BLIND SIGNALING IDENTIFICATION FOR MULTIMODE SDR RECEIVER WITH APPLICATIONS TO PUBLIC SAFETY COMMUNICATIONS

H. Ercument ZORLU, Murat CEVEN, Ibrahim OLCER, Hamza OZER (UEKAE - TUBITAK , Kocaeli, TURKEY;{ercument, ceven, iolcer, hozer}@uekae.tubitak.gov.tr);
Huseyin ARSLAN (Electrical Engineering Department, University of South Florida, Tampa, FL, USA; arslan@eng.usf.edu)

ABSTRACT

Public safety communications across the world operates over a wide range of frequencies with a variety of signaling and modulation formats. Interoperability between public safety agencies during major disasters is a significant concern [1-4]. Similar problem is also valid in military radio communications, and communication between military radios and public safety radios. Software Defined Radio (SDR) based transceivers can solve this problem with multimode and multiband operations. An SDR based radio capable of handling multiple public and military radio communications and serving as a gateway to bridge various incompatible public safety radios as well as military radios are being developed in The Scientific and Technological Research Council of Turkey (TUBITAK). By using that system an HF radio can communicate with a VHF/UHF radio.

1. INTRODUCTION

In this paper, our aim is to blindly identify various signaling/modulation formats corresponding to a variety of public safety and military radios. We expect the SDR radio to recognize the incoming signal blindly so that it can process the signal with the appropriate mode of receiver blocks. Blind modulation identification has a long and rich history especially for military applications [5]. In Cognitive Radio (CR) and SDR domain, relatively limited contributions are available in the literature [1, 6]. Used modulation at the transmitter is identified and classified at various parts of the receiver chain under mostly ideal and flat fading channel conditions. Some practical channel scenarios are available with limited and favorable modulation sets. Almost all of the work focus on identifying the modulation rather than the signaling and waveform (or used standard). More importantly, most of the proposed techniques use assumptions that are nonrealistic and often not practical. Also, one need to note that in some of the current and most of the upcoming wireless standards there might be several forms of modulations in a single waveform. A good example for this case is Long Term Evolution (LTE) and WiMAX. Even many of the old and current standards use different modulation in training and data modes of operations, like in the case of Stanag-4285 and Stanag-4539. Therefore, modulation identification is not the main focus of this study. In SDR/CR, the goal should be shifted to identify the signaling rather than the modulation. Also, in these systems, the identification is required at the very early stage of the receiver chain so that the appropriate receiver blocks can be used. In other words, the identification should be done under the impact of all types of channel and radio impairments (including the effects of frequency offset, sample clock offset, symbol timing offset, without achieving frame synchronization, under the impact of IQ imbalances, possibly under the effect of frequency selective fading channel conditions and before the equalization). It can not be assumed that the time, phase, and frequency synchronization is achieved and also we can not assume that the equalization and other channel compensations are performed before identifying the signaling type. In addition, it can not be assumed that the receiver sampling rate is integer multiple of the transmitted symbol rate as we don't know what is being transmitted and we would not know what should be the appropriate sampling rate before deciding on the signaling type. Therefore, the blind identification should be done before sample rate correction as well. All these practical and realistic assumptions make the blind signaling identification a very difficult task. Especially, without any type of a priori information and without limited sets of possible signaling formats, the problem of identifying any arbitrary signaling is an extremely difficult process, if not impossible. With the current digital communication technologies, the possible waveforms that can be designed are limitless. Therefore, in our study, we focus on identification from a finite set of signaling formats and we assume that the a priori standard information is available at the receiver. It is assumed that all the practical channel and operating conditions and identifying the signaling as early as possible in the receiver chain. As mentioned above, our focus is on public safety and military type of waveforms and standards.

Advantage of the proposed work is not only providing multi-mode operation of the receiver, but also in optimizing the receiver performance based on the detected signaling format. An excellent application of this is Association of Public Safety Communications Officials International (APCO) P-25 Phase-II receiver design. The current APCO P-25 Phase-II receivers are required to demodulate both Phase-I and Phase-II signals to achieve backward compatibility. Therefore, it is suggested to use a non-coherent detector based on FM discriminator along with integrate and dump filtering to demodulate both C4FM (which is the modulation for Phase-I) and CQPSK (which is the modulation for Phase-II). This limits the possibility of designing optimal coherent receivers for demodulation of Phase-II signals. Such a receiver suggestion makes sense if the receiver does not have the capability of identifying the transmitted waveform. However, with the proposed blind signaling identification, we don't have to use the non-coherent reception and have the opportunity to optimize the receiver performance. At this point, we have focused on the identification of the following standards; Stanag-4285, Stanag-4197, Stanag-4539, APCO P-25 Phase-I, APCO P-25 Phase-II, and Terrestrial Trunked Radio (TETRA). This list will grow further eventually.

Some specifics of the interested standards:

- APCO P-25: Symbol rate is 4.8 ksps. Phase-I and Phase-II use different modulations but compatible, C4FM and CQPSK, respectively.
- TETRA: Symbol rate is 18 ksps. Used modulation is pi/4-DQPSK.
- Stanag-4285: Symbol rate is 2.4ksps. Used modulations are BPSK, QPSK, and 8PSK
- Stanag-4197: This is a parallel multicarrier modem. Various modulations are used in the carriers of preambles (DPSK, bi-phase DPSK) and data frames (DQPSK).
- Stanag-4539: Symbol rate is 2.4 ksps. Multi-level PSK (2/4/8-PSK) and QAM (16/32/64-QAM) modulations are used.

2. FEATURES FOR SIGNAL IDENTIFICATION

In this study, it is assumed that the captured signal is oversampled with sampling rate possibly not matched to the symbol rate, and we assume the received signal includes all the practical impairments. The features given in Table 1 can be used to identify the signals from one another.

Table 1. Signal classification features used in this paper and the type of analysis to capture the corresponding feature.

Used feature	Analysis type
Operating frequency	Spectrum analysis
Correlation / Partial match filtering	Time and modulation analysis
Moment / Cumulant	Higher order statistics of time signal
Used bandwidth	Spectrum analysis

To be able to simulate the signal identification performance, we have used the last three of the above features. The proposed algorithm has the following steps:

1. Classification by used bandwidth. TETRA has the bandwidth of 25 kHz which is the widest among all the signal set. APCO P-25 Phase-I (C4FM) and Phase-II (CQPSK) has also different bandwidths, the bandwidth of Phase-I is 12.5 kHz while the bandwidth of Phase-II is 6.25 kHz. All the remaining Stanag signals occupy the bandwidth of 3 kHz. The resultant algorithm estimates the bandwidth and discriminates the signals as TETRA, APCO P-25 Phase-I, APCO P-25 Phase-II and Stanag.

2. Classification by Moment/Cumulant. To discriminate between Stanag type signals a moment based algorithm is used that separates the signals as multi-carrier and single-carrier [7]. Since the performance of the algorithm depends on the SNR estimation, it is assumed that the SNR is estimated with in the -/+3dB uniform error range. Following the moment estimation Stanag signals are classified as multi-carrier (Stanag-4197) and single-carrier (Stanag-4285, Stanag-4539).

3. Classification by Correlation / Partial match filtering. Stanag-4285 and Stanag-4539 distinguished by their autocorrelation properties. Both of the signals have different frame structures and repeating parts of different block lengths as shown in Figure 1 and Figure 2. Since the length of repeating parts and repetition frequency is known, it can be used as a discriminating attribute for Stanag-4285 and Stanag-4539.

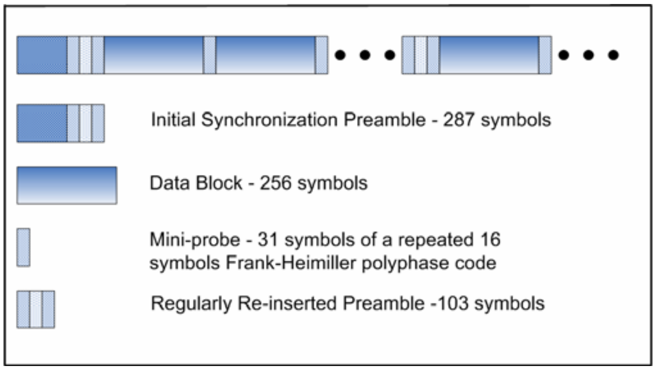

Figure 1. Stanag-4539 frame structure.

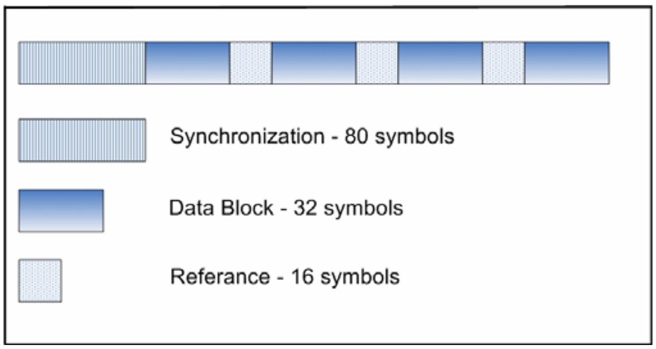

Figure 2. Stanag-4285 frame structure.

3. GENERAL BLOCK DIAGRAM OF THE RECEIVER

The block diagram of the signal identification is given in Figure 3. The first stage of our receiver will be the spectrum and time analysis. The second stage is the signal extraction. The final stage is the feature extraction and blind classification. In this paper, the first two stages are assumed to be done and the focus will be in the third stage.

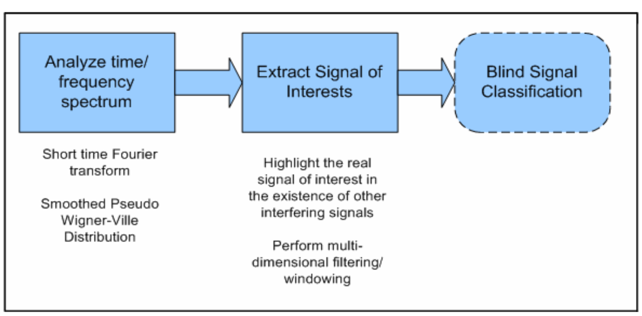

Figure 3. General block diagram of signaling identification module.

In the signal classification stage, it is assumed that the baseband signals are sampled at fs=100 kHz, sufficient to cover the bandwidth of whole signal set.

At the first stage of the classification algorithm (Figure 4), bandwidth estimation and comparison is carried out. While estimating the bandwidth, power spectral density (PSD) of the signal is obtained by Welch method which is based on the concept of averaging calculations of DFT of an N-sample overlapping sequence. In the PSD estimation, 1024 point FFT and Hamming windowing is used while the overlap ratio has been chosen as %50. In the PSD, the number of bins whose value is greater than a certain threshold level relates the bandwidth of the signal. Threshold level is estimated as the mean value of the 75 (%15) least values of 512 points around the center. Then, the number of the bins over this value is calculated and compared with the assigned numbers to discriminate between TETRA, APCO P-25 Phase-I, APCO P-25 Phase-II and Stanag (4285-4539-4197).

At the following stage remaining Stanag signals are classified as single-carrier (4285-4539) and multi-carrier (4197) by comparing the estimated moment value. The moment value is estimated by the following equation:

$$M_{30}=E\{|y(n)|^{6}\}/\ E^{3}(|y(n)|^{2}) \qquad (1)$$

This value is compared with a specified threshold, depending on the SNR, to decide whether single-carrier or multi-carrier Stanag signal.

At the last stage of the algorithm, Stanag-4285 and Stanag-4539 signals are separated by their autocorrelation properties arising from their frame structures. In the synchronization part of the Stanag-4285, the first 31 symbols repeat itself in each frame. On the other hand, Stanag-4539 comprises mini-probe blocks where the first 16 symbols repeat itself. The autocorrelation of the signal is estimated according to these values, and the resulting maximum values are compared to match between Stanag-4285 and Stanag-4539. The flowchart of the algorithm is given in Figure 4.

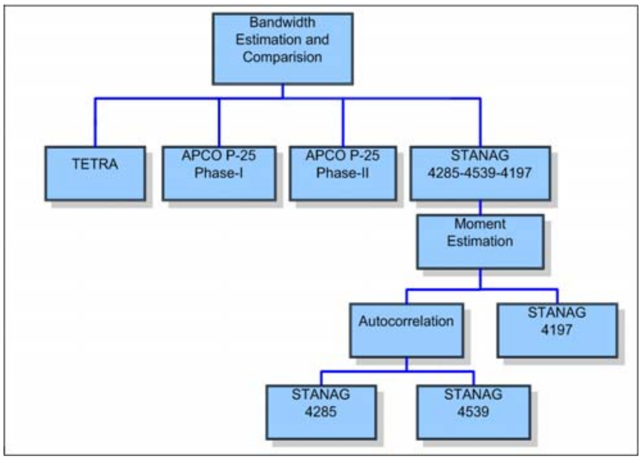

Figure 4. Algorithm flowchart.

4. REPRESENTATIVE RESULTS

Several simulations are performed in variety of channel and interference conditions. The following tables show the success rates in Additive White Gaussian Noise (AWGN) and dispersive medium with different SNR values (Table 2 and Table 3).

Table 2. Success rates for signaling identification in AWGN radio channel.

SNR(dB)	3	5	6	8	10	13	15	20
TETRA	100	100	100	100	100	100	100	100
APCO Phase-I	96	100	100	100	100	100	100	100
APCO Phase-II	100	100	100	100	100	100	100	100
Stanag - 4285	72	95	99	99	99	99	99	99
Stanag - 4539	74	88	92	100	100	100	100	100
Stanag - 4197	84	98	99	99	99	99	99	99

The above results indicate that the SNR value of 6 dB is enough to detect the signal correctly with a success rate over %90. For low SNR values (3-5 dB), Stanag-4285 and Stanag-4539 signals are mostly confused with Stanag-4197 and rarely confused between each other (1-2%).

Table 3. Success rates for signaling identification in multipath radio channel (delay length=1/2400sec).

SNR(dB)	3	5	6	8	10	13	15	20
TETRA	48	94	99	100	100	100	100	100
APCO Phase-I	49	74	84	94	100	100	100	100
APCO Phase-II	95	99	99	100	100	100	100	100
Stanag - 4285	60	72	80	83	86	89	90	91
Stanag - 4539	53	56	65	71	73	80	80	81
Stanag - 4197	86	97	99	99	99	99	99	99

In the multipath channel, for an identification success rate over %80 at least 10 dB SNR is required. The success rate of multipath channel isn't as good as it is in AWGN channel, since the rate of confusion increases between single-carrier (4285-4539) and multi-carrier (4197) Stanag signals with respect to AWGN channel.

5. CONCLUSION

SDR brings solutions to interoperability issues in public safety communications and in military communications. A multi-band, multi-mode SDR transceiver is expected identify the type of the signal automatically and operate in the appropriate mode. In this paper, it has been shown that the correct signal type can be identified with a certain success rate from a signal set under different channel conditions. The signal set contains three public safety radio standards TETRA, APCO P-25 Phase-I, APCO P-25 Phase-II and three military radio standards Stanag-4285, Stanag-4539, Stanag-4197. In AWGN channel, success rate over 90% is reached if SNR>6dB, in multipath channel, success rate over 80% is reached if SNR>8dB. Better success rates could be reached if the algorithm performance of multi-carrier and single-carrier discrimination is increased.

6. ACKNOWLEDGEMENT

This work has been supported by TUBITAK project, number 106A013. The main scope of the project is to establish a test center to test and evaluate SDR products. One of the main objectives of this project is to develop a universal test platform which will provide the necessary test infrastructure and advanced R&D facilities for software defined radio and Software Communication Architecture

(SCA) compliant waveform development in the 1.6 MHz - 2.6 GHz frequency band.

7. REFERENCES

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