ON CHANNEL ESTIMATION FOR RAKE RECEIVER IN A MOBILE MULTIPATH FADING CHANNEL

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ABSTRACT

Multipath fading is one of the major practical concerns in wireless communications. Multipath problem always exists in mobile environment, especially for mobile unit which is often embedded in its surroundings. RAKE receiver has been used to reduce the multipath fading in a wide-band spread spectrum mobile system. However, the tap weights of the multipath channel model need to be estimated. In this paper, we proposed a least-square approach to tap weight estimation based on chip rate channel estimates in a realistic mobile environment. Simulations show that the new approach outperforms the existing approaches.

1. INTRODUCTION

Multipath fading is one of the major practical concerns in wireless communications. A multipath transmission takes place when a transmitted signal arrives at receiver by two or more paths of different delays. Such multiple paths may be due to atmospheric reflection or refraction, or reflections from buildings or other objects. In mobile environment, the source of multipaths normally attributes to the surroundings to the mobile unit. The different paths may consist of several discrete paths, or might consist of a continuum of paths [1] (see Figure 1). In a building-up area, there may not even be a line-of-sight path (direct path) from the vehicle-borne antenna to the base-station transmitter. Propagation is therefore mainly by way of scattering from the surface of the buildings and by diffraction over and/or around them.

In a multipath environment, the signals arrive from different directions each with a different attenuation and different time delay. They combine vectorially at receiver to give a resultant signal which fluctuates in its level. Without correction of such fading, multiple paths will generally cause severe degradation the quality of the mobile communications.

Multipath fading channel is usually modeled as a time-variant tapped delay line [4, 5]. Based on this model, a RAKE receiver can be used to detect the signal from the multipath fading channel. the tap weights were assumed known when deriving RAKE receiver, but in practice a correlator is used to estimate the tap weights.

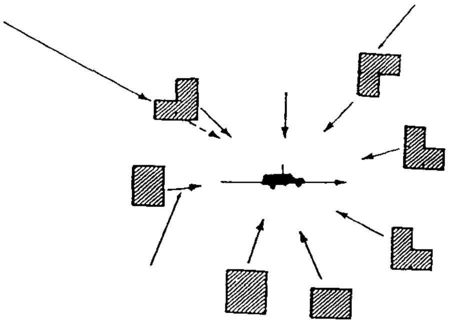

Figure 1: Typical Multipath Environment

The objective of the paper is to explore the possibility of using the advanced signal processing algorithms to estimate the multipath channels and to investigate the performance of the RAKE receiver based on chip rate channel estimates in a realistic mobile environment.

Contributions included in this paper are:

1. A general description of RAKE receiver based on chip rate channel estimate.
2. A new tap weight estimation approach for the multipath fading channel modeling using the signal processing algorithms.
3. The performance of the RAKE receiver in a realistic mobile multipath fading channel [2, 3].
4. Simulation results on bit-error-rate (BER) as a function of E_b/N_0 using BPSK modulation for the multipath fading channel.

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2. MULTIPATH CHANNEL MODEL

Multipath fading channel is usually modeled as a time-variant tapped delay line model [4, 5]. In a frequency-selective slowly fading situation, the tapped delay line model can be truncated at $L = [T_m W] + 1$ taps, where T_m is multipath time spread and W is the signal bandwidth. The signal arrived at receiver can be expressed as (see Figure 2)

$$r(t) = \sum_{n=1}^{L} c_n(t) u(t - \frac{n}{W}) + z(t) \qquad (1)$$

where z(t) is the additive noise, and $u(t)$ is the signal transmitted through the multipath fading channel. The time-variant tap weights $\{c_n(t)\}$ are zero-mean complex-valued stationary processes statistically independent to each other [5].

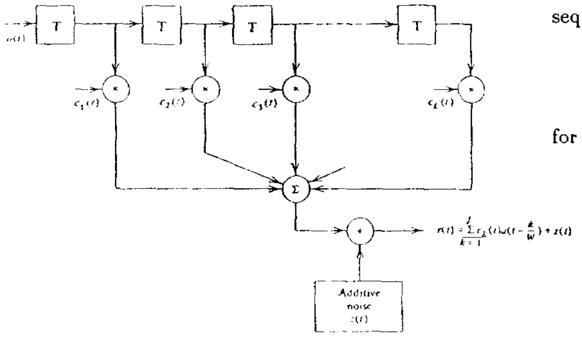

Figure 2: Tapped Delay Line Model for Multipath Fading

3. RAKE RECEIVER

Based on the tapped delay line model, a RAKE receiver (as in Figure 3) [5] can be used to detect the signal from the multipath fading channel. Let us consider binary signaling over the channel, we have two equal energy signals $u_1(t)$ and $u_2(t)$. The RAKE receiver, an optimum receiver, consists of two filters matched to $\sum_{n=1}^{L} c_n(t)u_1(t - \frac{n}{W})$ and $\sum_{n=1}^{L} c_n(t)u_2(t - \frac{n}{W})$, followed by samplers and a decision circuit that selects the signal corresponding to the largest output, or alternatively consists of a cross-correlator rather matched filters. The decision variables for the coherent detection of the binary signals are

$$U_m = \Re \int_0^T r(t) \left(\sum_{k=1}^{L} c_k^*(t) u_m^*(t - \frac{k}{W}) \right) dt \quad m = 1, 2 \qquad (2)$$

where $T = \frac{1}{W}$ is the chip period. If the transmitted signal is $u_1(t)$, then the received signal is

$$r(t) = \sum_{n=1}^{L} c_n(t) u_1(t - \frac{n}{W}) + z(t). \qquad (3)$$

Substitute (3) into (2) gives

$$U_m = \Re \left[\sum_{k=1}^{L} c_k^*(t) \sum_{n=1}^{L} c_n(t) \int_0^T u_1(t - \frac{n}{W}) u_m^*(t - \frac{k}{W}) dt \right] + \Re \left[\sum_{k=1}^{L} c_k^*(t) \int_0^T z(t) u_m^*(t - \frac{k}{W}) dt \right]. \qquad (4)$$

Since $u_1(t)$ and $u_2(t)$ are generated from pseudo-random sequences, which satisfy

$$\int_0^T u_1(t - \frac{n}{W}) u_m^*(t - \frac{k}{W}) dt = 0 \qquad (5)$$

for $n \neq k$, then (4) is simplified as

$$U_m = \Re \left[\sum_{k=1}^{L} |c_k|^2 \int_0^T u_1(t - \frac{k}{W}) u_m^*(t - \frac{k}{W}) dt \right] + \Re \left[\sum_{k=1}^{L} c_k^*(t) \int_0^T z(t) u_m^*(t - \frac{k}{W}) dt \right]. \qquad (6)$$

When the binary signals are antipodal, a single decision variable suffices

$$U_1 = 2\mathcal{E} \sum_{k=1}^{L} |c_k|^2 + \Re \left[\sum_{k=1}^{L} c_k^*(t) \int_0^T z(t) u_1^*(t - \frac{k}{W}) dt \right]. \qquad (7)$$

An alternative realization of RAKE receiver is shown in Figure 4.

4. PREVIOUS WORK

In the derivation of RAKE receiver [5], the channel tap weights are assumed known at receiver. However, to practically implement RAKE receiver, the tap weights $\{c_n(t)\}$ need to be estimated.

To estimate the tap weights, earlier work [5] employed a single correlator. Its output is fed to the input of the low-pass filter after information-bearing signal is removed. To accomplish this, a delay of one signaling

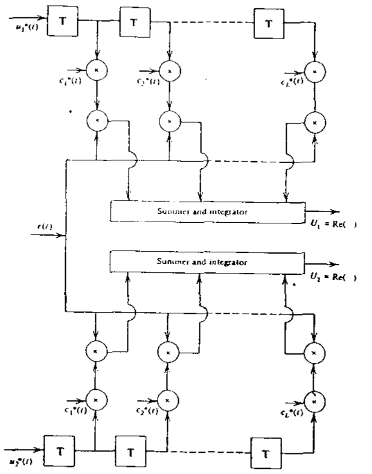

Figure 3: RAKE Receiver

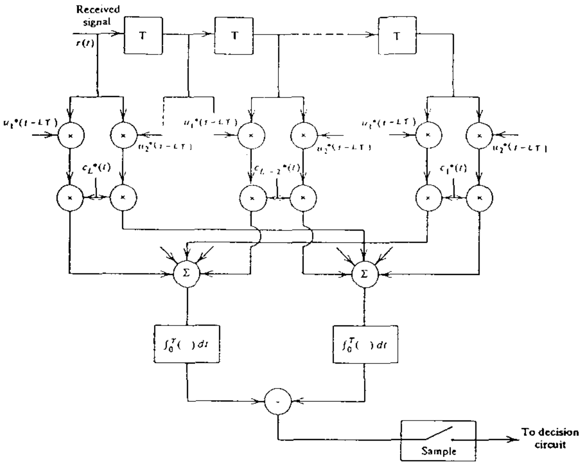

Figure 4: Alternative RAKE Receiver

interval is introduced into the channel estimation procedure, as illustrated in Figure 5. That is, first the receiver must decide whether the information in the received signal is +1 or −1 and, then, it uses the decision to remove the information from the correlator output prior to feeding it to the low-pass filter.

5. NEW APPROACH

We now propose the new tap weight estimation method for the RAKE receiver based on chip rate channel estimates in a realistic mobile environment. The wide-band spread spectrum technique can be used to provides effective diversity gain to improve system performance. In such a spread spectrum mobile communication system, when user information is transmitted through the *traffic* channel, there is always a companion *pilot* channel used as reference signal for channel estimation.

The binary phase shifted signal (BPSK) $m(t)$ with a given fundamental frequency ω_0, is added, modulo 2, by a binary sequence $b(t)$ from a pseudonoise (PN) code generator with much higher chip rate frequency. The sum $u(t)$ can then be used to modulate a carrier.

For simplicity, we let the reference signal $v(t)$ in pilot channel to be constant 1 or −1 throughout, which also added, modulo 2, by the same PN sequence.

Without loss of generality, only the base-band modulation or demodulation is considered in this paper.

Upon receiving the signals at receiver end, the pilot channel signal, which could be separated from the traffic channel signal through some well-known techniques, is used to estimate the tap weights. The estimated tap weights are used for RAKE receiver to recover the multipath fading signal in the traffic channel.

Using (1), the received pilot channel signal after multipath fading is

$$s(t) = \sum_{n=1}^{L} c_n(t)v(t-\frac{n}{W}) + z(t) \qquad (8)$$

where for each symbol $t = 1, \cdots, N$. Notice that c_n is a constant within a symbol period $c_n(1) = c_n(N) = c_n$. In vector notation, (8) is

$$\begin{pmatrix} s(1) \\ \vdots \\ s(N) \end{pmatrix} = \begin{pmatrix} v(1-\frac{1}{W}) & \cdots & v(1-\frac{L}{W}) \\ \vdots & \ddots & \vdots \\ v(N-\frac{1}{W}) & \cdots & v(N-\frac{L}{W}) \end{pmatrix} \times \begin{pmatrix} c_1 \\ \vdots \\ c_N \end{pmatrix} + \begin{pmatrix} z(1) \\ \vdots \\ z(N) \end{pmatrix} \qquad (9)$$

or equivalently

$$\mathbf{s} = \mathbf{V}\mathbf{c} + \mathbf{z}. \qquad (10)$$

We can now easily see that

$$\hat{\mathbf{c}} = \mathbf{V}^{\dagger}\mathbf{s} \qquad (11)$$

gives $\{c_n\}$ a least-square error (LSE) estimate at a given symbol time. In (11), the left pseudo-inverse † is defined as

$$\mathbf{V}^{\dagger} = (\mathbf{V}^T\mathbf{V})^{-1}\mathbf{V}^T \qquad (12)$$

$\hat{c}_n$ can now be used in RAKE receiver as in Figure 4. The estimation error covariance can be found as

$$E_z[(\hat{c}-c)(\hat{c}-c)^T] = \sigma_z^2(\mathbf{V}^T\mathbf{V})^{-1} \qquad (13)$$

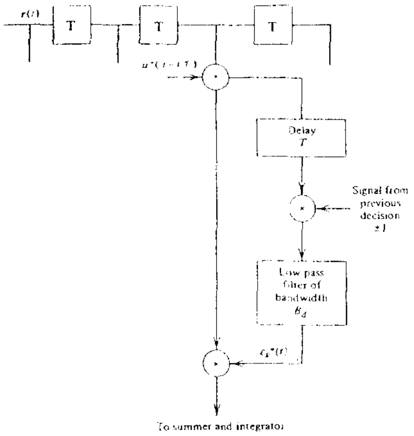

Figure 5: Tap Weight Estimation

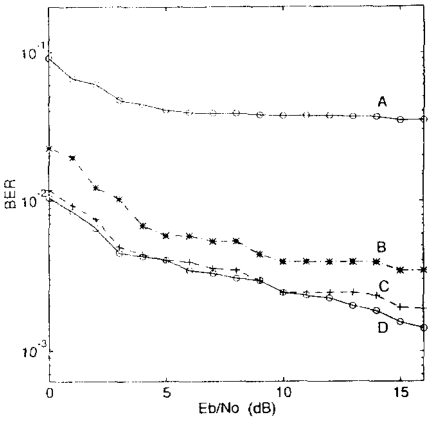

Figure 6: Performance of BER verse E_b/N_0

6. PERFORMANCE COMPARISON

In our computer simulations, we choose three paths with delays $\tau = 1, 7, 20$ (T), respectively. The ratio of amplitude attenuation of the second path over that of first path is −3dB, and of third path over the second path is −6dB. The fundamental frequency of the binary message signal $m(t)$ is chosen to be 19.2 KHz, and the fundamental frequency of PN code sequence $b(t)$ is 64×19.2 KHz = 1.2288 MHz.

We simulate the new approach in two different scenarios: (i) the pilot channel has the same energy-per-bit-over-noise-density E_b/N_0 as the traffic channel, and (ii) the pilot channel has a constant E_b/N_0 of 20 dB.

The Bit-Error-Rate (BER) verse E_b/N_0 of the RAKE receiver is used to measure the performance, as shown in Figure 6. RAKE receiver using LSE tap weight estimates is plotted in line B for scenario (i) and line C for scenario (ii) in Figure 6. Figure 6 also has the BER verse E_b/N_0 of the RAKE receiver using the tap weight estimation shown in Figure 6 in line A. Clearly, LSE approach proposed in this paper outperform the previous approach. BER verse E_b/N_0 for receiver with exact channel tap weights is also shown in line D. We can see that performance measured in BER of the RAKE receiver using LSE tap weights is very closed to that using exact weights.

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