EXTRACTING THE CHANNEL ALLOCATION INFORMATION IN A SPECTRUM POOLING SYSTEM USING CYCLIC FEATURE DETECTION

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ABSTRACT

Spectrum pooling is a resource sharing strategy, which allows a license owner to share a sporadically used part of his licensed spectrum with a renter system, until he needs it himself. For a frictionless operation of a spectrum pooling system, the license owner has to have the absolute priority to access the shared spectrum. This means, the renter system has to monitor the channel and extract the channel allocation information (CAI), i.e. it has to detect, which parts of the shared spectrum the owner system accesses to, in order to immediately vacate the frequency bands being required by the license owner and to gain access to the frequency bands, which the license owner has stopped using. This paper proposes using cyclic feature detection for the extraction of the CAI in a specific spectrum pooling scenario, where the license owner is a GSM network and the spectrum renter is an OFDM based WLAN system.

1. INTRODUCTION

The spectrum pooling concept, which has been investigated in [1] and [2] can be considered as a first step towards a fully dynamic demand oriented spectrum allocation strategy. In [2], an OFDM based spectrum pooling system has been proposed, which makes it possible for the spectrum renter to adapt the number and the position of the modulated carriers according to the channel allocation information (CAI), i.e. the channel occupation of the license owner, thus minimizing the impact of the renter system on the operation of the owner system. In [2], the CAI is extracted from the channel at regular intervals, during the so called silent periods, in which the renter system stops transmitting and performs energy measurements to detect the presence of the owner system in the channel. The energy detection approach requires the introduction of the silent periods, since this method is unable to discriminate between the signals of the owner and renter systems, and it has a poor reaction speed, because no detection is possible between two silent periods. To be able to monitor the CAI continuously, algorithms are required, which are capable of discriminating between the two signals and of detecting the presence of the owner signal even under the interference from the renter signal in the same frequency band. This paper investigates a specific spectrum pooling scenario which has a GSM network as the license owner and a wireless LAN system based on OFDM as the spectrum renter, as shown in Fig.1. Fig.2 illustrates a possible channel occupation of the proposed spectrum pooling system at a given time. In our paper, we propose exploiting the cyclostationary properties of the license owner signal to extract the CAI from the channel. We employ a cyclic feature detector to detect GSM-specific cyclic features at each GSM subband. Since the cyclic signatures of the OFDM based WLAN and GMSK modulated GSM signals differ significantly, this approach allows the detection of the presence of the owner signal in the channel under severe interference from the renter signal. A detailed discussion about cyclostationarity and cyclic detectors can be found in [3].

2. CYCLOSTATIONARITY

Cyclic feature detection exploits the cyclostationary properties, which exists in most man-made communication signals, providing improved presence detection performance compared to simple energy detection methods. The main advantage of the cyclic feature detection is its discriminatory capability. Since the cyclostationary properties of different signals are usually unique, distinct cyclic signatures can be used to separate the signals, even if they overlap in the frequency domain.

A signal \( x(t) \) is called cyclostationary, when its time varying autocorrelation function \( R_{xx}(t,t+\tau) = E\{x(t)x^*(t+\tau)\} \) is periodic in time \( t \) and admits a fourier series representation

\[
R_{xx}(t,t+\tau) = \sum_{\alpha} R_{xx}^{\alpha}(\tau)e^{j2\pi\alpha t} \tag{1}
\]

where the sum is taken over integer multiples of fundamental frequencies \( \alpha \). The Fourier coefficients, which depend on the lag parameter \( \tau \) can be calculated as

\[
R_{xx}^{\alpha}(\tau) = \lim_{T \to \infty} \frac{1}{T} \int_{-T/2}^{T/2} R_{xx}(t,t+\tau)e^{-j2\pi\alpha t} dt \tag{2}
\]

With the assumption of cycloergodicity [3], this expression reduces to

\[
R_{xx}^{\alpha}(\tau) = \lim_{T \to \infty} \frac{1}{T} \int_{-T/2}^{T/2} x(t)x^*(t+\tau)e^{-j2\pi\alpha t} dt \tag{3}
\]

\( R_{xx}^{\alpha}(\tau) \) is called the cyclic autocorrelation function, and is continuous in \( \tau \) but discrete in cycle frequency \( \alpha \). For \( \alpha = 0 \), it reduces...
A useful modification of the cyclic autocorrelation function is obtained by deleting the conjugate in the lag product functions (conjugate or nonconjugate) are discrete functions of the frequency impulse with the symbol sequence.

With the unknown symbol timing $\epsilon$, we see that the sequence $z_n$ consists of alternating real and imaginary symbols. This property results in a conjugate cyclostationarity of the GMSK signal, which is going to be investigated in the next section.

### 4. CYCLOSTATIONARY PROPERTIES OF A GMSK SIGNAL

We start our analysis with the conjugate cyclic autocorrelation $R^{\alpha}_{xx}(\tau)$ of a GMSK signal. In light of the discussion above, we are going to consider only the linear part of the signal. Assuming that the timing of the signal is unknown to the receiver, we can express the conjugate cyclic autocorrelation function due to the linear component of the signal as:

$$R^{\alpha}_{xx}(\tau) = \lim_{T \to \infty} \frac{1}{T} \int_{-T/2}^{T/2} s(t+\tau)e^{-j2\pi\alpha\tau}dt.$$  

With the unknown symbol timing $\epsilon$, the following integral of (12) $y(t) = \overline{s^{lin}(t+\epsilon)}s^{lin}(t+\tau+\epsilon)e^{-j2\pi\alpha\tau}dt$ more closely, we see that it contains a periodic component $y_{per}(t)$

$$y(t) = \sum_{m=-\infty}^{\infty} z_m c_0(t-\tau-mT_s) + y_{per}(t)$$  

$y_{per}(t)$ is nonrandom and periodic with a period of $2T_s$ because of the fact that $z_n$ is a sequence of alternating real and imaginary.
expressing the infinite sum of phasors as an infinite sum of impulses, we get

\[ R_{\alpha}^{kf_{s}/2}(\tau) = \frac{w}{T_s} \int_{-\infty}^{\infty} e^{-j2\pi f \tau} C_0(f) \text{df} \]

From (18), we conclude that the energy contained in the \( R_{\alpha}^{kf_{s}/2}(\tau) \) depends on the amount of the spectral overlapping between \( C_0(f) \) and \( C_0(\frac{0}{T_s} - f) \), which is illustrated in Fig.4(a) for \( k = 1 \). Since the spectral overlapping is maximum for \( k = 1 \) the resulting cyclic correlation for \( k = 1 \) is obviously the strongest one. The magnitude of the conjugate cyclic autocorrelation function \( R_{\alpha}^{kf_{s}/2}(\tau) \) of a GMSK signal with \( BT_s = 0.3 \) is shown in Fig.5, where the discrete cyclic correlation surfaces of the signal at \( \alpha = \pm f_s/2 \) are clearly visible.

It can also be shown, using a similar analysis, that the GMSK signal also exhibits nonconjugate cyclostationarity with a cycle frequency \( \alpha = kf_s \). The cyclic correlation function can be calculated as

\[ R_{\alpha}^{kf_{s}/2}(\tau) = \frac{w}{T_s} \int_{-\infty}^{\infty} e^{-j2\pi (f + kf_s) \tau} C_0(f) C_0(kf_s - f) \text{df} \]

Fig.4(b) illustrates the spectral overlapping between \( C_0(f) \) and \( C_0(kf_s - f) \) for \( k = 1 \). The spectral overlapping in this case is very small, leading to a very faint cyclic signature, which is much more difficult to detect under noise and interference. From this reason, we have chosen to exploit the conjugate cyclostationarity of the GMSK signal for the extraction of the CAI.

5. CYCLIC FEATURE DETECTION

The cyclic feature detector used in our paper detects the presence of the GMSK modulated signal exploiting its conjugate cyclostationarity at the cycle frequency \( \alpha = f_s/2 \). The detector operates by generating a decision statistics integrating the frequency components of the conjugate spectral correlation density estimate \( \hat{S}_{xx}^{\alpha}(f) \) of the received signal \( r(t) \).

\[ V(\alpha) = \int_{-\infty}^{\infty} \hat{S}_{xx}^{\alpha}(f) \text{df} \]

This detector is very similar to the single cycle detector proposed in [3] and in [5], the only difference being that we use the conjugate...
spectral correlation density to form the decision statistics, instead of the nonconjugate one. In our work, $S_{\alpha_f}(f)$ has been estimated using a time smoothing method on a data segment of length $T_0$. Fig. 6 shows the decision statistics for a GMSK signal with $BT_0 = 0.3$ for different values of the cycle frequency $\alpha$. As expected, the decision statistics $V(\alpha)$ exhibits maxima at the cycle frequencies $\alpha = \pm f_c/2$. For the decision making, we use an algorithm devised to detect the presence of those maxima.

6. SIMULATION RESULTS

In the following simulations, the license owner is a GSM system with a bandwidth of 200 kHz per channel and a symbol rate $f_c = 1/T_s = 270.833$ kbit/s. The spectrum renter is an OFDM based WLAN system with 8 carriers and a carrier separation of 200 kHz, and uses QPSK modulation on each carrier. Both pure AWGN and frequency selective multipath fading channels are considered. In the latter case, we chose the typical urban channel model [6] for the GSM and Indoor B channel [7] for the WLAN system with user speeds of 5m/s. The signal to interference ratio SIR is defined as the ratio of the power of the GSM signal to the power of the interfering WLAN signal which falls into the same 200 kHz band. Fig 7 plots the receiver operating characteristics (ROC) of the proposed detector for a SIR of 0 dB and three different $T_0$ for the multipath case. As a comparison, the ROC for a case without multipath propagation is also shown. The probability of detection $P_d$ and the false alarm rate $P_{false}$ are defined as:

$$P_d = \text{Prob}(\text{GSM detected} | \text{GSM and WLAN are present})$$

$$P_{false} = \text{Prob}(\text{GSM detected} | \text{only WLAN is present})$$

The results indicate a degradation in the performance of the detector due to the frequency selective nature of the multipath propagation channel. Increasing the length of the observation window $T_0$ leads to an increase in the performance of the detector, at the expense of reducing the reaction speed of the overall system. The same effects can be observed in Fig 8, where $P_d$ vs. SIR for a fixed false alarm rate $P_{false} = 0.05$ is plotted. For the multipath case, which has more practical relevance, a satisfactory detection performance is achieved for SIR $\geq 3$dB and $T_0 \geq 2$ms.

7. CONCLUSION

We have demonstrated the use of cyclic feature detection in extracting the CAI in a spectrum pooling system where a GSM network is the license owner and a WLAN system is the spectrum renter. The proposed algorithm eliminates the need of silent periods and allows continuous channel monitoring. The simulation results indicate that a satisfactory performance can be achieved for SIR $\geq 3$ dB. The overall detection probability of the spectrum pooling system can be further increased by using multiple cyclic feature detectors distributed inside the WLAN cell, which perform independent channel measurements. Determining the SIR levels which can be encountered in practice is a subject of further investigations.

REFERENCES


