STONY BROOK UNIVERSITY

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Application of Particle Filtering to RAKE Receiver

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Abstract

In this report, RAKE receiver is probed to derive *dynamic state equation* so that we can apply Particle Filtering on RAKE receiver to demodulate signal.

It will turn out that the same dynamic state model will be derived as in Space Diversity Receiver(multiple antennas) model[1] even though different channel fading model has been applied to each model. In RAKE receiver, we always assume that the fading channel model is *Frequency selective.* But in Punskaya[1], just plain *flat fading* channel model is assumed.

This result might have been expected before concluded because in classical way of detecting signal, the performance of RAKE receiver is same as in Space Diversity receiver(multiple antennas) too[2].

Contents

0.1 What Is *RAKE* Receiver?

A RAKE receiver does this-
It attempts to collect the time-shifted versions of the original signal by providing a separate correlation receiver for each of the multipath signals. Each correlation receiver is adjusted in time delay, so that a microprocessor controller can cause different correlation receivers to search in different time windows for significant multipaths. The range of time delays that a particular correlator can search is called a search window[3]. The RAKE receiver estimates channel and captures the delays of each paths making use of searcher in current CDMA system. In view of current method of demodulating, the searcher synchronizes mobile radio's internal PN generators to the received *pilot* channel, a process known as *pilot acquisition*. The RAKE receiver then uses this phase reference for coherent detection of received data. To recover the transmitted data, the digital demodulator typically decodes the received symbols using Viterbi algorithm[4].

RAKE receiver is an extension of the matched correlator receiver. The signals are identified by the searcher algorithm and are specified by relative offsets in the short PN sequence[**?**]. Fig1 shows the structure of typical,traditional RAKE receiver.

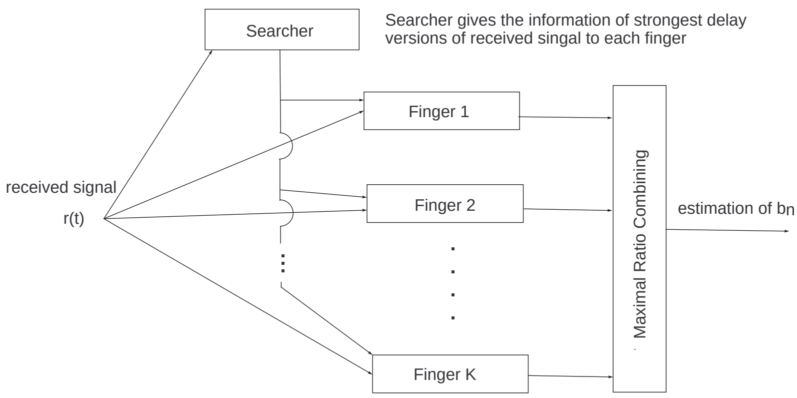

Figure 1: Structure of a RAKE receiver.

0.2 Fading Channel

0.2.1 Linear Time Variant Channel Impulse Response

Let us define transmitted signal as $s(t)$ in time domain, $s(t)$is pseudo-random sequences. We assume that there are multiple propagation paths. Each path has a propagation delay and an attenuation factor. Both propagation delays and attenuation factors are time-variant as a result of changes in the structure of the medium. When we define impulse response of multipath fading channel as $c(\tau;t)$ and we assume that $c(\tau;t)$ is wide-sense-stationary. Then we can define some correlation function as Table 1. $c(\tau;t)$ can be explained as the response of the channel at time t due to an impulse applied at time t-τ. Then, the output which impulse input $s(t)$ will be[2]

$$y(t) = \int_{-\infty}^{\infty} c(\tau;t)s(t-\tau)d\tau \tag{1}$$

This is impulse response of *Linear Time Variant* system[5].

Or in terms of the frequency functions $C(f;t)$and $S(f)$,

$$y(t) = \int_{-\infty}^{\infty} C(f;t)S(f)e^{j2\pi ft}df \tag{2}$$

0.2.2 Band Width

The channel bandwidth, B required to pass M-ary PSK signals(more precisely, the main spectral lobe of M-ary PSK signals) is given by[6]

$$B = \frac{2}{T} = \frac{2}{T_b log_2 M} = \frac{2R_b}{log_2 M} \tag{3}$$

For M-ary FSK,

$$B = \frac{M}{2T} = \frac{M}{2T_b log_2 M} = \frac{R_b M}{2log_2 M} \tag{4}$$

where T is symbol duration, T_b is bit duration, $log_2 M$ is bits/symbol and R_b=$1/T_b$ is bit rate

So, we can say that B is proportional to $1/T$, especially when $M = 2$.

Table 1:

$c(\tau,t) \xrightarrow{A.C.,t} \phi_c(\tau;\Delta t) - (1) \xrightarrow{F.T.,(\tau,\Delta f)} \phi_C(\Delta f;\Delta t) - (2)$
$\phi_C(\Delta f;\Delta t) \xrightarrow{F.T.,(\Delta t,\lambda)} S_C(\Delta f;\lambda) \xrightarrow{set \Delta f=0} S_C(\lambda) - (3)$
$\phi_c(\tau;\Delta t) - (1) \xrightarrow{F.T.,(\Delta t,\lambda)} S(\tau;\lambda)$
$S_C(\Delta f;\lambda) \xrightarrow{F.T.,(\Delta f,\tau)} S(\tau;\lambda)$
$\phi_C(\Delta f;\Delta t) \xrightarrow{F.T.,(\Delta f,\tau),(\Delta t,\lambda)} S(\tau;\lambda)$
$S(\tau;\lambda)$; Scattering Function Of The Channel
$\phi_c(\tau) = \phi_c(\tau;\Delta t)\|_{\Delta t=0}$; Multipath Intensity Profile
From $(1)\|_{\Delta t=0}$, T_m ; Multipath Spread or Time Spread, the range of values of τ over which $\phi_c(\tau)$ is essentially nonzero
From $\|(2)\|\|_{\Delta t=0}$, $(\Delta f)_c$; Coherence Bandwidth Of The Channel ($\simeq \frac{1}{T_m}$),the range over which value is essentially nonzero
From $\|(2)\|\|_{\Delta f=0}$, $(\Delta t)_c$; Coherence Time Of The Channel($\simeq \frac{1}{B_d}$), the range over which value is essentially nonzero
From (3), B_d ; Doppler Spread, the range over which value is essentially nonzero

where A.C.; Auto Correlation F.T. ; Fourier Transform

0.2.3 Frequency Selective/Non-selective Fading

Fading is distortion of received signal in either destructive or constructive way. It is caused by *moving* transmitter or *multipaths* of the received signal depends on the channel property characterized by channel impulse response. And there are two kinds of fading in terms of in time domain or frequency domain.

When W(Band Width of the transmitted signal)$\ll (\Delta f)_c$(refer to table 1), it is called *frequency non-selective* fading and also called *flat fading.* In that situation, all of the frequency components in transmitted signal undergo the same attenuation and phase shift in transmission through the channel. All frequency components of a received signal vary in the same proportion simultaneously. Under the condition of *frequency non-selective* channel, we can set $f = 0$ in transfer function of channel, $C(f;t)$.

On the other hand, when $W \gg (\Delta f)_c$, it is called *frequency selective* fading. Under this condition, every frequency components in transmitted signal undergoes different channel distortion. And we use $C(f;t)$ as the transfer function of the channel that has two variables.

In the case of *frequency selective*, we can make use of *frequency diversity* which result in RAKE receiver. In *flat fading* situation, we may not able to make use of *frequency diversity* to estimate or detect our desired signal.

0.2.4 Fast/Slow Fading

When T(symbol period)$\ll (\Delta t)_c$, the channel response is essentially fixed at least for the duration of *one signaling* interval(T). In this case, the happening fading will be called *slow fading* and the channel transfer function,$C(f,t)$ does not depends on t any more every signaling interval. Otherwise, the channel character change so fast and even during one signaling interval, channel response change so fast and the problem will be harder to track.

In our RAKE receiver model, we assume that *frequency selective and slow fading channel* as usual literature.

0.3 Tapped Delay Line Channel Model

In our model, *direct sequence spread spectrum* signal is used as usual literature where RAKE receiver is applied. *Linear time variant* fading channel can be modeled by *Tapped Delay Line model* as Fig2. where $c_l(t)$ is defined as

$$c_l(t) = \frac{1}{W}c(\frac{l}{W};t) \quad , \; l \in \{1, 2, ..., L\}, \; L \; is \; number \; of \; paths. \tag{5}$$

where W is band width of spreading sequence signal $s(t)$ or $\{b(t)s(t)\}$, $b(t)$

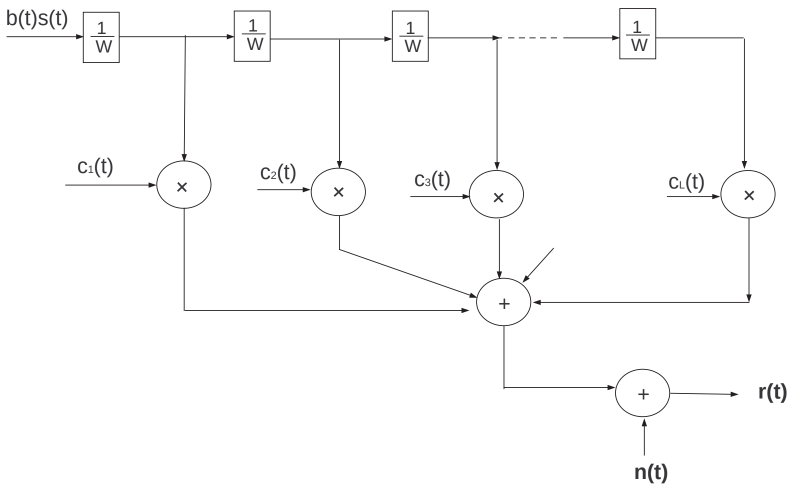

Figure 2: Received signal,$r(t)$ through frequency-selective channel.

and $s(t)$ is defined in Fig3. $b(t)$ is data signal and $s(t)$ is spreading signal. Utilizing *sampling theorem* and equation (2), we will have received signal with additive noise $n(t)$

$$r(t) = \sum_{l=-\infty}^{\infty} c_l(t)b(t - \frac{l}{W})s(t - \frac{l}{W}) + n(t) \tag{6}$$

as in Fig2. According to this result, we achieve the resolution of $1/W$ in *multi path profile*, $\phi_c(\tau)$. We just need $L = \lfloor T_m W \rfloor + 1$ paths(taps) because any path which arrives later than T_m does not affect received signal. Then the received signal will be

$$r(t) = \sum_{l=1}^{L} c_l(t)b(t - \frac{l}{W})s(t - \frac{l}{W}) + n(t) \tag{7}$$

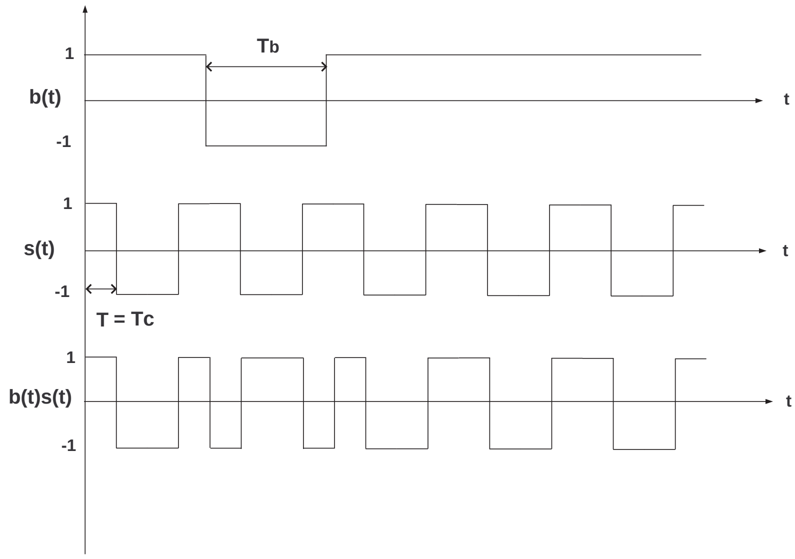

Figure 3: BPSK direct-sequence spreading.

0.4 Estimating Data Bits Using Particle Filtering

A reference to this section is section 0.1 on page 2. RAKE receiver uses *matched filter* or *replica correlators* to detect or estimate the data signal in traditional way. But in this report, we are trying to recover the data bit using *Particle filtering*[7] method so that we can improve the performance of the current RAKE receiver.

0.4.1 Deriving Dynamic State Equation

In order to apply *particle filtering*, we need to find dynamic state equation from received signal through *frequency selective* fading channel. From equation(7), we have the received signal $r(t)$. To make it discrete time, we have to sample the received signal. At every sampling moment, extract paths as many as the number of fingers(K) making use of searcher finding delay of each path. So we know delays of each path of finger at every sampling moment. As the first step, we have $y_l(t) = r(t)s(t - l/W)$ after correlating spreading signal $s(t)$ once we know the delay of each extracted path signal, where $l \in \{1, 2, ..., L\}$. Integrating correlated signal $y_l(t)$ with the limits from $t = l/W$ to $t = l/W + T_b$, where T_b is the interval of data bit, we will have

$$\int_{t+l/W}^{t+l/W+T_b} y_l(\tau) d\tau =$$

$$\int_{t+l/W}^{t+l/W+T_b} c_l(\tau) b(\tau - l/W) d\tau + \int_{t+l/W}^{t+l/W+T_b} n(\tau) s(\tau - l/W) d\tau \qquad (8)$$

If we suppose as in [8]

$$\int_{0}^{T_b} s(\tau - n/W) s(\tau - k/W) d\tau \simeq 0, k \neq n \qquad (9)$$

then equation (8) will be

$$c_{ln} b[n] + \int n(\tau) s(\tau - l/W) d\tau, \;\; n \triangleq nT_b = t, \;\; n = 0, 1, 2, 3, ... \qquad (10)$$

where we suppose $c_l(t) \simeq c_{ln}$ so that constant for any one signaling interval and $b(t - l/W)$ is also constant for any one signaling interval as either 1 or -1.

$$\therefore y_l[n] = c_{ln} b[n] + \int_{t+l/W}^{t+l/W+T_b} n(\tau) s(\tau - l/W) d\tau \qquad (11)$$

Second term of equation (11) is Gaussian random variable[9].

$$\therefore y_l[n] = c_{ln} b[n] + \eta_l[n] \quad l \in \{1, 2, 3, ..., L\} \qquad (12)$$

,where $\eta_l[n] \triangleq \int_{t+l/W}^{t+l/W+T_b} n(\tau) s(\tau - l/W) d\tau$, n: current time

0.5 Conclusion

Equation (12) is the observation dynamic state equation of our received signal in discrete time model. There are K of fingers and at any time sequence n, we have K independent observations with K independent channel paths and additive noises. It was assumed that the channel is *frequency-selective* and *slow* fading channel. Basically we are taking advantage of *frequency diversity* in this model. On the other hand, if we use space diversity with K

antennas spaced sufficiently far apart to ensure different propagation paths of the transmitted signal through *flat(frequency-non-selective)* fading channel, we will have exact same dynamic space state equation as in [1]. Therefore we will get the same result and performance when we apply *particle filtering* to RAKE receiver as in space diversity with many antennas. In conclusion, we can improve the performance of RAKE receiver applying *particle filtering*.

Bibliography

[1] E. Punskaya, C. Andrieu, and A.Doucet, “Particle filtering for optimal detection in fading channels,” Tech. Rep. TR.384, CUED(Cambridge University Engineering Department), 2000.

[2] John Proakis, *Digital Communications*, McGraw-Hill, 4th edition, 2000.

[3] Theodore S. Rappaport, *Wireless Communications*, Prentice Hall, 2nd edition, 2002.

[4] John B. Groe; Lawrence E.Larson, *CDMA Mobile Radio Design*, chapter 5, p. 100, Artech House, 2000.

[5] Matthias Pátzold, *Mobile Fading Channles*, John Wiley & Sons, 1st edition, Feb 2002.

[6] Simon Haykin, *Communication Systems*, Wiley, 1994.

[7] Arnaud Doucet, Nando de Freitas, and Neil Gordon, *Sequential Monte Carlo Methods in Practice*, Springer, 2001.

[8] John G. Proakis, *Digital Communications*, chapter 14, p. 844, McGraw-Hill, 4th edition, 2000.

[9] Sergio Verdú, *Multiuser Detection*, pp. 93,105,57, Cambridge University press, 2001.