-cell environment, each cell employs a different hopping pattern.
(b) Because Reed-Solomon sequences are used as hopping patterns, a collision between two hopping patterns can occur at most in one frequency.

Because signal strength changes slowly in a Rayleigh fading indoor channel[1], we can assume that the signal strength is flat over a retransmission unit length when the fading period is longer than the retransmission unit length. In these calculations, we assume that collision of the hopping frequencies causes a BER of 0.5.

(1) Probability of the successful transmission with collision of the hopping frequencies.

$$P1 = (1 - (N - 1)^{m-1} / N^{m-1}) * (2^{-n} \sum_{k=0}^{t} nCk)^{L} \quad \text{(N: number of hopping in each cell)}$$

(2) Probability of the successful transmission without collision of the hopping frequencies.

$$P1 = (1 - (N - 1)^{m-1} / N^{m-1}) * \int_0^{\infty} \{\sum_{k=0}^{t} nCk\, p^{k}(1 - p)^{n-k}\}^{L} * (\mathrm{Exp}(-\Gamma / \Gamma o) / \Gamma o)\, d\Gamma$$

where

$p = 0.5 * \mathrm{Exp}(-\Gamma / \alpha)$、 Γ : Eb/No、 α : 1 (BPSK、 QPSK)、 2 (BFSK)、 Γo : Mean of Eb/No .

Hence, the retransmission probability P is

$$P = 1 - (P1 + P2)$$

3. Retransmission Probability Characteristics of Rayleigh Fading Channel

In a Rayleigh fading channel environment, the probability density function of the BER is described as follows:

$$f(p) = \alpha / \Gamma o * 2^{\alpha / \Gamma o} * p^{\alpha / \Gamma o}$$

Employing P = log p, the probability density function F(P) is

$$F(P) = \alpha / \Gamma o * 2^{\alpha / \Gamma o} * \exp\{(\alpha / \Gamma o) P\}$$

Figure 2 shows that when the mean Eb/No is 20 dB, probability density increases linearly with the log of BER. That is, that the probability density function is flat over a wide range of BER. This results in flat retransmission probability characteristics over a wide range of retransmission unit length.

From fig. 3, we can see that the retransmission probability is indeed almost independent of the retransmission unit length.

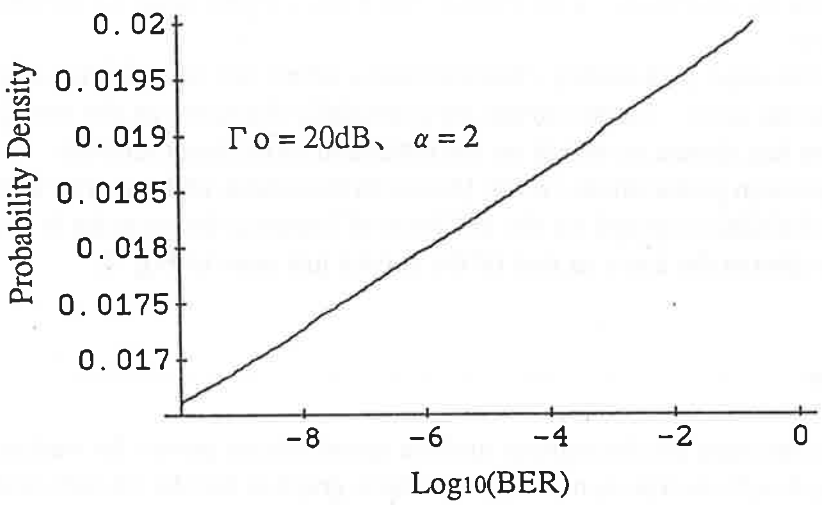

Fig. 2 Probability Density of BER in Rayleigh Fading Environment

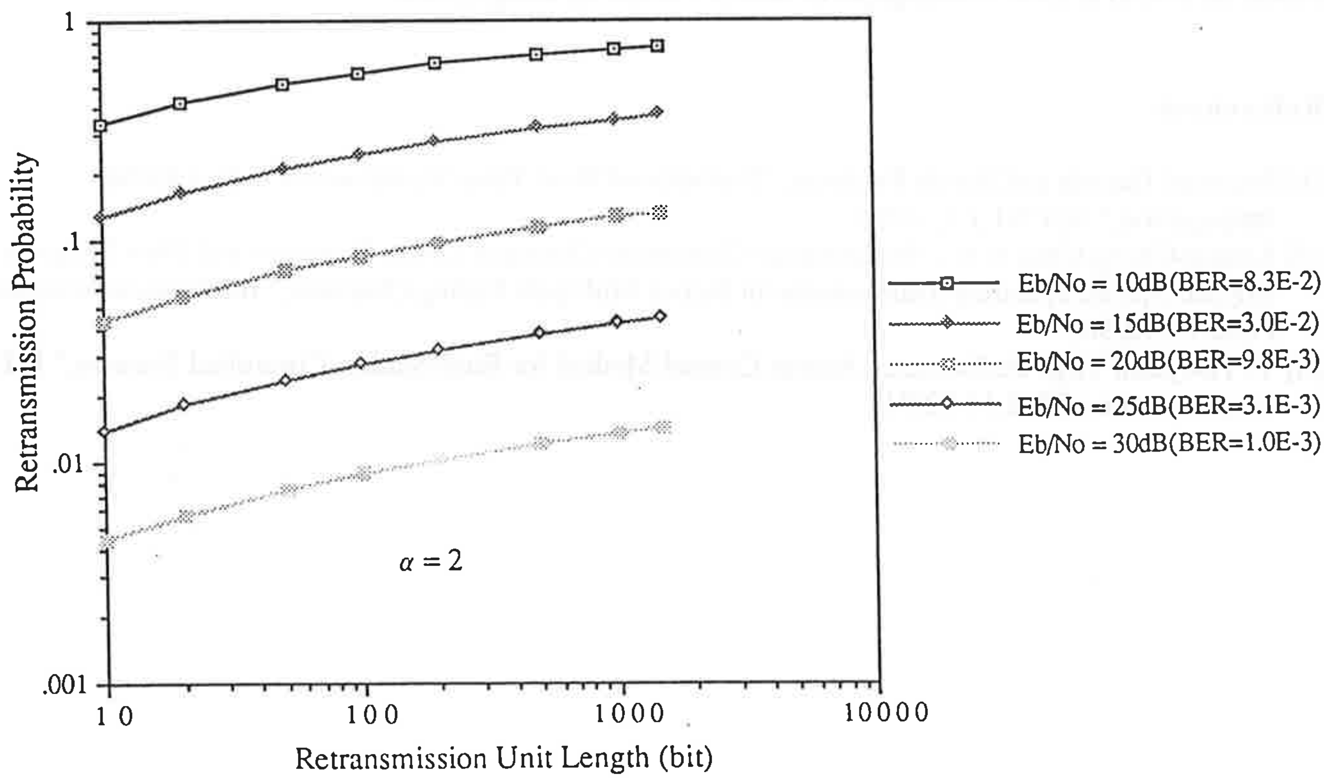

Fig. 3 Retransmission Unit Length vs. Retransmission Probability

4. Retransmission Probability Characteristics in Multi-Cell Environment

Figure 4 shows the relationship between retransmission probability and the number of hopping frequencies in the 4-cell environment. When Eb/No is greater than 25 dB, the retransmissions caused by collision of hopping frequencies are essential. This means that values higher than 25 dB cannot improve of the retransmission probability.

Figure 5 shows the retransmission probability characteristics when we use 127-bit error correction blocks with 2-fold error correction code. These curves are essentially the same as the ones just shown in Fig. 4. That is, error correction has almost no effect on the retransmission characteristics.

Figure 6 shows the retransmission probabilities in the 16-cell environment without error correction. We see that the retransmission probabilities caused by the collision of hopping frequencies is slightly higher, but the trend of these curves is almost the same as that of the curves just seen in Fig. 4.

5. Throughput Evaluation

Figure 7 shows the relation between the throughput and the transmission power for various numbers of hops. The top graph is for the 4-cell environment, and the bottom graph is for the 16-cell environment.

Both are for the 2.4GHz ISM band, and for BFSK. The transmission distance is 20 m, and the noise density is -143 dBm / Hz.

We can see here that in the 4-cell environment, a throughput of nearly 0.25 Mbps can be achieved when there are 100 frequency hops, and we use a transmission power of 600 mW.

And because, for a givin band width, we can get almost 4 times as higher data rate by using QPSK, we should be able to achieve a throughput of nearly 1 Mbps by using QPSK.

References

[1] Pajamani Ganesh and Kaveh Pahlavan, "Statistics of Short Time Variations of Indoor Radio Propagation," ICC'91,1.1, 1991.

[2] Kwang-Cheng Chen et al., "Performance Comparison Between Direct Sequence and Slow Frequency Hopped Spread Spectrum Transmission in Indoor Multipath Fading Channels," IEEE Documentation P802.11-92/80.

[3] Y. Takiyasu,"High Performance Access Control Method for Base-Station-Controlled Systems," IEEE Documentation P802.11-92/71.

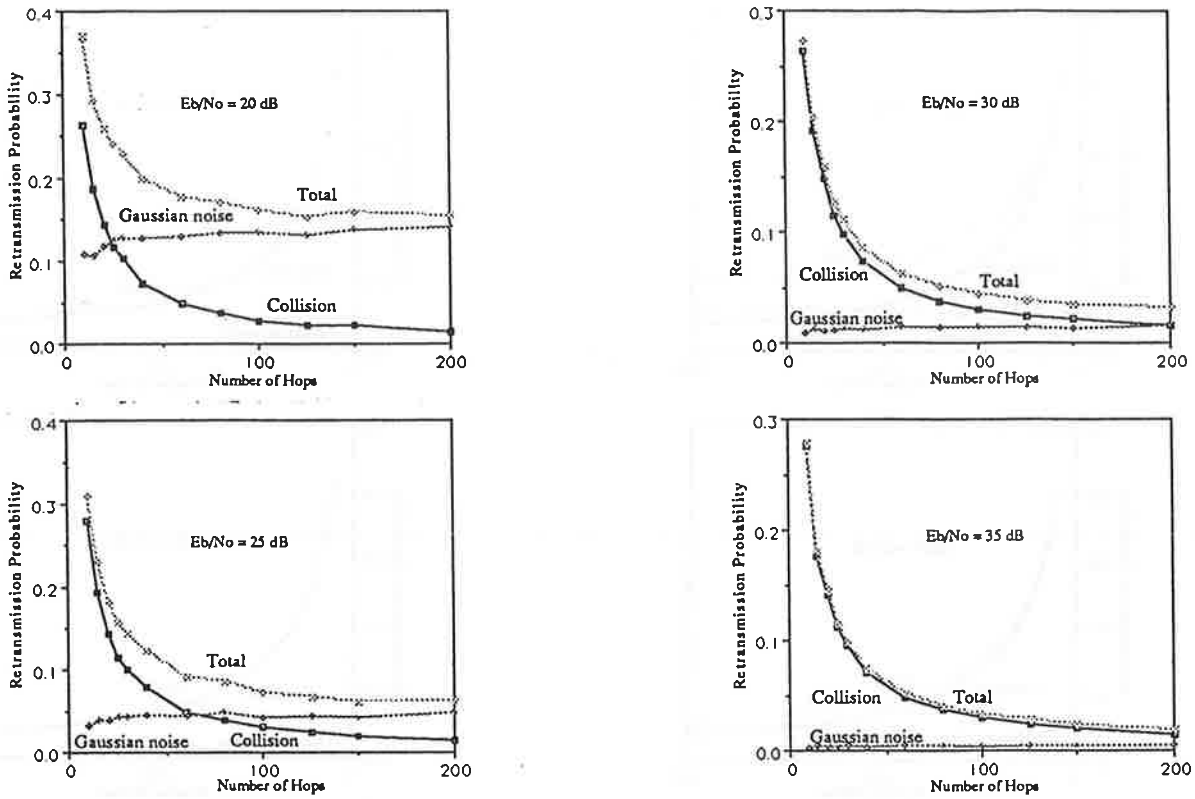

Fig. 4 Retransmission Probability vs. Number of Hops
(4-cell、No Error Correction、Retransmission Unit Length : 2048)

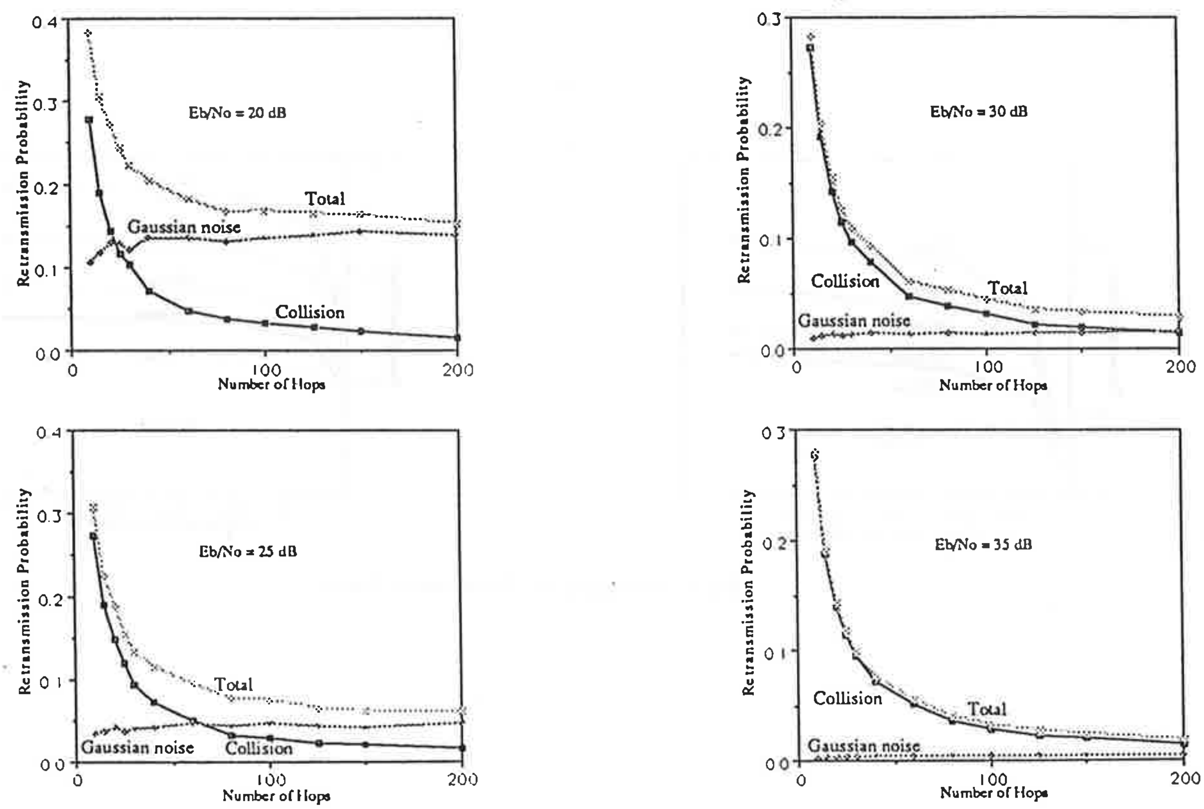

Fig. 5 Retransmission Probability vs. Number of Hops
(4-cell、With Error Correction、Retransmission Unit Length : 2048)

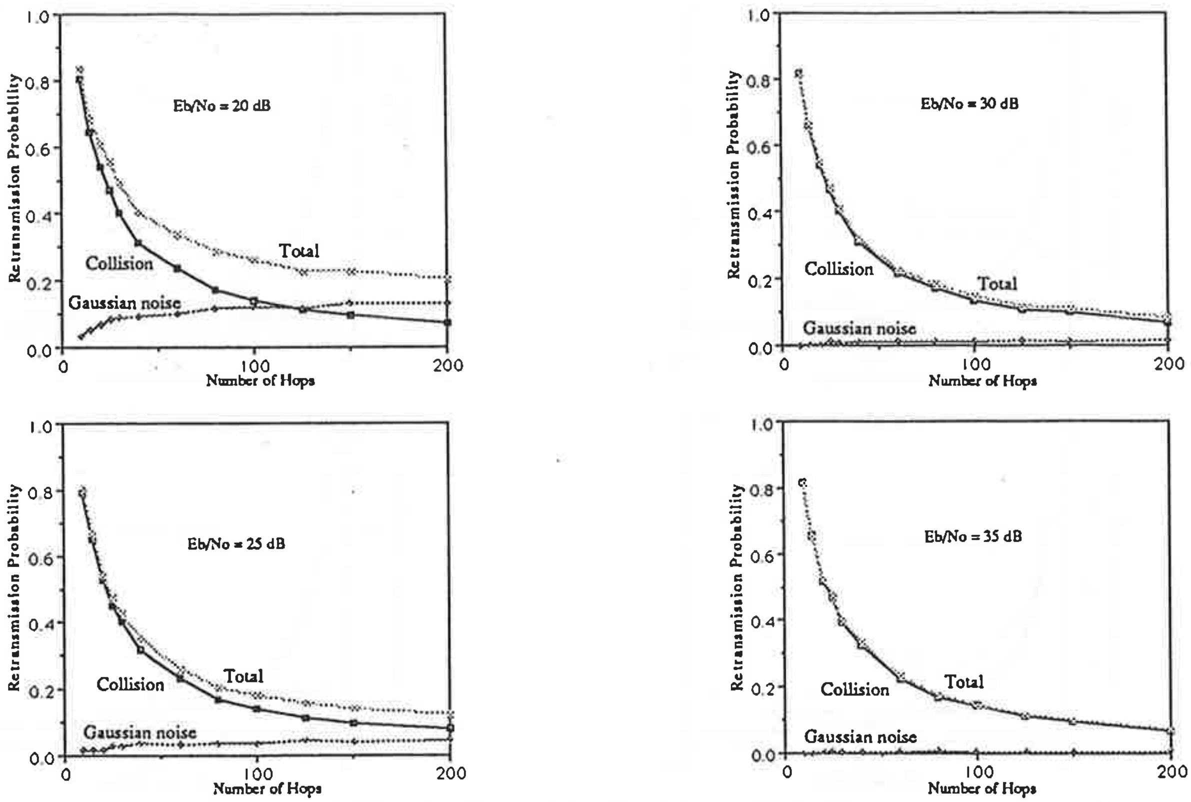

Fig. 6 Retransmission Probability vs. Number of Hops
(16-cell、 No Error Correction、 Retransmission Unit Length : 2048)

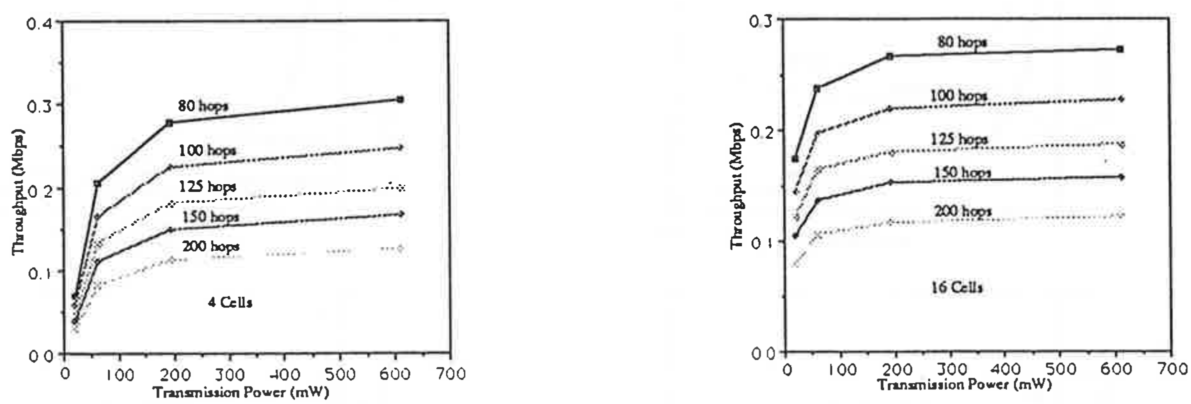

Fig. 7 Throughput vs. Transmission Power