

A solution for increasing data rate of Doppler-RAKE system

Minh Nguyen Nguyen and Józef Modelski

Abstract — Doppler-RAKE detection in the CDMA system has been further developed and offers better performances in comparison to conventional RAKE detection, especially in fast-fading environments. Also, the multi-user Doppler-RAKE system works more effectively with channel coding applications. However, by means of exploring the Doppler effect, the system's data rate is decreased. We propose a simple solution to increase the data rate for the system while keeping the Doppler gain.

Keywords — diversity, Doppler-RAKE, CDMA, multi-path, fast-fading, spread-time signaling, multi-user detection, channel coding.

1. Introduction

As it was discussed in [1], channel coding with convolutional code and interleaving for the multi-user Doppler-RAKE detection offered improved performance. However, due to the length of the code, the data rate of the transmission is decreased. A method for increasing the data rate, while keeping the Doppler gain for the system, is to make the channel more time selective as discussed in [2, 3]. In this paper, we propose the signal dividing process, which helps to increase the data rate. The advantage is that this process has a realization similar to multi-user detection, which is already applied in the system. Therefore, our solution is more general and easier for system application and calculation.

2. System representation

A mobile wireless channel can be generally described as a time-varying linear system. The base-band signal $r(t)$ at the receiver is given by

$$r(t) = s(t) + n(t) = \int_0^{\infty} h(t, \tau) x(t - \tau) d\tau + n(t), \quad (1)$$

where $x(t)$ is the transmitted base-band signal, $h(t, \tau)$ is the time-varying channel impulse response and $n(t)$ is the zero-mean, complex, circular additive white Gaussian noise (AWGN) with power spectral density N_0 .

An equivalent representation of the channel, in terms of the spreading function is defined as:

$$H(\theta, \tau) \stackrel{\text{def}}{=} \int h(t, \tau) e^{-j2\pi\theta t} dt \quad (2)$$

and

$$s(t) = \int_0^{Tm} \int_{-Bd}^{Bd} H(\theta, \tau) x(t - \tau) e^{j2\pi\theta\tau} d\delta d\tau, \quad (3)$$

where Tm is the multi-path spread and Bd is the Doppler spread (one-sided) of the channel.

The time-varying impulse response $h(t, \tau)$ is best modeled by a wide-sense stationary uncorrelated scatterer (WSSUS) channel. The received signal consists of a linear combination of time-shifted and frequency-shifted (Doppler) copies of the transmitted signal. Its finite-dimensional representation is:

$$s(t) \approx \frac{T_c}{T_s} \sum_{n=0}^N \sum_{k=-K}^K H\left(\frac{k}{T_s}, nT_c\right) x_{k,n}(t), \quad (4)$$

where $N = [Tm/T_c] \approx [TmB]$, $K = [BdT_s]$, T_c is the chip interval of spread codes, B is the signal bandwidth, T_s is the symbol duration.

By virtue of orthogonality of the basis waveforms $x_{k,n}(t)$'s, and the statistical independence of the channel coefficients $H(\theta, \tau)$, the representation (4) effectively decomposes the channel into $(N + 1) \times (2K + 1)$ independent, flat-fading (diversity) channels by appropriately sampling the multi-path Doppler plane.

Note that the number of diversity channels is proportional to the product $TmBd(T_s/T_c)$. Thus, for fixed channel parameters Tm and Bd – the level of diversity is proportional to the time-bandwidth product (TBP), $T_sB \approx (T_s/T_c)$, of the signal waveform. This also illustrates the remarkable ability of CDMA systems with spread-spectrum signals to exploit channel diversity.

Based on the concept described above, the detector structure (time-frequency (TF) RAKE receiver) for joint multi-path Doppler diversity is developed in [4, 5], which consists of a bank of conventional RAKE receivers shifted in time and frequency to take samples. These samples are combined (by the maximum ratio combining (MRC) method) to estimate the transmitted signal. Analytical results demonstrate that even the small Doppler spreads encountered in practice can be leveraged into significant diversity gains in the proposed Doppler-RAKE detection system.

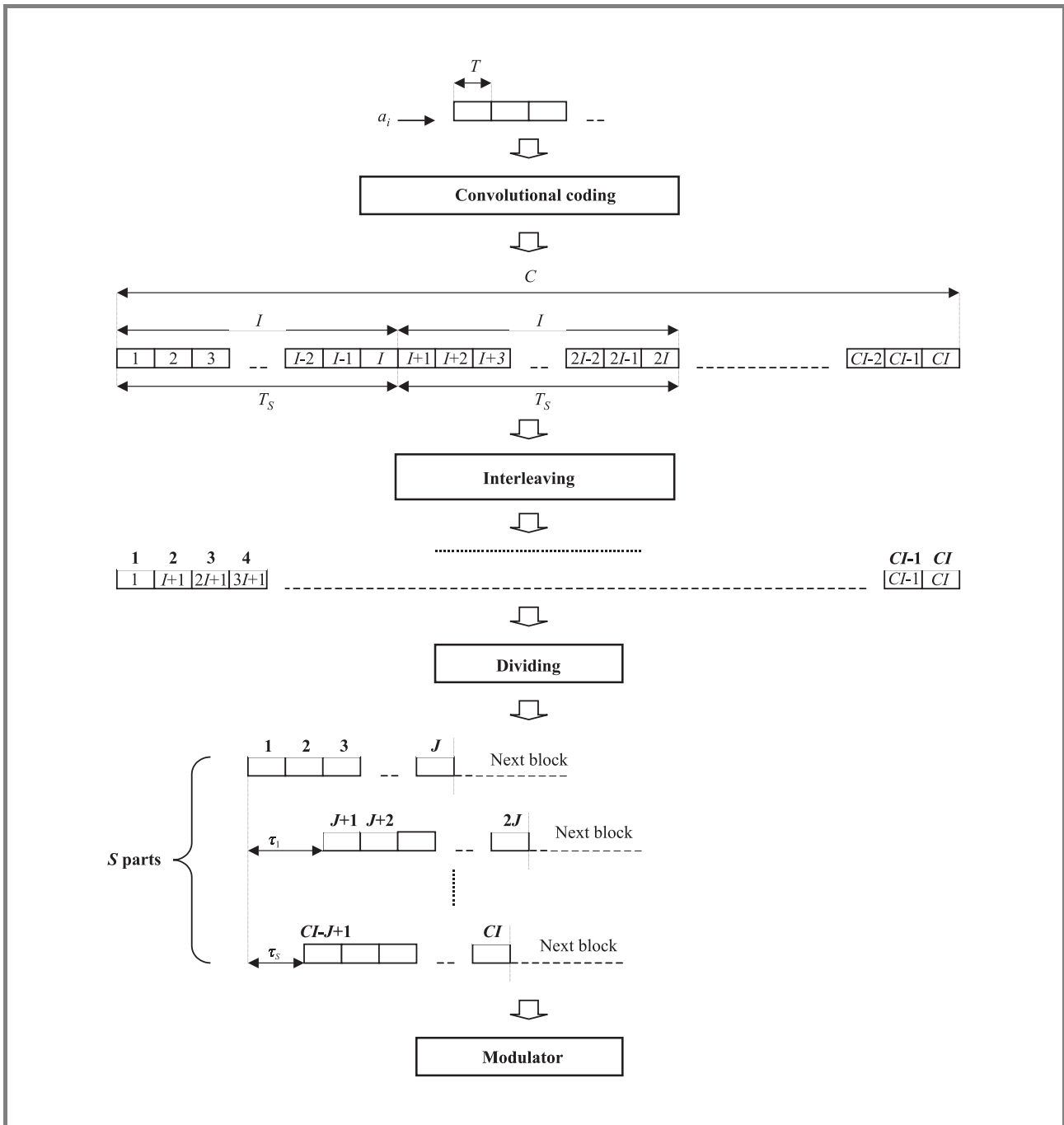


Fig. 1. Divide the symbols to increase data rate.

Also, because the system’s performance strongly relies on channel estimation accuracy, the application of channel coding (i.e. convolutional coding and interleaving) has proven to have useful results. Channel coding mitigates the estimation errors and increases Doppler diversity gain.

3. System signaling

The symbol duration for the system without channel coding is T . After channel coding the symbols are spread, and

their duration now is $T_s(> T)$. According to formula (4), for maximal exploitation of channel diversity, T_s should be increased as much as possible. Our intention is to make the desired inter-symbol duration T' , which determines the data rate, smaller than T_s . So, the basic idea is to divide the symbol block after channel coding into several parts and send them in parallel. We could use regulated time shifts τ_s between parts to gain Doppler effects and channel coding to prevent interference. Figure 1 illustrates the process. During the channel coding, the symbols from the source are first coded by convolutional code of length I ,

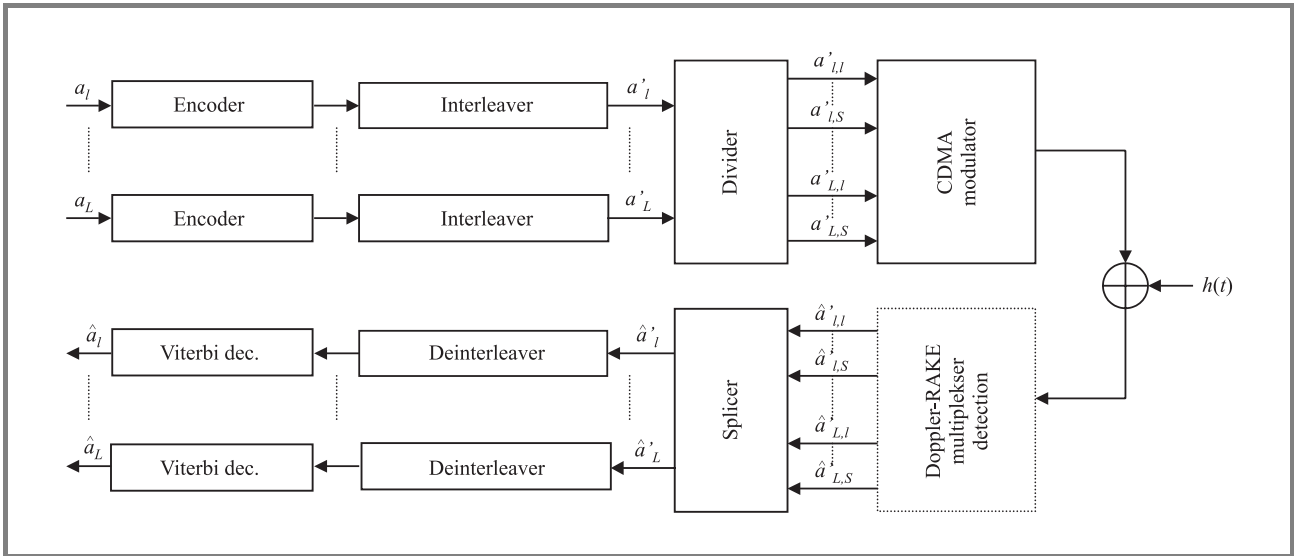


Fig. 2. Multi-user Doppler-RAKE detection structure.

then every block of C coded symbols is interleaved. In the dividing process, each of these blocks then is divided into S parts of J bits and sent in parallel. The inter-symbol duration T' in this method is (assuming that $\tau_s \ll T_s$):

$$T' \cong \frac{T_s}{S} = \frac{IT}{S}. \quad (5)$$

So, if $S \geq I$ we have the data rate, after dividing, comparable with the data rate from the source (i.e. the data rate before channel coding with symbol duration T):

$$R' = \frac{1}{T'} \geq R = \frac{1}{T}. \quad (6)$$

Even in the case that $R' > R$ we cannot make the transmission faster than the case without channel coding, because the maximal data rate is R , due to the relevant signal transmission speed from the source. So we are only interested in the case where $T_s < T' \leq T$ (i.e. $1 < S \leq I$). The symbol duration after dividing is: $T'_s = T_s I / J$ and $T'_s > T$. This retains the Doppler effect. Also, the choice of S, J and τ_s (as well as C^1 if needed) depends on the interference between signals, interleaving and Doppler effects. This provides many variances in the dividing process that need to be analyzed and compared to find the optimal solution. The time-selective signaling method mentioned above, with parameters: $\tau_s = T$, $J = I$, and $S = I$, is one of the cases which has no interleaving processes.

After Doppler-RAKE detection, the signals are rejoined by the splicing process, and then de-interleaved and decoded by the Viterbi algorithm [6].

¹Normally, C is dependent on the effect of data interleaving and should be as small as possible because it decreases data rate.

Detection technique. For easier representation, consider a CDMA system with L users and employing binary phase-shift key (BPSK) signaling. The signal at the receiver is:

$$r(t) = s(t) + n(t) = \sum_{l=1}^L \sum_{s=1}^S a'_{l,s} s_{l,s}(t - \tau) + n(t), \quad (7)$$

where $a'_{l,s} \in \{-1, 1\}$ is the bit sign and $s_{l,s}(t)$ is the received baseband for the s th part of the l th user; $n(t)$ is an AWGN. $s_{l,s}(t)$ can be expressed as:

$$s_{l,s} \approx \frac{T_c I}{T_s J} \sum_{n=0}^N \sum_{k=-K}^K H_{l,s} \left(\frac{k}{K}, nT_c \right) x_{l,s}^{k,n}(t - \tau_s). \quad (8)$$

Here $x_{l,s}^{k,n}(t)$ is the spread waveform of the l th user, $H_{l,s}(k/K, nT_c)$ is the channel coefficient, $N = [Tm/T_c] \approx [TmB]$ and $K = [BdT_s I / J] = [BdT'_s]$, where T_s and T'_s are symbol durations, respectively, before and after dividing, (if $I = J$ then $T'_s = T_s$).

Multi-user Doppler-RAKE detection was described in [5], though we now have $L \times S$ users instead of L users. Figure 2 shows the proposed detection scheme. The Doppler-RAKE detector's structure (dotted rectangle) is similar to that mentioned above in Section 2. For multi-user cases, a detection process was added to combat multi-access interference (MAI). This process has many solutions that were discussed in [5]. Because of increased complexities within the system, due to the data-dividing process, we applied our PIC (parallel interference cancellation) method to this case. The PIC solution has offered positive results while its calculation was much simpler than the others.

4. Performance analysis

As discussed above, the system's performance is similar to the case described in [5] but with a higher number of users ($L \times S$ instead of L). While the Doppler effect remains nearly the same, the data rate is increased. This is achieved at a relatively minor cost of encountering more multi-user interference and more complex calculations, each increasing proportionally to the rise in the number of users.

For numerical simulation, the time-varying channel is simulated using the Jakes model [7] corresponding to a data rate ($R = R'$) of 2 kHz (i.e. 2000 symbols/s) and a carrier frequency of 1.8 GHz. Here a low data rate is chosen to show the fast-fading effect. Also, in practice, a longer code length will cause a lower data rate. The code length is 64. A system of two multi-paths ($N = 1$) and three Doppler paths ($K = 1$) with four users ($L = 4$) is applied. Tests are over 10 000 symbols for each variance. The TBd 's are 0.1 and 0.2 corresponding to Doppler spread Bd 200 Hz and 400 Hz, mobile speed 120 km/h and 240 km/h. Fast-fading channels encountered in practice exhibit Doppler spreads on the order of 100-200 Hz ($TBd = 0.1$) due to the relative movement of the users (60-120 km/h). The parameters used for the convolutional code are: constraint length $m = 3$, code rate $R_c = 1/2$ ($n = 2$), free distance $d_f = 5$. The interleaving parameters are: $I1 = 2$, $C1 = 2$ (intended choice) and $I2 = 7$, $C2 = 3$ (accidental choice). The dividing parameters are chosen to keep the data rate the same as that after convolutional coding. Also, a pilot-based estimation process is used for channel estimation [8].

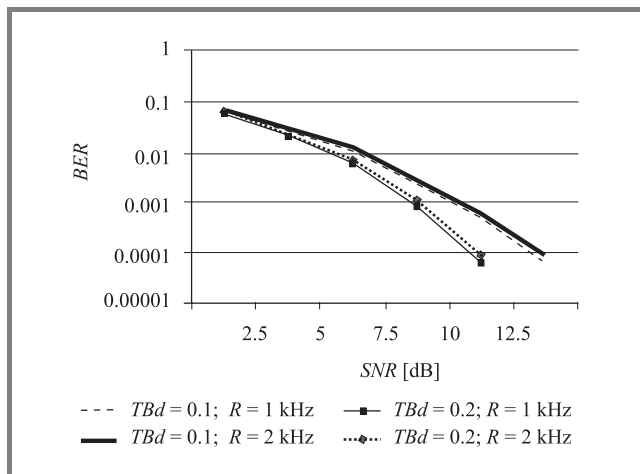


Fig. 3. BER as a function of SNR_{user1} (of 4 user-Doppler-RAKE system).

The performance results of the two choices of interleaving are nearly the same. We surmise that this is because of limiting the parameter values for simulation simplification. But the main results, which verify our intentions, are shown.

As we can see, the simulation shows that the performance of the system is nearly as efficient as that of the system with-

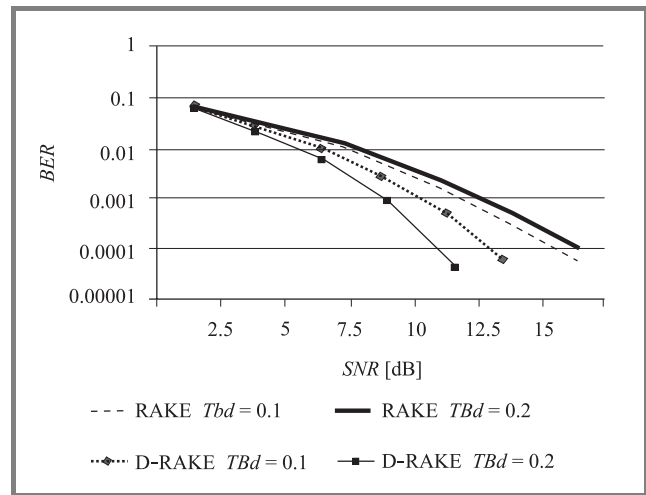


Fig. 4. BER as a function of SNR_{user1} (of 4 user conventional RAKE and Doppler (D)-RAKE systems).

out the dividing process (see Fig. 3), and we have a gain in data rate (in this case – 2 times higher). Also, it can be seen that with more Doppler effect, the system out-performs the conventional RAKE system. In Fig. 4, when TBd is increased from 0.1 to 0.2, the efficiency is more obvious: at $BER = 10^{-4}$, Doppler -RAKE system gains about 3 dB of SNR.

5. Conclusions

Interleaving is beneficial in cases where several consecutive bits are damaged. Our solution is more general in dealing with these situations than the time-selective case provided in [2].

Channel coding (including convolutional coding and interleaving) is an indispensable process of the Doppler-RAKE system. By taking into account advantage of the code and block code length of these processes, we can increase both Doppler effect and data rate. With good multi-user detection methods, as were provided, the downside effects of increased signal interference and more complex calculations will have an insignificant impact on performance results. Our analysis is simplified because of the complexity of the calculations. In the next step, more practical propagation model will be needed for more thorough investigation. We offer that our resolution can make the Doppler-RAKE system work better.

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