A SIMPLE MULTIPATH DELAY ESTIMATION METHOD FOR DIGITAL MOBILE RADIO

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INTRODUCTION

In a multipath fading channel typically encountered in mobile/portable communications, the bit-error-rate (BER) gets severely degraded when multipath delay difference becomes large and comparable to a bit interval, resulting in frequency-selective fading. Thus, the measurement of multipath delay time is very important to estimate the transmission performance in a mobile or portable radio communication channel.

Thus far, special signals either a very sharp pulse [1] or a pseudo-random code sequence combined with a sliding correlator[2] are used to measure the multipath delay profiles. This normally requires very broad bandwidth and complicated measurement equipments.

On the other hand, it is well-known that an asymmetric transfer function causes cross-channel-interference (CCI) between in-phase and quadrature channels[3]. In a multipath fading channel, the arrival time delay difference among the signal components of a multipath signal gives rise to an asymmetric transfer function of the channel and thus becomes a cause of eye pattern closure due to CCI [4].

In the previous papers[5][6], we analyzed the relation between CCI and multipath delay difference by computer simulation and laboratory measurements. As a result, it was shown that the estimation of multipath delay difference was possible for BPSK, QPSK and an anti-multipath modulation technique double phase shift keying(DSK)[7], merely by measuring the CCI.

In this paper, we will report the results of field experiment made in Kyoto and show that the proposed method is useful even in an urban area where the multipath propagation model is far more complicated than a few-ray model assumed in laboratory measurements.

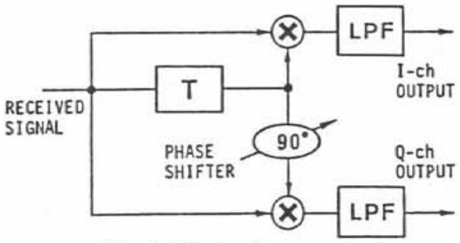

Fig.1 Block diagram of a differential detector

PRINCIPLE

Fig.1 shows a block diagram of a differential detector. If we assume that the upper part shows the in-phase channel (I-ch) detection output yielding eye pattern, then the lower part shows the quadrature channel (Q-ch) detection output and no signal appears for BPSK, for instance. However, as the multipath delay is increased from zero, the signal tends to appear even at Q-ch detector output [5]. The main idea of the proposed method is to estimate the multipath delay time from the output signal of this Q-ch detector.

The Q-ch detector output for a static two-ray model is calculated analytically. If we refer to the first coming wave as a D-wave and delayed signal, delayed by τ second, as a U-wave, then the output of Q-ch detector for a BPSK signal is divided into two regions as shown in Fig.2 and is given as follows:

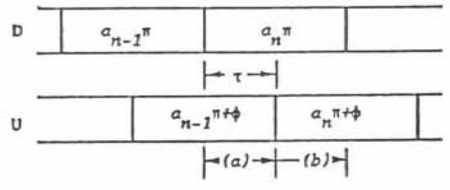

Fig.2 Carrier phase of a BPSK signal

$$
\begin{aligned}
&\text{(a)}\ \mathrm{Im}\{[\exp(ja_n\pi)+\rho\exp(j(a_{n-1}\pi+\phi))]\\
&\qquad[\exp(ja_{n-1}\pi)+\rho\exp(j(a_{n-2}\pi+\phi))]^*\}\\
&\qquad=2\rho\,|a_n-a_{n-2}|\sin\phi\\
&\text{(b)}\ \mathrm{Im}\{[\exp(ja_n\pi)+\rho\exp(j(a_n\pi+\phi))]\\
&\qquad[\exp(ja_{n-1}\pi)+\rho\exp(j(a_{n-1}\pi+\phi))]^*\}\\
&\qquad=0\ , \qquad\qquad\qquad\qquad (1)
\end{aligned}
$$

where Im: Imaginary part, *: complex conjugate, a_n: information symbol $\{0,1\}$, ϕ: phase difference between D and U-waves and ρ: the inverse of DU ratio. From eq.(1), we notice that as the multipath delay τ increases, the width of non-zero output region (a) is also increased proportionately.

Two practical measuring procedures of CCI quantity are given, i.e., measurement of the root-mean-square (rms) and measurement of the mean of the absolute value (simply referred to as MABS, hereafter) of the Q-ch detector output. The latter will be studied in detail in this paper, though no vivid difference is observed between two methods in practice. Assuming a quasi-static two-ray multipath model, where the signal strengths and multipath delay are fixed and carrier phase difference between two rays is assumed to be uniformly distributed, MABS of eq.(1) is given as follows

$$
\frac{1}{t_2-t_1}\int_{t_1}^{t_2}|V_Q(t)|\,dt=\frac{2}{\pi}\rho\frac{\tau}{T}\ . \quad (2)
$$

If this is divided by the average signal power, we have

$$
V_{Q,MABS}=\frac{2}{\pi}\,\frac{\rho}{1+\rho^2}\,\frac{\tau}{T}\ . \quad (3)
$$

On the other hand, multipath delay spread S defined by the next formula

$$
S\equiv\sqrt{\frac{\sum_k(\tau_k-D)^2P(\tau_k)}{\sum_k P(\tau_k)}} \quad (4)
$$

seems to be a good measure of the effective multipath delay difference, where D is the average delay time and $P(\tau_k)$ is the average power of the k-th multipath component signal. In a quasi-static two-ray multipath model, (4) becomes

$$
S\equiv\frac{\rho}{1+\rho^2}\,\frac{\tau}{T}\ . \quad (5)
$$

Comparing (3) and (5), we have

$$
S=\frac{\pi}{2}V_{Q,MABS}\ . \quad (6)
$$

That is, at least in a two-ray multipath model, the MABS of Q-ch detector output is a linear function of the multipath delay spread.

Fig.3 shows the theoretical and computer simulation results of the relation between delay spread and MABS of Q-ch detector output assuming a quasi-static two-ray model. From this figure, we observe that the simulation results agree well with the theoretical curve.

LABORATORY MEASUREMENTS

Laboratory measurements have been made to confirm the effectiveness of the proposed method assuming a Rayleigh-distributed a few-ray multipath model. Fig.4 summarizes laboratory measurement results of delay spread vs. MABS of Q-ch detector output, based on a few-ray multipath models with various power ratios and delay times among rays. The close correlation between MABS of Q-ch detector output and multipath delay spread was confirmed.

FIELD EXPERIMENTS

The field experiments have been performed in Kyoto city in 400 MHz band. The major specifications of the field test are given in Table 1.

Typical results measured on the street near Kyoto University and on Kitayama street, located in northern suburban area of Kyoto, are shown in Fig.5 and Fig.6, respectively. Fig.5(a) shows the variations of MABS of Q-ch detector output (solid line) over 10.4m intervals, together with the variations of delay spread (dotted lines). We calculated the multipath delay spread from multipath delay profiles measured on the same test courses based on the principle of sliding correlator of PN sequence[8]. From Fig.5(a), the variation of MABS of Q-ch detector output agrees with that of delay spread very well. Fig.7 shows multipath delay spread vs. MABS of Q-ch detector output of Fig.5(a), and good correlation is observed, while, in case of Fig.6(a), there seems to be no good correlation between two quantities. By analyzing the actual delay profiles[8], we found that on the course near Kyoto University, the maximum delay time is less then 6 μsec; while on Kitayama street, the delay times distribute up to 35 μsec. This delay time exceeds the effective range of the proposed method, i.e. a bit interval, and thus can not be reflected on Q-ch detector output correctly.

Next, we will examine the relation between Q-ch detector output and BER. Fig.5(b) and Fig.6(b) show the variations of average BER's. In both cases the variations of MABS of Q-ch detector output correspond to those of BER's, even in such places where MABS of Q-ch detector output has no good correlation with delay spread. Fig.8 shows BER vs. MABS of Q-ch detector output for these two courses. Although not strictly linearly proportional, BER is confirmed to get worse as the MABS of the Q-ch detector output increases. In addition, Fig.9 shows BER vs. delay spread of these two courses. By comparing Fig.8 with Fig.9, we observe that the MABS of the Q-ch detector output seems to give a better estimation of BER than multipath delay spread.

CONCLUDING REMARKS

Taking a BPSK signal as an example, the relationship between CCI or Q-ch detector output and a multipath delay spread was studied. Q-ch detector output was confirmed to be a good measure of a multipath delay spread even in an urban area where the multipath model is complicated. In addition , the variation of the Q-ch detector output corresponds to that of BER, and seems to give a better estimation of BER than multipath delay spread. This method may be extended to QPSK and DSK signals, as suggested in the previous papers[5][6]. Thus, Q-ch output may be used as a channel quality measure in a frequency-selective fading channel.

One direct application of this method is its application to branch-selection control for the diversity reception or its application to adaptive array antenna control in a multipath fading channel.

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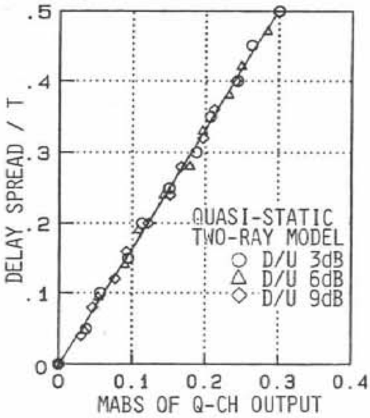

Fig.3 Delay spread vs. MABS of Q-ch output for a quasi-static two-ray model

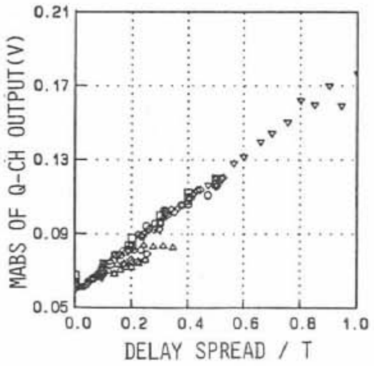

Fig.4 Laboratory measurement of delay spread vs. MABS of Q-ch detector output

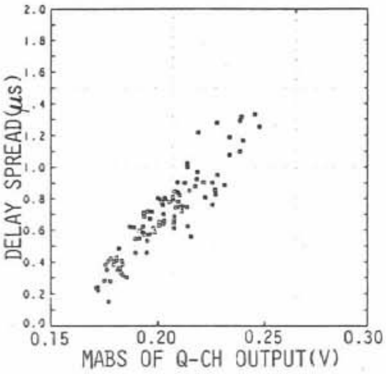

Fig.7 Delay spread vs. MABS of Q-ch detector output for streets near Kyoto Univ.

Table 1 Major specs of field test

frequency	442.5 MHz
bit-rate	128 kbps
Tx power	10 W
Tx antenna height	30m above ground
polarization	vertical
Rx site(van)	on the streets of Kyoto city
Rx antenna	λ/4 monopole antenna

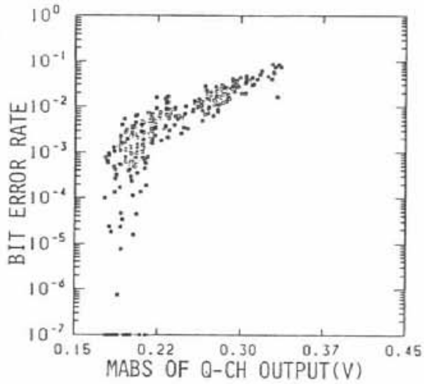

Fig.8 BER vs. MABS of Q-ch output

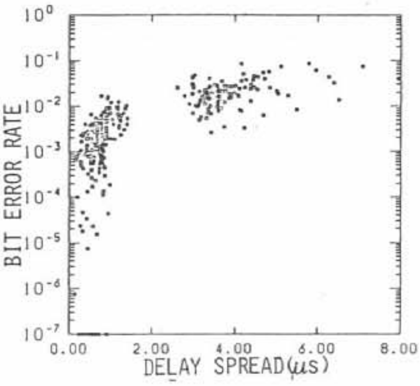

Fig.9 BER vs. delay spread

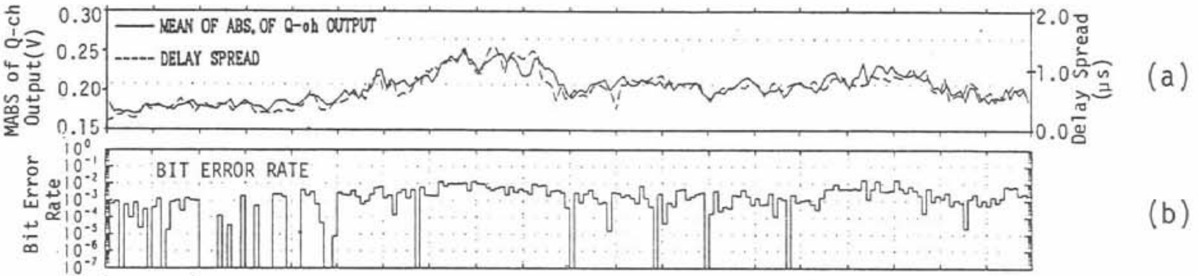

Fig.5 Field test results on the streets near Kyoto Univ.

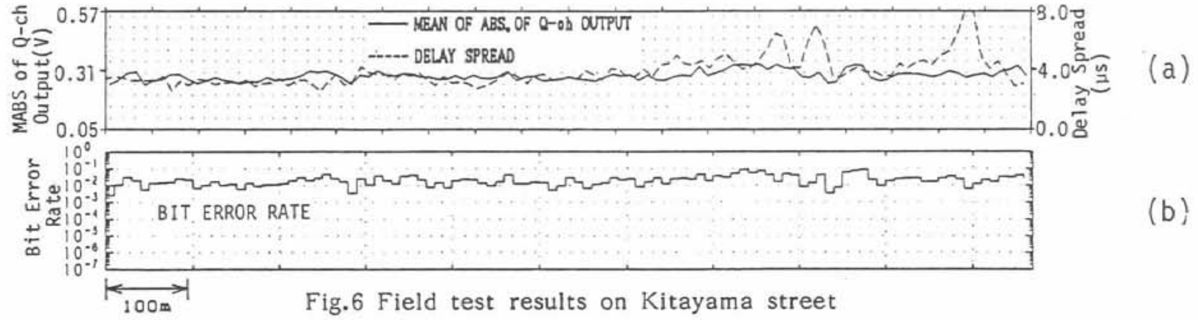

Fig.6 Field test results on Kitayama street