HOPPED LINEAR TIME-VARYING FILTERS: PRINCIPLES.

Aawatif Hayar, Daniel Roviras, Bernard Lacaze and Alban Duverdier

ENSEEIHT / GAPSE, 2 Rue Camichel, BP 7122
31071 Toulouse cedex, France
hayar@len7.enseeiht.fr

ABSTRACT

Privacy and security of radio communications becomes increasingly important. In this context, modulation techniques with embedded scrambling properties are suitable. The aim of this paper is to present a new transmitting technique using Linear Time Varying Filters with hopping in the frequency domain.

1. INTRODUCTION

As a consequence of the growing interest in spread spectrum techniques, many efforts are being done in order to exploit its properties in communication systems. Especially to protect data information against jamming and multipath rejection and to give it privacy and security features. The problem in communication techniques is how to transmit information as efficient as possible to the intended receiver in environment with noise and risk of interception.

There are two main techniques of spread spectrum: Direct-Sequence and Frequency Hopping modulations. They have been employed in fighting against jamming and fading and have good privacy properties. The first one uses a fast pseudorandomly generated sequence to cause phase transitions in the carrier containing data. In the second one, the carrier is frequency shifted in a pseudorandom way [1].

Previous works using Periodic Clock Changes (PCC) [2] based on linear periodic filters which transform stationary processes into cyclostationary signals, have shown that when the band limited signal is jammed, or affected by fading, multiple perfect reconstructions are possible [3]. The jammer tends to disturb only one reconstruction. The reconstruction from the other band give us a clean version of a signal. Although the noise band is unknown, the mean of several reconstructions permits a quasi-perfect demodulation.

In this paper we present a new method for transmitting signals in fading channels, derived from PCC using Linear Periodic Time Varying filters (LPTV). Using a method of PCC with hopping in the frequency domain gives a privacy feature to communication system. This is accomplished by improving the scrambling properties in order to lower the probability of detection of transmitted signals.

Part 2 presents the basic elements of LPTV and PCC techniques together with the reconstruction at the receiver's end. Part 3 deals with the utilisation of LPTV for scrambling and transmitting signals in fading channels. Part 4 gives the results and describes the performance of this new transmitting method. Part 5 concludes.

2. PERIODIC CLOCK CHANGE

2.1. Stationary process

Let the original signal, $Z = \{z(t), t \in R\}$ be a random stationary process with spectral density $S_z(\omega)$ defined by [5]:

$$E\left[z\left(t\right)z^{*}(t-\tau)\right] = \int_{-\infty}^{+\infty} e^{i\omega\tau} S_z(\omega) d\omega. \qquad (1)$$

2.2. Periodic Clock Change System

The signal $x(t)$ obtained by the transformation through a PCC filter is given by:

$$x(t) = z[t - f(t)]g(t) \qquad (2)$$

where $f(t)$ and $g(t)$ are two periodic functions with identical period $T_0 = \frac{2\pi}{\omega_0}$. It can be seen that we operate a variation in time together with an amplitude modulation. Such transformation is called Periodic Clock Changes (PCC)[2]. The main idea is to subject the original process to a Linear Periodic Time-Varying filter (LPTV) caracterized by its impulse response $h(t, s)$ and its time-varying frequency response $H_t(\omega)$ with period $T_0 = \frac{2\pi}{\omega_0}$:

$$H_t\left(\omega\right) = \int_{-\infty}^{+\infty} h(t, t-\tau) e^{-i\omega\tau} d\tau \qquad (3)$$

$$H_t(\omega) = e^{i\omega f(t)} g(t)$$

The Fourier development of $H_t(\omega)$ is given by :

$$H_t(\omega) = \sum_{-\infty}^{+\infty} \psi_k(\omega) e^{ik\omega_o t}, \quad (4)$$

$$\psi_k(\omega) = \frac{1}{T_0} \int_0^{T_0} H_t(\omega) e^{-i\omega_o k t} dt.$$

It has be shown in [4] that:

$$x(t) = \sum_{k=-\infty}^{+\infty} x_k(t) e^{ik\omega_0 t} \quad (5)$$

where:

$$\begin{aligned} x_k(t) &= z(t) * \varphi_k(t) \\ \varphi_k(t) &= TF^{-1}[\psi_k(\omega)] \end{aligned}$$

Figure 1 represents a bloc digram corresponding to the decomposition (5).

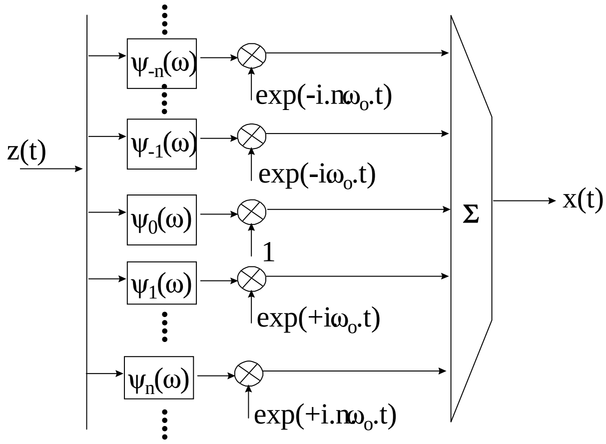

Figure 1: Time invariant decomposition of an LPTV

The spectral density of $x(t)$, $S_x(\omega)$, can be expressed as follows:

$$S_x(\omega) = \sum_{k=-\infty}^{+\infty} |\psi_k(\omega - k\omega_o)|^2 S_z(\omega - k\omega_o) \quad (6)$$

$S_x(\omega)$ is an infinite sum of weighted shifted versions of $S_z(\omega)$. Each version is centered around multiples of the LPTV filter frequency. The weights depend on $f(t)$ and $g(t)$. If, for example, we choose for $z(t)$ an NRZ signal with a symbol rate $D_s = \frac{1}{T_s} = \frac{2\pi\omega_0}{10}$ filtered by a Raised Cosine Filter (RCF) with roll-off coefficient $\alpha = 1$ and $f(t) = T_s \cos(\omega_0 t)$, we obtain the spectral density $S_x(\omega)$ shown in figure 2.

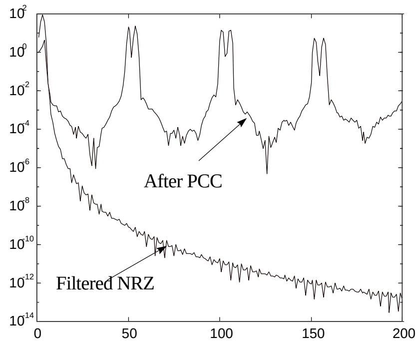

Figure 2: Spectral Density of the signal after PCC filtering

2.3. Reconstruction of the original process

We proceed by using a linear reconstruction [3] as shown figure 3.

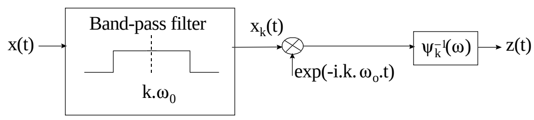

Figure 3: Inverse reconstruction

If $x(t)$ and $H_t(\omega)$ are known, we can therefore compute the functions $\psi_k(\omega)$. The reconstruction of $z(t)$ is obtained by inverting equation (5). This is possible if the spectral support of $z(t)$ is band limited. Under the condition that the functions $\psi_k(\omega)$ are different from zero, we can obtain the original signal $z(t)$ by filtering $x_k(t)$ with $\frac{1}{\psi_k(\omega)}$ (as shown in Figure 3). This method allows us to construct $z(t)$ from many bands. By averaging the obtained results we can minimize the influence of noise and jamming. We can then get a reconstruction of $z(t)$ even without any knowledge of the frequency support of the interferences. The privacy feature of this system makes it relevant for scrambling applications because without knowing the response of the LPTV filter it is not possible to reconstruct $z(t)$. In order to get our system stronger against noise and risk of interception, we suggest to do PCC hopping.

3. COMMUTED PERIODIC CLOCK CHANGE

3.1. Emission

Let $z(t)$ be a signal with frequency support $\left[\frac{-\omega o}{2}, \frac{\omega_o}{2}\right]$. In order to protect the information by minimizing the probability of detection by an unauthorized receiver and to improve its resistance against noise and interferences, such as jamming, we propose to change, in a random way, the used LPTV filter. The new proposed scrambling scheme is presented in figure 4. Let $c_1(t)$ be a pseudo-random code which, each time, subjects the signal $z(t)$ through one of N linear periodic filter $PCC_j, j = 1...N$. If T_c (chip period) is smaller than T_s (symbol period), we commute a filter inside one period of NRZ signal and we operate a Fast Frequency Hopping Periodic Clock Changes FFH/PCC. Otherwise, if T_c is larger than T_s, many symbols of $z(t)$ occur before the commutation of the LPTV filter. We then talk about Slow Frequency Hopping Periodic Clock Change SFH/PCC.

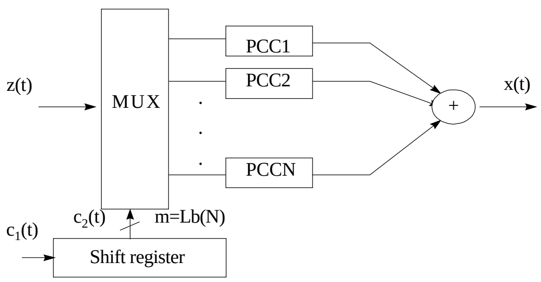

Figure 4: Direct SFH/PCC

3.2. Reception

The receiver is shown in Figure 5. If we suppose that $c_1(t)$ and all $h_j(t, s)$ are known, at each hop, the intended receiver knows the used PCC$_j$ and can therefore do the inverse reconstruction as shown in Figure 3.

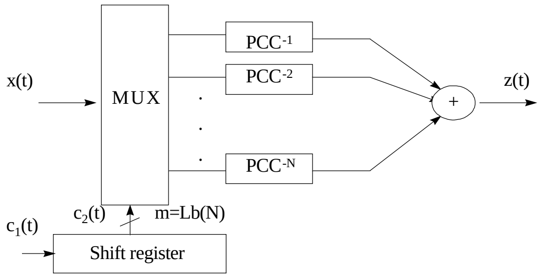

Figure 5: Reverse SFH/PCC

4. RESULTS

We have used a PN sequence with 7 chips (ML sequence with an internal shift register with 3 stages). With this PN sequence we can choose one of seven filters $H_{t,i}(\omega)$ as follow:

$$\begin{aligned} H_{t,i}(\omega) &= e^{-i\omega_0 f_i(t)} g_i(t) \\ i &= 1...7 \end{aligned}$$

let $z(t)$ be an NRZ signal with symbol rate, $D_s = \frac{1}{T_s}$, and

$$f_i(t) = T_s \cos(\omega_0 t) \text{ for } i = 1..7$$

with:

$$\begin{aligned} g_1(t) &= 1 \\ g_2(t) &= e^{-i\omega_0 t} \\ g_3(t) &= e^{-2i\omega_0 t} \\ g_4(t) &= e^{-3i\omega_0 t} \\ g_5(t) &= e^{i\omega_0 t} \\ g_6(t) &= e^{2i\omega_0 t} \\ g_7(t) &= e^{3i\omega_0 t} \end{aligned}$$

with $D_s = \frac{2\pi\omega_0}{10}$ and $SNR = 20\ dB$.

We have made a slow PCC hopping, by kepping the same filter during 10 transmitted symbols.

Figure 6 and 7 respectively represent the input signal, $z(t)$, and the output PCC hopped signal $x(t)$. Each PCC has a duration of 1e4 samples. For example, from 0 to $1e^4$ samples, we have PCC1 ($g_1(t) = 1$, baseband signal). From $1e^4$ to $2e^4$ we observe the modulated signal by PCC2 (scrambled by $f_2(t)$ and modulated by $g_2(t)$).

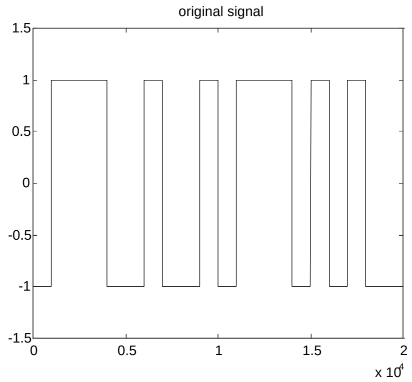

Figure 6: The original signal z(t)

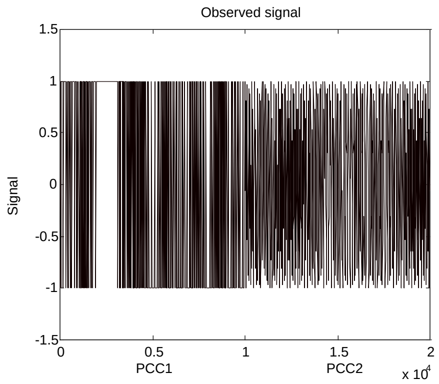

Figure 7: Observed signal x(t) after PCC1 and PCC2.

We can see, on Figure 8, the spectral density of the output signal, $x(t)$, during PCC1, PCC3 and PCC7. On this figure we can clearly see the different versions of the spectrum of the original signal, $z(t)$, shifted and wheighted arround $k\omega_0$ depending on the functions $f(t)$ and $g(t)$.

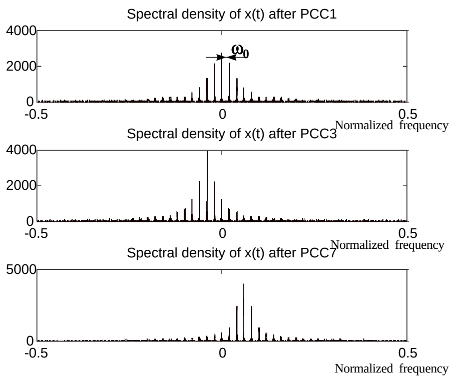

Figure 8: Spectral density of x(t) after PCC1, PCC3 and PCC7

The reconstruction of $z(t)$ uses five consecutive bands $([-\frac{\omega_0}{2}, \frac{\omega_0}{2}])$ of the spectrum of $x(t)$. The five bands correspond to the main shifted version of the spectrum together with the four adjacent bands. For example, for PCC3, the five considered bands will be centered around $[-4\omega_0, -3\omega_0, -2\omega_0, -\omega_0, 0]$ (see Figure 8-b). Figure 9 shows the reconstructed signal during PCC3 and PCC4 hops.

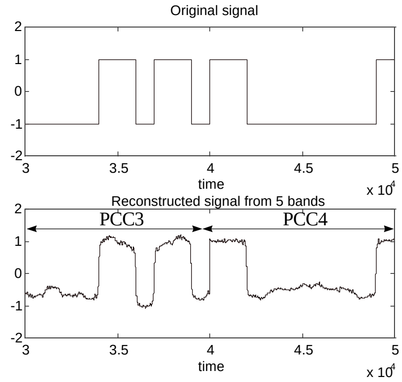

Figure 9: The original and the reconstructed signal after PCC3 and PCC4.

5. CONCLUSION

In this paper we have presented a new principle combining the scrambling and spreading properties of Periodic Clock Change technique together with filter hopping method. Scrambling properties are given by time domain variations related to function $f(t)$ and frequency domain variation through $g(t)$. In conclusion, this new method based on PCC technique opens a new perspective in the telecommunication application domain, especially those which need good properties concerning privacy and resistance against noise.

6. REFERENCES

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