Abstract:

It is desirable for cognitive radios and future dynamic C2 systems to recognize and process any type of received signal without a priori knowledge. This paper utilizes the properties of PSK (phase shift keying) modulation schemes to create an iterative detection algorithm that determines the modulation scheme and symbol rate of any received PSK signal.
An Iterative Blind Detection Algorithm for PSK Modulations

Nicholas Johnson, Michael Civerolo, Nicholas Lumsden
SPAWAR Systems Center Pacific, Information Operations Division
San Diego, CA 92152-5001

Abstract — It is desirable for cognitive radios and future dynamic command and control (C2) systems to recognize and process any type of received signal without a priori knowledge. This paper utilizes the properties of PSK (phase shift keying) modulation schemes to create an iterative detection algorithm that determines the modulation scheme and symbol rate of any received PSK signal. This is a critical military command and control (C2) capability...

Keywords—BPSK; QPSK; 8PSK; PSK; Detection; Modulation; Cognitive Radio;

I. INTRODUCTION

A. Background

Cellular networks, ISM (industrial, scientific, and medical), and even military frequency bands are becoming more crowded with less available spectrum. The threat of crowded spectrum, foreign jamming, and general electromagnetic interference (EMI) may lead to a future military command and control (C2) domain that would require data links to change their modulation and frequency dynamically. Dynamic frequency would allow available spectrum to be utilized while dynamic modulation would allow the signal’s properties to adjust to dynamic bandwidth or signal-to-noise ratio (SNR) requirements at the new frequencies. In this scenario, any future C2 receiver would have to be able to quickly detect any unexpected modulation changes to keep up with changing spectral environments. The digital modulation family of phase shift keying (PSK) is widely used in commercial and military applications. This paper focuses on a blind iterative detection technique to quickly find any PSK modulation and determine what type of PSK modulation it is [1,2,3,4].

Phase shift keying is a type of digital modulation which translates digital binary data into phase shifts on a carrier wave. For example a binary phase shift keyed (BPSK) system will transmit a particular sinusoidal signal to indicate a binary 1 and transmit the same sinusoid 180 degrees out of phase to indicate a binary 0. These two modulated waves would be referred to as the two BPSK “symbols”. [5] This type of modulation can transmit more information into every symbol by allowing more discrete phase states. For instance, having four possible phase shifts in the transmitted sinusoid provides four different symbols and can therefore transmit twice as much information per symbol (i.e. can transmit two bits per symbol as there are now 4 different symbols to transmit). Phase shift keying (PSK) is a very common type of modulation that is used in many applications including cellular phones, wireless modems, military applications, satellite communications, and many more applications.

With the introduction of cognitive radios, software defined radios, and other similar systems, it is desirable to have methods to detect the modulation of a received signal without having prior knowledge of the signal. This allows a receiver to be used to receive a various number of signals instead of only those it was designed to receive. Current cognitive radios either detect modulation based on brute force methods of successively attempting several demodulation techniques or by using a lookup table to determine what the signal might be at a certain frequency. The first method is not computationally efficient and the second method is not dynamic and adaptable to new signals. Several other widely used techniques for identifying PSK communication utilize analog circuits with differing methods of synchronous detection [7, 8]. Much research has also been focused on applying methods of statistical analysis to determine the likelihood of a PSK signal being present in a given channel [9, 10]. The method presented in this paper takes advantage of the signal properties and its inherent mathematical decomposition.

B. M-PSK Signal Properties

PSK digital modulation consists of symbols that have digital information coded into the phase of a sinusoidal carrier at a specified frequency. All M-PSK modulations (where M is a power of 2) consist of M number of possible sinusoidal symbols representing log_2(M) bits of information. These M number of possible sinusoidal symbol waveforms are represented in (1) where A is the amplitude, M is a power of 2 representing the number of possible symbols, and C is a constant phase offset to obtain the desired digital constellation shape.

\[ A \cos(\omega_{c}t + \frac{n\pi}{M} + C) \text{ where } n= 0, 1, \ldots, M-1 \] (1)
C. Algorithm and Applications

In this paper, a detection algorithm is presented that uses a simple iterative algorithm to detect any PSK modulation scheme. This algorithm uses a repeating process of squaring and high pass filtering to turn the M-PSK waveform into a single frequency sinusoid absent of phase changes. The number of algorithm iterations that it takes to collapse the waveform into a single sinusoid indicates the value of M for any M-PSK modulation.

This algorithm facilitates blind detection of only M-PSK waveforms. There are many other types of modulation schemes, but PSK detection is applicable to IEEE 802.11a,b,g, many RFID standards, IEEE 802.15.4 (Zigbee), cable modems, deep space telemetry, Bluetooth 2, LTE, IEEE 802.16 (WiMax), CDMA cellular, TETRA, PHS, and TFTS.

II. ALGORITHM DEVELOPMENT

This new detection algorithm uses iterations of squaring, high pass filtering, and FFTs to determine the type of M-PSK modulation. The algorithm is most easily explained with an example. A QPSK example signal is used to show how the algorithm blindly detects the symbol rate, bit rate, and modulation type.

A QPSK signal is used with the binary digits 00, 01, 11, and 10 mapping to the four symbols S1, S2, S3, and S4 respectively below in (2) through (5). The additive I and Q (in-phase and quadrature) sinusoids on the left side of (2) through (5) can be simplified to a single sinusoid on the right side of (2) through (5). This can be easily verified by squaring both sides of the equality and simplifying with the Pythagorean trigonometric identity and a double angle formula. These QPSK waveforms are also shown pictorially in Fig. 1 as their time based waveforms and in Fig. 2 as a digital constellation.

\[
S1: \frac{\sqrt{2}}{2} \cos(\omega_c t) + \frac{\sqrt{2}}{2} \sin(\omega_c t) = \cos(\omega_c t - \frac{\pi}{4}) \\
S2: \frac{\sqrt{2}}{2} \cos(\omega_c t) - \frac{\sqrt{2}}{2} \sin(\omega_c t) = \cos(\omega_c t - \frac{3\pi}{4}) \\
S3: \frac{\sqrt{2}}{2} \cos(\omega_c t) - \frac{\sqrt{2}}{2} \sin(\omega_c t) = \cos(\omega_c t - \frac{5\pi}{4}) \\
S4: \frac{\sqrt{2}}{2} \cos(\omega_c t) - \frac{\sqrt{2}}{2} \sin(\omega_c t) = \cos(\omega_c t - \frac{7\pi}{4}) 
\]

The results on the right hand side of (6) through (9) contain a DC term (½) and phase shifted sinusoids at twice the original frequency. Equations (10) through (13) show the results of the squared symbols after using HPF (high pass filtering) to remove the DC term and scaling to get the sinusoidal amplitude equal to 1. Notice that the phase constants in (6) through (9) have been reduced to equivalent phase constants with absolute...
values less than $2\pi$ in (10) through (13) (e.g. phase shift of $-7\pi/2$ is equivalent to phase shift of $-3\pi/2$).

\[
S1^2: \frac{1}{2} + \frac{1}{2} \cos(2\omega_0t - \frac{\pi}{2}) \xrightarrow{HPF} \cos(2\omega_0t - \frac{\pi}{2}) \hspace{1cm} (10)
\]

\[
S2^2: \frac{1}{2} + \frac{1}{2} \cos(2\omega_0t - \frac{3\pi}{2}) \xrightarrow{HPF} \cos(2\omega_0t - \frac{3\pi}{2}) \hspace{1cm} (11)
\]

\[
S3^2: \frac{1}{2} + \frac{1}{2} \cos(2\omega_0t - \frac{5\pi}{2}) \xrightarrow{HPF} \cos(2\omega_0t - \frac{\pi}{2}) \hspace{1cm} (12)
\]

\[
S4^2: \frac{1}{2} + \frac{1}{2} \cos(2\omega_0t - \frac{7\pi}{2}) \xrightarrow{HPF} \cos(2\omega_0t - \frac{3\pi}{2}) \hspace{1cm} (13)
\]

The QPSK signal has been squared, high pass filtered, and scaled (one algorithm iteration). The possible waveforms now take on the form of those shown in Fig. 3.

Figure 3. QPSK Time Based Waveforms After First Algorithm Iteration

\[
\begin{align*}
S1, S3 \quad & \quad S2, S4
\end{align*}
\]

B. Second Algorithm Iteration

The first iteration of the algorithm transforms the four possible QPSK symbols into two different sinusoids at twice the frequency. The second iteration of the algorithm again consists of squaring, high pass filtering, and scaling. This is shown below in (14) through (17) where the results of (10) through (13) are squared.

\[
S1^4: \cos^2(2\omega_0t - \frac{\pi}{2}) = \frac{1}{2} + \frac{1}{2} \cos(4\omega_0t - \pi) \hspace{1cm} (14)
\]

\[
S2^4: \cos^2(2\omega_0t - \frac{3\pi}{2}) = \frac{1}{2} + \frac{1}{2} \cos(4\omega_0t - 3\pi) \hspace{1cm} (15)
\]

\[
S3^4: \cos^2(2\omega_0t - \frac{\pi}{2}) = \frac{1}{2} + \frac{1}{2} \cos(4\omega_0t - \pi) \hspace{1cm} (16)
\]

\[
S4^4: \cos^2(2\omega_0t - \frac{3\pi}{2}) = \frac{1}{2} + \frac{1}{2} \cos(4\omega_0t - 3\pi) \hspace{1cm} (17)
\]

The results on the right hand side of (14) through (17) show that the fourth power symbols contain a DC term ($\frac{1}{2}$) and phase shifted sinusoids at four times the original frequency. Equations (18) through (21) show the results of the fourth power symbols after using HPF (high pass filtering) to remove the DC term and scaling to get the sinusoidal amplitude equal to 1. Notice that the phase constants in (14) through (17) have been reduced to equivalent phase constants with absolute values less than $2\pi$ in (18) through (21) (e.g. phase shift of $-3\pi$ is equivalent to phase shift of $-\pi$).

\[
S1^4: \frac{1}{2} + \frac{1}{2} \cos(4\omega_0t - \pi) \xrightarrow{HPF} \cos(4\omega_0t - \pi) \hspace{1cm} (18)
\]

\[
S2^4: \frac{1}{2} + \frac{1}{2} \cos(4\omega_0t - 3\pi) \xrightarrow{HPF} \cos(4\omega_0t - \pi) \hspace{1cm} (19)
\]

\[
S3^4: \frac{1}{2} + \frac{1}{2} \cos(4\omega_0t - \pi) \xrightarrow{HPF} \cos(4\omega_0t - \pi) \hspace{1cm} (20)
\]

\[
S4^4: \frac{1}{2} + \frac{1}{2} \cos(4\omega_0t - 3\pi) \xrightarrow{HPF} \cos(4\omega_0t - \pi) \hspace{1cm} (21)
\]

The result of the second iteration of the algorithm is four identical symbols. Running the four symbols through two iterations of the algorithm makes them all collapse to the same identical sinusoid. This shows that running any QPSK signal through two iterations of the algorithm will collapse the signal to a single sinusoid since the QPSK signal is equal to one of the four symbols at any given time. This result shows the purpose of the algorithm: repetitively squaring, high pass filtering, and scaling a PSK signal will eventually collapse it to a single sinusoid. A cognitive radio receiver could determine what type of PSK modulation any signal had by running iterations of the algorithm until the spectrum collapsed to a single sinusoid.

Figure 4. QPSK Time Based Waveforms After Second Algorithm Iteration

\[
\begin{align*}
S1, S2, S3, S4
\end{align*}
\]

III. SPECTRAL PROPERTIES AND FURTHER PROOF OF ALGORITHM

Using this algorithm in a cognitive radio receiver requires a Fourier transform or some means of evaluating the spectral content of the signal after each algorithm iteration. Figure 5 illustrates the spectral content of a typical QPSK signal. Once the PSK detection algorithm runs its first iteration, the FFT is taken once again and shown in Figure 6. It can be seen that the spectral content of Figure 6 indicates properties of a PSK signal now at twice the original frequency. However, no further information can be extracted at this point. The algorithm is run for a second iteration, and it is shown in Figure 7 that the plot has collapsed into a more concise spectral line centered at four times the original frequency. This indicates that the PSK signal has collapsed to a sinusoid after two iterations of the algorithm.
Expanding these results to M-PSK modulations, the spectrum plots would collapse after the first algorithm iteration for BPSK, the third iteration for 8-PSK, and so-forth.

IV. CONCLUSION AND FUTURE WORK

The algorithm presented in this paper has shown that PSK modulation techniques can be identified without a priori knowledge of the signal. Through the use of iterative mathematical operations, M-PSK techniques are recognized with minimal computations. The algorithm further defines the modulation type by evaluating spectral content at each iteration through Fourier analysis.

Future work could be performed by expanding the algorithm to account for the increase in frequency at each algorithm iteration. In addition, an extension could be provided to autonomously evaluate the spectral content of the signal under test after each FFT operation. This would be a necessary feature to enable operation in an actual radio receiver.

REFERENCES