Trade-off Between the Number of Fingers in the Prefilter and in the Rake Receiver in Time Reversal IR-UWB

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***Abstract*—In this paper we investigate the trade-off between the number of fingers in the prefilter of a TR-IR-UWB system versus the number of fingers in the rake receiver. This allows studying the gain brought by time reversal when the complexity is switched from the receiver to the transmitter i.e. when the number of fingers is increased in the prefilter, while it is reduced in the rake receiver.**

I. Introduction

Impulse Radio Ultra Wide Band (IR-UWB) communications are classically based on the use of a rake receiver. Many studies have been made on the number of fingers to be used in the rake in order to obtain good performance [1], [2], [3], [4], [5]. Time Reversal (TR) IR-UWB systems use a prefilter at the transmitter side [6], that has the function of convolving the UWB pulse with the impulse response of the channel reverted in time; when the signal traverses the channel, the output of the channel presents the correlation of the channel with itself. Thus, the Time Reversal prefilter has a function somehow analog to the rake receiver i.e. creating the correlation of the channel with itself. As a matter of fact one of the main advantages which is often claimed for TR is to move the complexity from the receiver to the transmitter. Moreover, like the rake receiver, the rake of the prefilter at the transmitter side may be implemented 'partially' by selecting a number of fingers lower than the total number of paths in the channel, reducing thus the complexity of implementation. Our study aims at investigating how TR UWB effectively shifts the complexity from the receiver to the transmitter. To this purpose, we analyze performance as a function of the number of fingers in the rake receiver and the number of fingers in the TR prefilter. As a matter of fact, while using TR, the receiver should still use a rake adapted to the new signal. Therefore, one can tune both parameters at once: the number of fingers of the prefilter versus the number of fingers of the rake receiver.

II. Signal Model

The classical TH-IR UWB (Time Hopping Impulse Radio Ultra Wide Band) signal using PAM (Pulse Amplitude Modulation) may be written as:

$$y(t) = \sum_m a_m w(t - mT_f - c_m T_c) \tag{1}$$

In this expression, $w(t)$ is the unit-energy basic pulse waveform with a time support included in $[0, T_c)$, a_m the information symbol at symbol interval m, having its values in the set $\{-1, 1\}$. The so-called frame time is $T_f = N_h T_c$, where T_c is the so-called chip time interval (N_h is the frame length in chips). The time hopping code is represented by the sequence $(c_l)_{l\in\mathbb{Z}}$, the elements of which belong to $\{0, \dots, N_h - 1\}$.

Fig. 1 represents the general transmission chain:

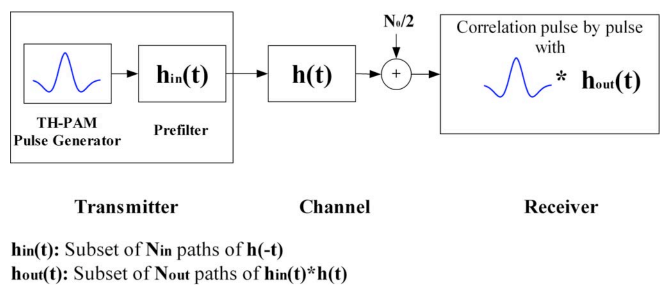

Fig. 1. Time Reversal (TR) combined with Selective RAKE (SRAKE)

In a 'full' TR (Time Reversal) system the signal is convolved with $h(-t)$ in the prefiltering block. $h(t)$ is the channel impulse response (see Fig. 2):

$$h(t) = \sum_{i=0}^{L-1} \gamma_i \delta(t - \tau_i) \tag{2}$$

with L the total number of paths in the channel and τ_i the delay associated to the i^{th} path and γ_i its amplitude.

To reduce the complexity, we can use a pre-filter $h_{in}(t)$ (see Fig. 3) where only a subset of paths is considered:

$$h_{in}(t) = \sum_{i=0}^{N_{in}-1} \alpha_i \delta(-(t - \tau_i)) \tag{3}$$

with $\{\alpha_i\}_{i\in[0,N_{in}-1]}$ the strongest $N_{in} \leq L$ paths of $h(t)$.

At the receiver side, the full rake has to perform the correlation of the received signal with $w(t) * h_{in}(t) * h(t)$ (see Fig. 4). One can also implement a partial rake receiver, making the correlation of the received signal with $w(t) * h_{out}(t)$ (see Fig. 5), where:

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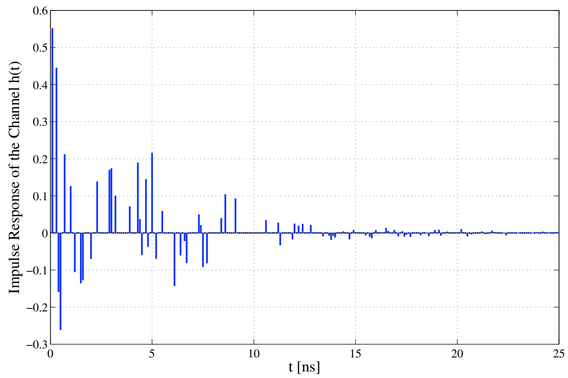

Fig. 2. Example of $h(t)$

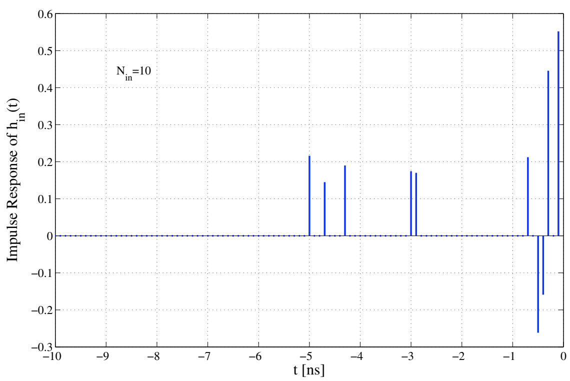

Fig. 3. Example of $h_{in}(t)$

$$h_{out}(t) = \sum_{i=0}^{N_{out}-1} \beta_i \delta(-(t-\tau_i)) \tag{4}$$

with $\{\beta_i\}_{i \in [0, N_{out}-1]}$ the strongest $N_{out} \leq (2 \cdot L)$ fingers of $h_{in}(t) * h(t)$.

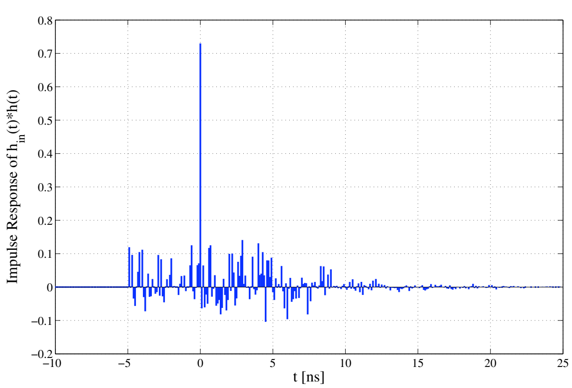

Fig. 4. Example of $h_{in}(t)*h(t)$

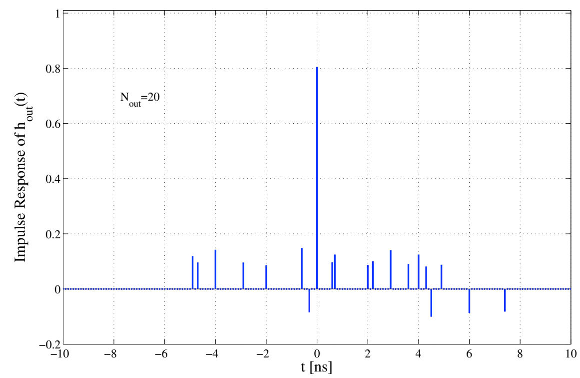

Fig. 5. Example of $h_{out}(t)$

III. Simulations and Results

In order to obtain the performance of TR UWB in terms of BER, we have run simulations using channel models named CM1 (line-of-sight, LOS) and CM3 (non-line-of-sight, NLOS) according to [7]. We use the classical Scholtz's pulse: $w(t) = \left[1 - 4\pi \left(\frac{t}{\tau}\right)^2\right] \cdot exp\left[-2\pi \left(\frac{t}{\tau}\right)^2\right]$. System parameters are $\tau = 0.5ns$, $T_c = 1ns$ and $N_h = 280$ chips. We analyze the BER as a function of the number of fingers in the prefilter N_{in} and in the rake receiver N_{out}. The N selected paths from the fingers correspond to the N strongest ones (Selective RAKE).

Results are shown in Fig. 6 and 7; performance changes when switching the number of fingers from the receiver to the transmitter. For instance, when $N_{in} = 1$ and $N_{out} = 10$ (i.e. without time reversal) performance is better than when $N_{in} = 10$ and $N_{out} = 1$.

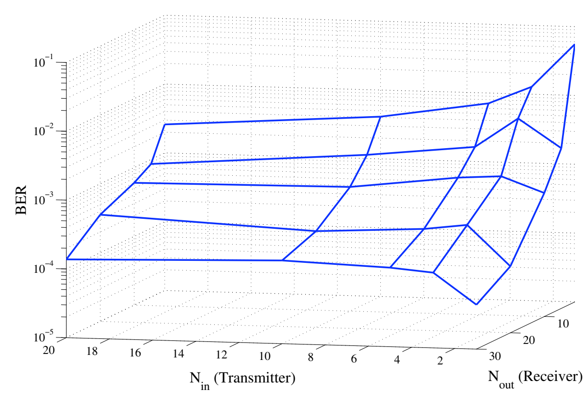

Fig. 6. $BER(N_{in}, N_{out})$, $E_b/N_0 = 9dB$, LOS

In order to keep same performance when the number of fingers at the rake receiver is lowered, the number of fingers at the transmitter must be increased in a more important way, and a small number of fingers has still to be kept at the receiver. For instance, a bit error rate of $0.5 \cdot 10^{-2}$ with the initial value of $N_{out} = 8$ and $N_{in} = 1$ may be kept by lowering N_{out} to 5 but increasing N_{in} to 10, as shown in Fig. 12.

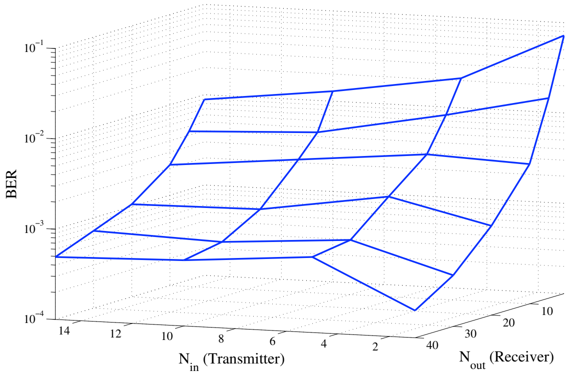

Fig. 7. $BER(N_{in}, N_{out})$, $E_b/N_0 = 9dB$, NLOS

Moreover, in some situations, increasing the number of fingers at the transmitter while keeping the number of fingers at the receiver may reduce performance. This can be explained by a major spreading of the energy on various paths: while the main path is strongest in time reversal, many sub paths may appear, creating thus a major energy spreading. The strengthening effect of the main path due to time reversal is shown on Fig. 8 and 9, that show the percentage of the total received energy on the main path as a function of the number of fingers N_{in} in the time reversal pre-filter. Note that for $N_{out} = 1$, the lower energy values on the main path is obtained for $N_{in} = 1$, i.e. without time reversal.

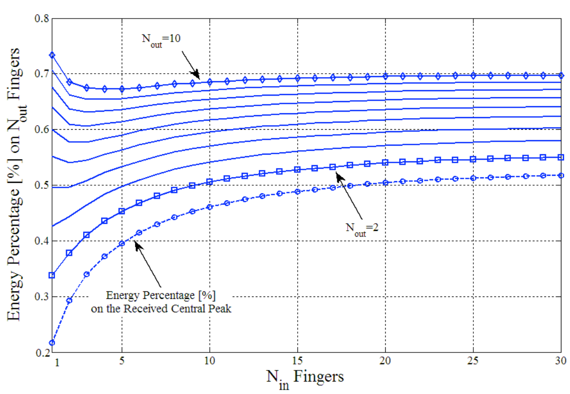

Fig. 8. LOS, Energy percentage on N_{out} fingers at the receiver ($N_{out} = 1$ to 10). The curve with $N_{out} = 1$ gives the energy percentage on the main central path.

The spreading effect of the total energy on an increased number of paths in time reversal is shown in Fig. 10 and 11. For a fixed number of fingers $N_{out} \geq 10$ in the rake receiver (LOS) or $N_{out} \geq 30$ (NLOS), the percentage of the total energy at the output of the rake receiver decreases when the number of fingers in the time reversal pre-filter increases.

As expected, increasing the number of fingers in the rake receiver while keeping a fixed number of fingers at the prefilter always increases performance.

Finally, Fig. 12 shows the iso-BER curves as a function

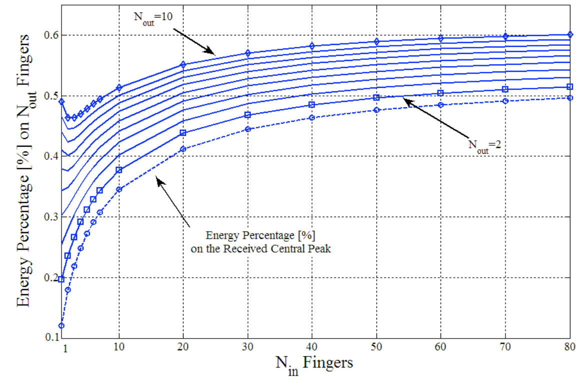

Fig. 9. NLOS, Energy percentage on N_{out} fingers at the receiver ($N_{out} = 1$ to 10). The curve with $N_{out} = 1$ gives the energy percentage on the main central path.

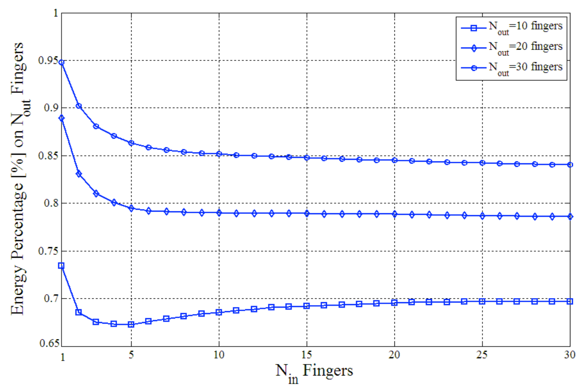

Fig. 10. LOS, Energy percentage of N_{out} fingers

of N_{in} and N_{out}, where the values of the pairs (N_{in}, N_{out}) producing the same BER performance are shown. Note that with respect to the no time reversal case ($N_{in} = 1$), a same performance can be obtained by increasing N_{in} and by decreasing the number of fingers N_{out} in the rake receiver only when the initial BER is high, i.e. only when the rake

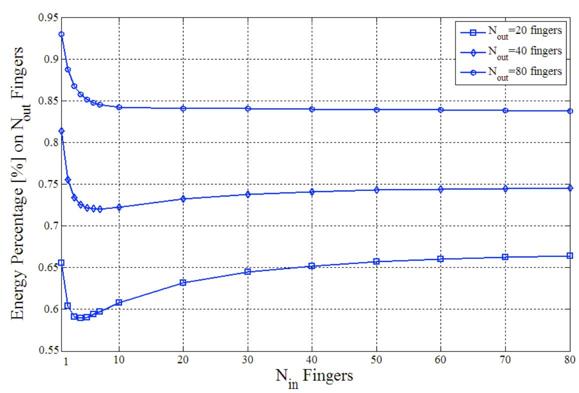

Fig. 11. NLOS, Energy percentage of N_{out} fingers

receiver without time reversal uses a small number of fingers (less than about 10).

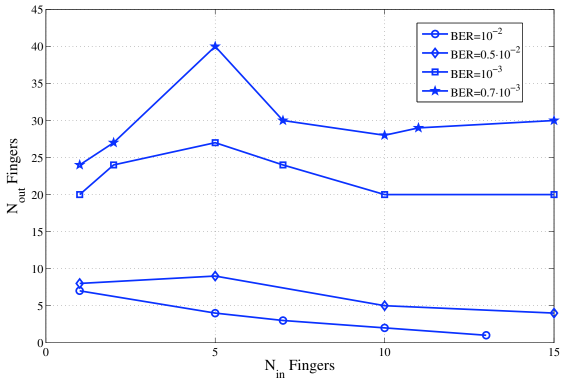

Fig. 12. Constant BER curves, NLOS, $E_b/N_0 = 9dB$

In summarily, results show that time reversal helps moving complexity from receiver to transmitter, only when receiver has initially a low number of fingers, otherwise the use of time reversal with reducted fingers at the rake receiver reduces performance.

The impact of time reversal seems more promising however, in a scenario with multi user interference (MUI). Fig. 15 shows that in the case of strong interferers, time reversal may lead to better performance (see $(N_{in} = 1, N_{out} = 40)$ versus $(N_{in} = 40, N_{out} = 40)$). This happens maybe due to the fact that TR modifies the MUI distribution, while from [9], [10] the MUI distribution may have a strong impact on the IR UWB performance. This effect must be investigated further, and will form the object of future investigations.

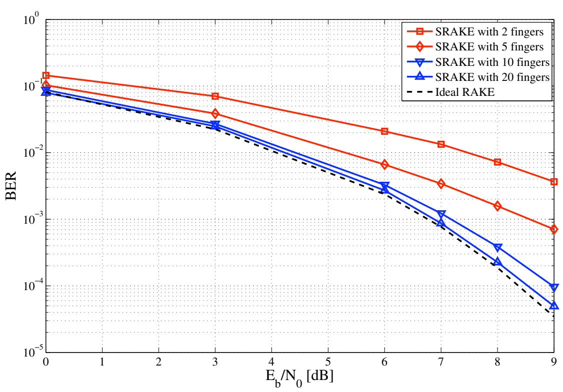

Fig. 13. SRAKE without TR for binary PAM-TH, LOS

IV. Conclusions

This study analyzed the impact of the number of fingers in the rake receiver and in the time reversal prefilter for IR-UWB. Results show that only in special conditions, i.e. for low number of fingers in the initial rake receiver, moving the complexity from the receiver to the transmitter by increasing the fingers in the prefilter and lowering it in the rake receiver produces better performance. In environments with very high interference, time-reversal combined with rake receiver could be more advantageous as it appears to have an important impact over the MUI distribution. This issue will be investigated further in future work.

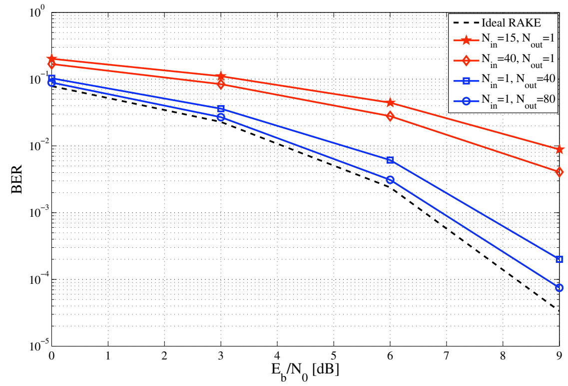

Fig. 14. TR and SRAKE for binary PAM-TH, NLOS

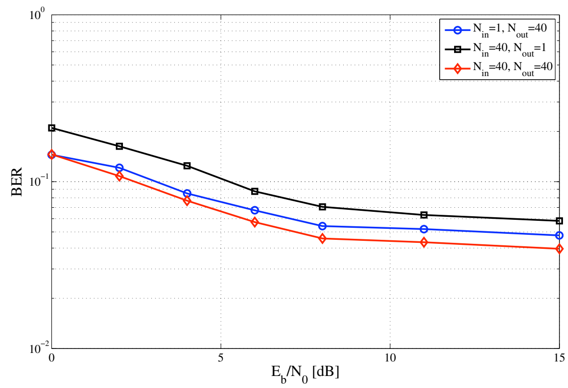

Fig. 15. NLOS, strong interference from 5 users with $10dB$ above the usefull signal

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References

[1] B. Mielczarek, M. O. Wessman and A. Svensson. "Performance of Coherent UWB Rake Receivers with Channel Estimators", Vehicular Technology Conference (VTC), Orlando, Florida, 6-9 Oct. 2003.

[2] A. Rajeswaran, V. S. Somayazulu and J. R. Foerster. "Rake Performance for a Pulse Based UWB System in a Realistic UWB Indoor Channel", IEEE International Conference on Communications (ICC), Anchorage, Alaska, USA, 11-15 May 2003.

[3] M. Z. Win and Z. A. Kostic. "Virtual path analysis of selective Rake receiver in dense multipath channels", IEEE Commun. Lett., Vol. 3, no. 11, pp. 308-310, Nov. 1999.

[4] D. Cassioli, M. Z. Win, F. Vatalaro, A. Molisch. "Performance of low-complexity rake reception in a realistic UWB channel", Proc. ICC 2002, pp. 763-767.
[5] M. -G. Di Benedetto, G. Giancola. "Understanding Ultra Wide Band, Radio Fundamentals", Upper Saddle River, New Jersey: Prentice Hall Pearson Education, Inc., 2004.
[6] T. Strohmer, M. Emami, J. Hansen, G. Papanicolaou, and A. J. Paulraj, "Application of time-reversal with MMSE equalizer to UWB communications", in Proceedings of IEEE Global Telecommunications Conference (GLOBECOM '04), vol. 5, pp. 3123-3127, Dallas, Tex, USA, November-December 2004.
[7] J. Foerster. "Channel Modeling Sub-Committee Report Final", IEEE P802.15-02/490r1-SG3a, February 2003.
[8] M. Z. Win and R. A. Scholtz. "Ultra-Wide Bandwidth Time-Hopping Spread-Spectrum Impulse Radio for Wireless Multiple-Access Communications", IEEE Trans. on Com., vol.48, no.4, pp. 679-691, Oct. 2000.
[9] J. Fiorina and W. Hachem. "Central Limit Results for the Multiple User Interference at the SUMF Output for UWB Signals", Proceedings of International Symposium on Information Theory and its Applications ISITA'04, Parma, Italy, pp. 563-566, Oct. 2004.
[10] J. Fiorina and D. Domenicali. "Revisiting TH-IR-UWB performance limits dependency on essential system parameters using the Generalized Gaussian Approximation", IEEE International Conference on Ultra Wide-band (ICUWB'07), Sept 24-26, 2007, Singapore.