Classification of Digital Modulations Mainly Used in Mobile Radio Networks by means of Spectrogram Analysis

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Abstract. In this paper a new method of modulation classification is proposed. For the analysis, modulation signals and their spectrograms were obtained in the Matlab program. The classification method is based on spectrogram image recognition and it can discriminate between various digital signal modulations, such as FSK, BPSK, MSK, QPSK and QAM. The new method was tested using modulated signals corrupted by Gaussian noise, and it is well usable with signal-to-noise ratios as low as 10 dB.

Keywords: Modulation, Classification, Spectrogram.

1 Introduction

In connection with the requirement for faster and more reliable communication, the present digital processing methods and digital communications are mainly used. Together with the rapid growth of cellular technologies, PCS (Personal Communication Services) and WLAN services in the last decade, a number of different wireless communication standards were proposed and employed, and each of them has its own unique modulation type, access technique, etc. To realize a seamless inter-communication between these different systems, a multiband, multimode smart radio system, such as software radio, is becoming the focus of commercial and research interests. The automatic modulation classification technique, which is indispensable for the automatic choice of the appropriate demodulator, plays an important role in such a multimode communication system [1]. Automatic identification of the type of digital modulation has found application in many areas, including electronic warfare, surveillance, and threat analysis [2].

ASK (Amplitude Shift Keying), BPSK (Binary Phase Shift Keying), QPSK (Quadrature Phase Shift Keying), FSK (Frequency Shift Keying), QAM (Quadrature Amplitude Modulation), MSK (Minimum Shift Keying) belong to the best-known digital modulations. These modulation types are used in modern radio telecommunication systems (GSM, WiFi, WiMAX, etc.).

In recent years, various methods of the modulation classification were developed. However, most of them are based on the knowledge of some parameters of received signal and the other methods are computationally very intensive.

This paper describes a new method of modulation classification, which is based on spectrogram image recognition.

2 Obtaining Signal Spectrograms

Spectrograms for long signal intervals were analyzed. Simulations were performed in the Matlab simulation software, where the examined signal was obtained from modulator models. The signals with FSK, MSK, BPSK, QPSK and QAM16 modulation types were submitted to spectral analysis. For simplification, the same settings were used for all modulators, i.e. the modulation signal with the same data-signaling rate was used for all modulators. All the modulators used the same carrier frequency. For the FSK modulation, frequencies f_1 and f_2 were set so that the medium frequency was equal to the carrier frequency of the other modulations. The sampling rate for all types of modulation was chosen identical.

It is necessary to take into account some requirements while determining the segment size for spectrum calculation. The first one is the requirement that solely signal elements with the same value in the segment should appear. The simplest solution of this problem is to choose the segment size equal to the signal element size. The second requirement, which must be satisfied, is sufficient discrimination ability along the frequency axis. It is necessary for the discrimination of nearby frequencies that are present in MSK modulation. Then the obtained module and phase spectrograms (Figs. 2.1. – 2.6.) were analyzed by means of the recently proposed analysis.

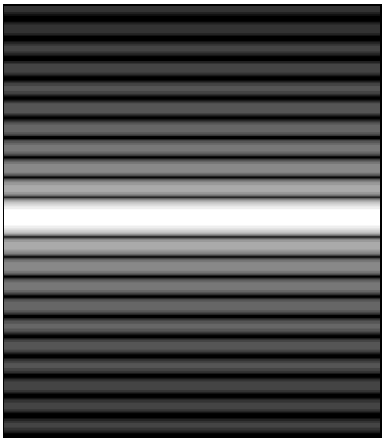

Fig. 2.1. Module spectrogram of BPSK, QPSK signals

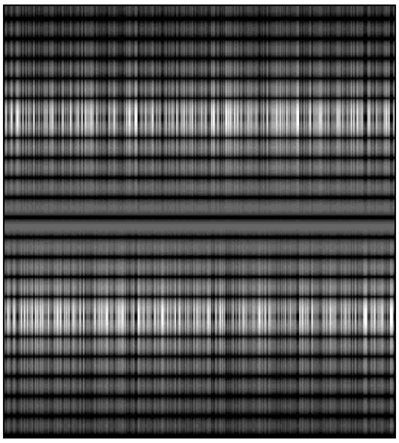

Fig. 2.2. Module spectrogram of FSK signal

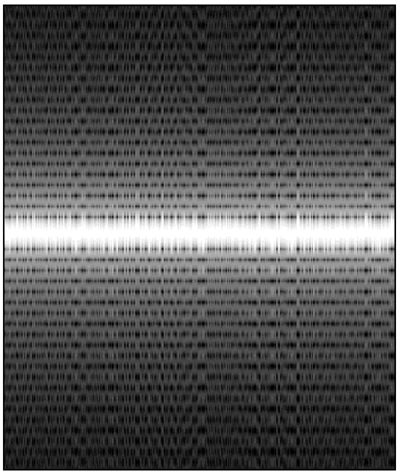

Fig. 2.3. Module spectrogram of MSK signal

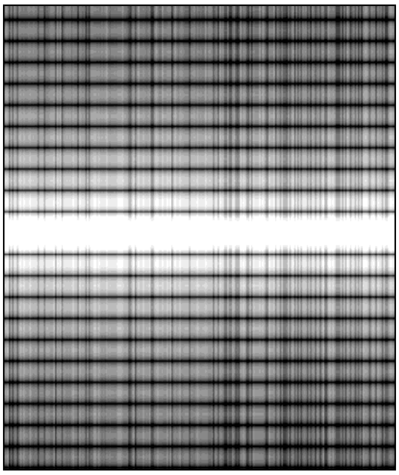

Fig. 2.4. Module spectrogram of QAM-16 signal

Fig. 2.5. Phase spectrogram of BPSK signal

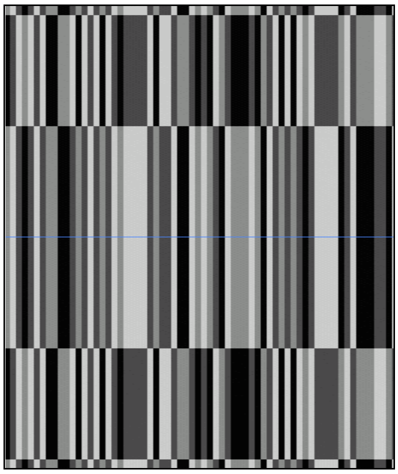

Fig. 2.6. Phase spectrogram of QPSK signal

For the purpose of classifying noisy signals, the broadband white noise was added to the modulated signals so that the signal-to-noise ratio decreased to a value of 10 dB. The spectrograms of noisy signals were obtained in the same way.

3 Detection of Signal Element Size

As previously said, the analysis results are very dependent on the segment size used for spectrum calculation. The characteristic properties of modulation types are apparent only in spectrograms that were obtained with the segment size equal to the signal element size. If the segment size is equal to several lengths of signal element, the modulation recognition method based on the spectrogram image analysis is unusable. Therefore it is necessary to find the signal element length prior to obtaining a spectrogram. For this purpose we suggested three methods: wavelet transform, cepstrum analysis, and autocorrelation function.

4 Analysis of Signal Spectrograms

4.1 Analysis of Module Spectrograms

For the estimation of spectrogram features, it is advantageous to use histograms of their images. The digital grey-scale image can be presented as a matrix of numbers $\mathbf{A}(i, j)$, where i in the range [0, M-1] and j in the range [0, N-1] are indexes of rows or columns of the image (matrix).

For the analysis of module spectrograms it is suitable to observe the count of maximum brightness levels (amplitudes) in separate rows (on separate frequencies). The analysis results are shown in the following figures.

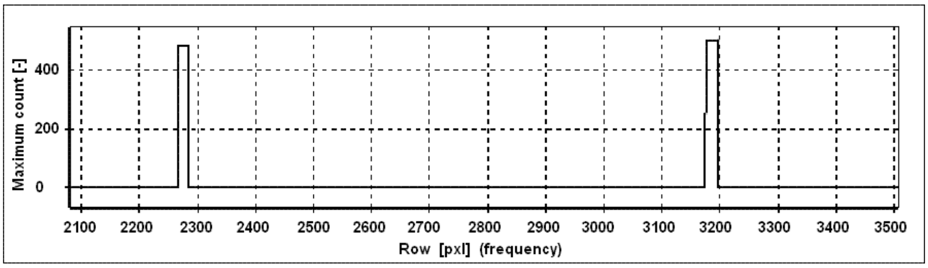

Fig. 4.1. Occurrence count of maxima in separate rows of FSK spectrogram

The FSK modulation type is easiest for recognition, because two distant carrier frequencies occur in the module spectrogram. Therefore the method of finding the maximum occurrence in separate rows easily detects two characteristic maxima for this modulation (Fig. 4.1).

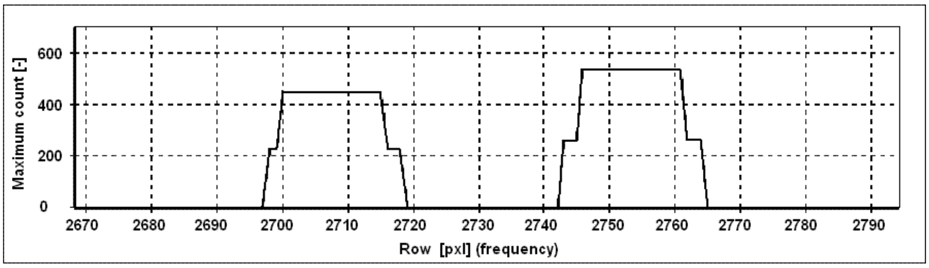

Fig. 4.2. Occurrence count of maxima in separate rows of MSK spectrogram

Similar to FSK modulation, two carrier frequencies can be found in the module spectrogram of the MSK modulation. However, it is not easy to recognize them from the spectrogram. Therefore a detailed cut of the spectrogram part was made in order to find more easily the areas of maximum brightness values. These areas allow the recognition of two carrier frequencies close to each other, as apparent in Fig. 4.2.

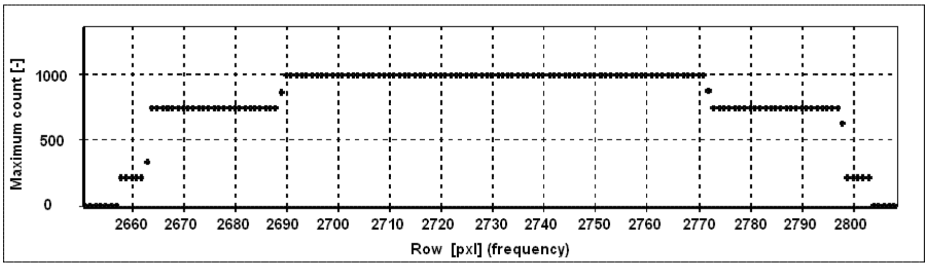

Fig. 4.3. Occurrence count of maxima in separate rows of QAM-16 spectrogram

The QAM-16 modulation has one carrier frequency with varying amplitude. It can be found from the constellation diagram of QAM-16 modulation that three different values of amplitude occur in the QAM-16 module spectrogram. In Fig. 4.3, the three amplitude levels are shown in the form of three main values of maximum count (in the form of three symmetrical steps in this discrete function).

4.2 Analysis of Phase Spectrograms

The analysis of module spectrograms described in chapter 4.1 can detect three different modulations with varying frequency or amplitude. For the remaining two modulation types (BPSK and QPSK) it is necessary to analyze the phase spectrogram. The graph of maximum occurrence count in separate rows does not provide any usable properties.

From the detailed view of phase spectrograms it is apparent that several different values of brightness (phases) occur in the area around the carrier frequency. The number of these values corresponds to the number of phase positions used in the modulation. Thus the analysis must evaluate how many phase values occur at the carrier frequency. If the carrier frequency is not known, it can be easily found from the module spectrogram. The counts of phase values at the carrier frequency of BPSK, QPSK and QAM16 spectrograms are shown in the following three figures.

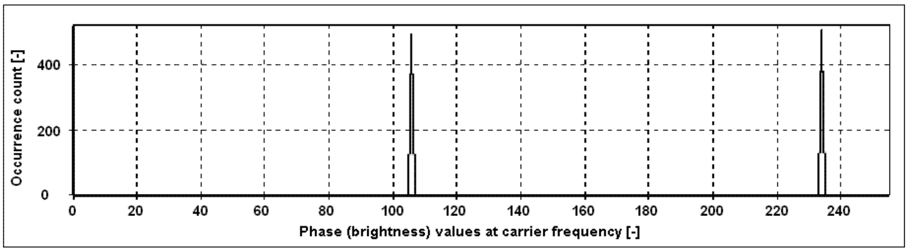

Fig. 4.4. BPSK: Occurrence count of phase (brightness) values at carrier frequency

The two maxima in the graph in Fig. 4.4 correspond with the theoretical expectation that BPSK modulation has two phase positions.

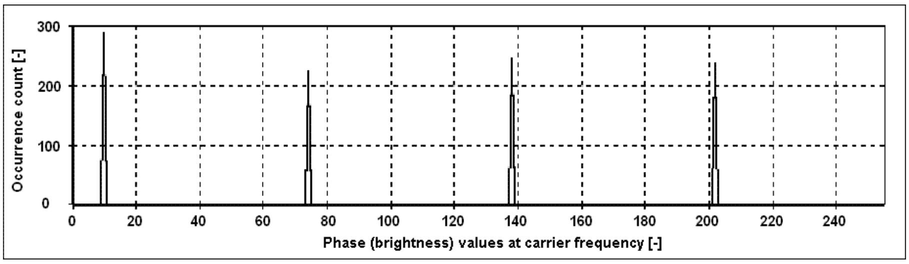

Fig. 4.5. QPSK: Occurrence count of phase (brightness) values at carrier frequency

From the analysis results, which are shown in Fig. 4.5 is apparent that the modulation has four possible phase positions. This corresponds again with the theoretical expectations for the QPSK modulation.

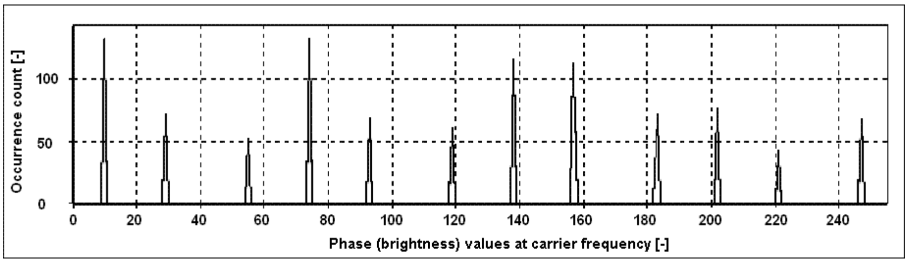

Fig. 4.6. QAM-16: Occurrence count of phase (brightness) values at carrier frequency

In addition to the analysis of the amplitude spectrogram of the QAM-16 modulation described in chapter 4.1, we can analyse also the phase positions. A constellation diagram of the QAM-16 modulation shows 12 various phase positions. Fig. 4.6 confirms this fact because 12 maxima are apparent there. This additional phase analysis is a suitable for the reliable determination of the modulation type because the discriminability of amplitude values markedly decreases with increasing noise.

4.3 Analysis of noisy signals

The module and phase spectrograms of noisy signals were analyzed in the same way. The signal-to-noise ratio of 10 dB was used in all cases.

The added noise in all the spectrogram analyses caused smoothing of acute transitions in the resulting graphs. This fact is insignificant for the FSK and MSK modulations and the characteristic properties are still clearly visible in the graphs. For the QAM-16 modulation, the smallest of the three characteristic symmetrical steps of discrete function (see Fig. 4.3) was smoothed due to the noise. However, the characteristic steps are still perceptible and the QAM modulation is distinguishable from the other modulation types. Due to the added noise, the determination of possible amplitude values is more complicated for signals with low amplitude variation. Therefore, the analysis of phase spectrograms is advisable for additional evaluation. The influence of noise is not significant in the analysis of phase spectrograms.

5 Conclusion

We designed a new method for the classification of digital modulations by means of spectrogram image analysis. Spectrograms, in which the characteristic properties of modulations are apparent, were obtained with the segment size equal to the signal element length. Thus it was necessary to find the signal element length prior to the spectrogram computation. Analysis of histograms of spectrogram images was used for the survey of modulation properties. By means of this analysis, the typical parameters of each modulation were found (carrier frequency, number of amplitude levels, number of phase positions). Spectrograms of noisy signals were also obtained and analysed. It has been proved that the recently designed method is also suitable for signals disturbed by noise.

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