An Efficient Rake Receiver Design for WCDMA System

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Abstract: In wideband code division multiple access system, Rake receiver is gernerally applied as its equalization algorithm. The equalizaer is the most critical part in terms of the computational complexity of the receiver. Hence more efficient receiver implementin is needed to save power consumption and reduce the computational complexity. In this paper, channel capacity and optimal energy allocation algorithm is applied to reduce the complexity of Rake receiver. We choose effective Rake fingers among multi-path components. Then we reallocate weight factors and combine effective Rake fingers. Applying proposed algorithm, we obtain advantage up to 2dB of performance at 0.1% of bit error rate. With about 0.57% additional computational complexity, we can find the optimal number of Rake fingers and reduce computations of unused Rake fingers.

1. Introduction

In wireless communication, there is inter-symbol interference (ISI) caused by multi-path fading channel and Doppler effect due to the speed of mobile, which makes distortion of transmitted signal. To reconstruct the data, most receivers have equalizer.

WCDMA system use Rake receiver as estimator and equalizer. In the paper, we propose selective channel algorithm. We compared performance and computations between proposed algorithm and conventional receivers. Using channel information, receiver choose effective multi-path component and determine optimal number of rake fingers to reduce computational complexity and save power consumption.

2. Rake Receiver

2.1 Rx signal model in WCDMA system

In WCDMA system, transmit signal $u(t)$ is given by

$$u(t) = \sum_{k=0}^{K-1} a_k \sum_{n=0}^{N-1} p_k(n) f(t - nT = knT)$$

In above equation, a_k is modulated symbols, p_k is complex channel coefficient of each multi-path tap, N is spreading factor of OVSF code, p_k is channelization (OVSF) code.

Received signal through channel is given by

$$y(t) = \sum_{j=0}^{J-1} h_j u(t - d_j) + n(t)$$

$y(t)$ is received signal, h_j is complex number channel coefficient at j-th tap delay. [6] $u(t)$ is transmitted signal, n is white Gaussian noise. Jake's model is applied to consider Doppler effect.

2.2. Rake receiver algorithm

Rake receiver is used while estimation and equalization process in WCDMA downlink system. Rake receiver use correlation property of scramble code. Scramble code, which is called gold code, has good auto correlation property. Receiver uses this property as a matched filter to detect correct frame and separate multi-path component. [5]
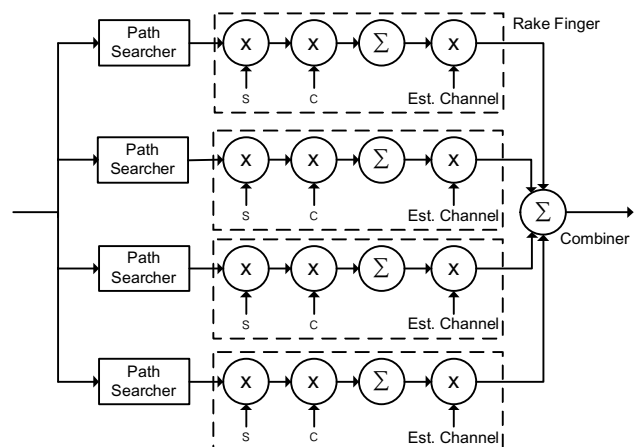

Figure 1. Convential Rake receiver structure

In WCDMA downlink system, receiver can estimate channel impulse response using common control channel (CPICH). CPICH is filled with ones for all data bits. Spreading factor is 256 and channelization code is zero. All user equipments in the same cell received same frame and use CPICH as pilot symbol sequence to estimate channel information. In this case, we can use whole frame symbols to get better channel estimation value. [2]

Maximum likelihood (ML) algorithm is applied for channel estimation and zero forcing (ZF) algorithm for equalization.

3. Proposed Finger Selection Algorithm

3.1. Optimal energy allocation

We assume single input single output (SISO) system that the number of transmit antenna is M_T, number of receive antenna is M_R. H is estimated channel. The channel capacity is

$$C = \log_2 \det\left(I_{MR} + \frac{E_S}{M_T N_0} HH^H \right)$$

In MIMO system, the channel capacity is the sum of SISO channel capacities. When the sum of r SISO channels is

$$C = \sum_{i=1}^{r} \log_2\left(I + \frac{E_S \gamma_i}{M_T N_0} \lambda_i \right), \ \lambda_i = HH^H$$

Using Lagrangian method, optimal energy allocation policy is

$$\gamma_i^{opt} = \left(\mu - \frac{M_T N_0}{E_S \gamma_i} \right)_+, \ \sum_{i=1}^{r} \gamma_i^{opt} = M_T$$

With above equations, we can calculate optimal energy for each multi-path.[1]

3.2. Proposed algorithm

Proposed receiver structure selects effective Rake fingers using channel capacity of each multi-paths using above optimal energy allocation policy. After selecting effective Rake fingers, reallocate weighted energy for each Rake fingers, combine finger components which considering channel information. [1]

$$\sum_{i=1}^{r} \gamma_i^{opt} = \sum_{i=1}^{r} \left(\mu - \frac{M_T N_0}{E_S \gamma_i} \right)_+ = M_T$$

Assume that each Rake fingers in WCDMA system as SISO components in MIMO system, we obtain optimal energy of each multi-path.

From above equation, threshold μ is

$$\mu = M_T - \sum_{i=1}^{r} \left(\frac{M_T N_0}{E_S \gamma_i} \right)_+$$

Figure 2 describes proposed method. The energy of Rake finger #1 and #2 does not exceed threshold μ. We select Rake finger #1 and #2 and combine two fingers. But finger #3 and #4 exceed threshold μ. We ignore these Rake fingers because these two Rake finger has not enough energy to combine. Receiver can decide optimal number of Rake fingers and reduce Rake finger computations.
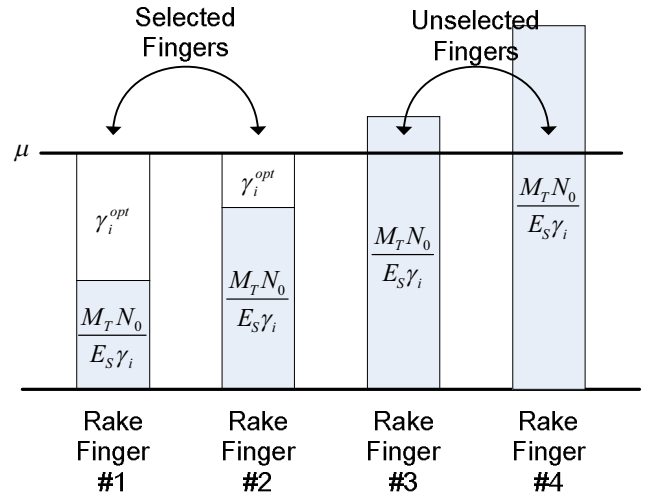

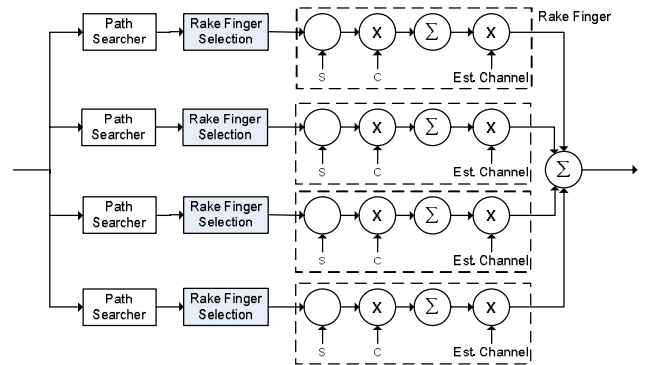**Figure 2. Rake finger selection**

Figure 3. Proposed receiver structure

Figure 3 is Rake receiver structure applied proposed algorithm. Before each Rake finger process, receiver can select useful Rake fingers applying proposed method. Ignoring unused Rake fingers, we can expect saving power consumption and reducing computation complexity.

4. Simulation Results

4.1 WCDMA system

WCDMA is based on frequency division duplex (FDD) for uplink and downlink. Modulation scheme is quadrature phase-shift keying (QPSK). Carrier frequency is 2GH band. WCDMA use scrambling codes for dividing transmit equipments and spreading codes for multi user. Scrambling code is gold code of 1 frame length (38400 symbols).

Spreading code is Orthogonal variable spreading factor (OVSF) code. For data transmission, dedicated physical data channel (DPDCH) use 4 ~ 512 spreading factor.

Table 1. System parameters

Parameters	Value
Carrier frequency	2.115GHz
Channel bandwidth	5MHz
Chip rate	3.84MHz
Frame duration	10ms
Modulation	QPSK
Spreading Factor	4~512

Figure 4 is WCDMA downlink transmitter and receiver structure. At the base station, before transmit frame, users' data is spreaded and scrambled [4]. Through the multi-path fading channel, added white Gaussian nose (AWGN) is added. Receiver estimates channel and equalize the received signal. [6]
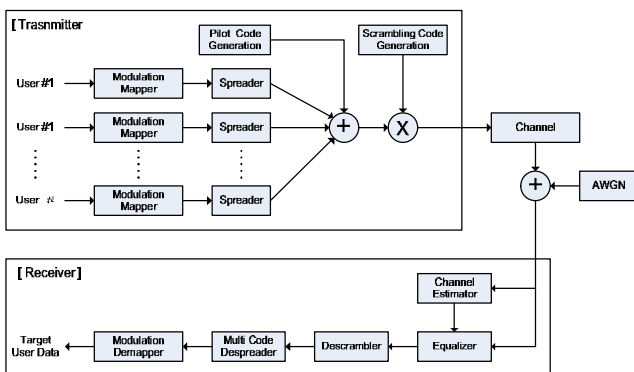

**Figure 4. WCDMA system block diagram**

4.2. Performance comparisons

We assumed WCDMA FDD downlink system. We use least square (LS) algorithm for channel estimation, Rake receiver as equalizer. Combine methods for performance comparison are single path, equal gain combine (EGC), maximum ratio combine (MRC). We did not consider MIMO, channel coding and interleaving. Channel model is tapped delayed line (TDL) model for multi-path fading, Jake's model for mobile of equipment and added white Gaussian nose (AWGN) [2]. We assumed speed of mobile equipment is 60km/h, spreading factor is 128.
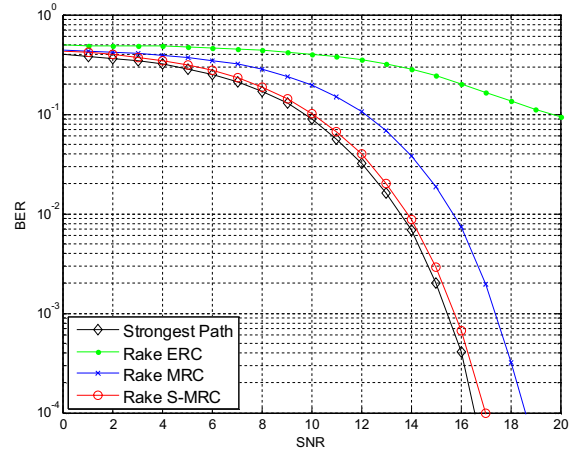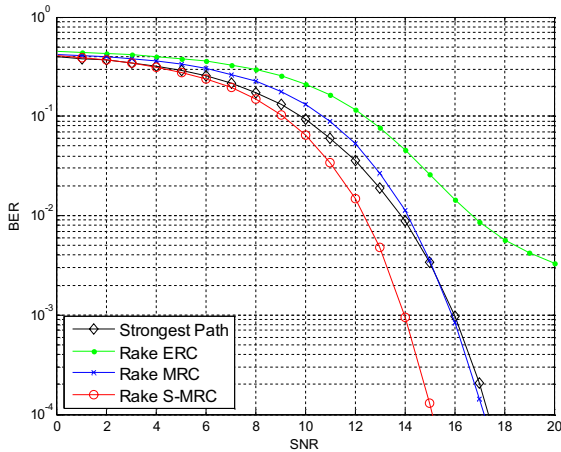

(a) Channel case 1
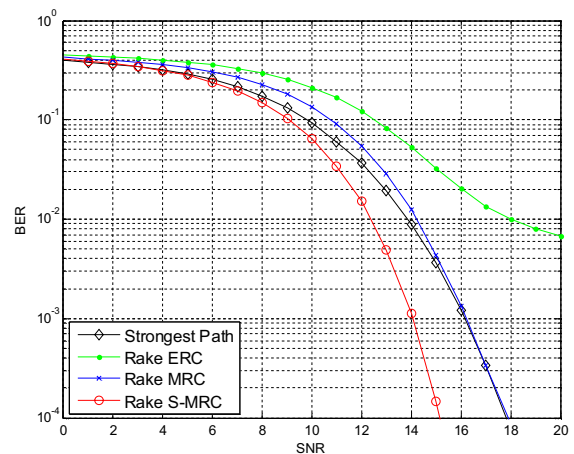
(b) Channel case 2
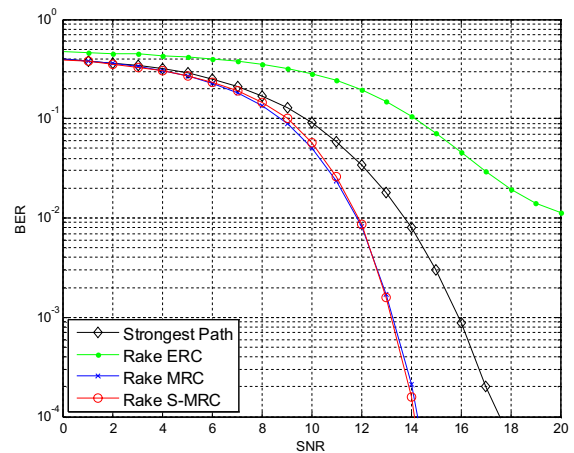
(c) Channel case 3

(d) Channel case 4

Figure 5. Performance comparison of Rake algorithms

We compared performance of Rake receiver algorithms, strongest path, equal gain combine (EGC), maximum ratio combine (MRC) and proposed combine algorithm.

Propose algorithm has good performance compare with other algorithms. Figure 5 shows proposed algorithm obtain advantage of performance up to 2.0 dB at 0.1% for bit error rate. When the channel is good, it works like in case of strongest path to save computations, otherwise it works like MRC algorithm using optimal number of Rake fingers to get better performance.

4.3. Complexity comparisons

Table 3 is computational complexity comparison between proposed algorithm and conventional Rake receiver. This table describes real number operations for each module. Proposed algorithm needs 0.57% additional computations compared with whole Rake finger, 7.28% additional computations compared with estimation and equalization part. With this additional computation complexity, we find effective Rake fingers and optimal number of Rake fingers. Ignoring unused Rake fingers, receiver save computational complexity and power consumption.

Table 2. Number of real number operation for complex number computations

Operation	ROP
Multiplication	4 ROP
Division	10 ROP
Square root	10 ROP

Table 3. Computational complexity comparison

Process		ROP/Frame
Rake Finger MF		76,800
Rake Est & Eq		1,208
Combiner (MRC)		76,802
Propose Algorithm		88
Increasing rate	Est & Eq + Proposed	7.28%
	Total + Proposed	0.57%

5. Conclusion

In the paper, we proposed efficient Rake receiver to save power consumption and reduce computational complexity in WCDMA FDD downlink system. Using estimated channel information, proposed algorithm selects effective Rake fingers and combine them reallocating weighted energy. Compared with conventional Rake receiver, performance advantage is up to 2.0 dB at 0.1% of bit error rate. With about 0.57% additional computational complexity, we can find the optimal number of Rake fingers and reduce computations of unused Rake fingers.

References

[1] Arogyaswami Paulraj, Rohit Nabar and Dhananjay Gore, "Introduction to Space-Time Wireless Commnucations", Cambrige University Press, 2003
[2] 3GPP TS 25.211, "Physical channels and mapping of transport channels onto physical channels (FDD)"
[3] 3GPP TS 25.101, "User Equipment (UE) radio transmission and reception (FDD)"
[4] 3GPP TS 25.213, "Spreading and modulation (FDD)"
[5] Rudolf Tanner, Jason Woodard, "WCDMA Requirements and Practical Design" WILEY, 2004
[6] Bernard Sklar, "Digital Communications Fundamentals and Appplications", Prentice Hall 2001