

Multiband Multi-rate Narrowband Software Defined Radio waveform based on CPM

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Abstract— Future Software Defined Radio (SDR) waveforms require increasing throughputs to support a wide variety of applications for military, commercial, and civilian applications. It requires a combination of spectral efficiency and better BER performance. To meet the heterogeneous requirement of future wireless networks, a multi-band multi-rate narrowband waveform for software-defined radio based on Continuous Phase Modulation (CPM) presented in this paper. The proposed waveform has ten modes of operation with the maximum achievable throughput of 176.2 kbps. Due to higher spectral efficiency provided by CPM, we show that the proposed waveform attains higher throughput by shifting towards multiple bandwidths and for the appropriate choice of alphabet size M , pulse length L and modulation index, h . In the end, the BER performance of proposed multiband modes for CPM is analyzed.

Keywords—Continuous Phase Modulation (CPM); SDR narrowband waveform

I. INTRODUCTION

A Software Defined Radio (SDR) is a radio transceiver that is well defined in software and whose physical layer conduct, parameters, and protocols can be fundamentally modified through software as a waveform. This approach will increase the flexibility of the device by changing its operating parameters while not having an upgrade or exchange of any hardware parts. Thus, SDR provides a platform capable of supporting distinctive waveforms. SDR waveform is defined as a program through which modulation, filtration, narrowband/wideband operation and all different components of radio functions are characterized [1]. Radios give diverse functionalities in various testing environments. The main distinction lies in the focus of implementation, a few waveforms are designed which accomplish higher data rate, whereas others prioritize range and transmission capacity. It is recognized that strategic military radios need wideband and narrowband waveforms for fulfilling most of the military requirements. Wideband networking waveform (WBNW) ensures a high data rate, this lowers the range whereas for applications requiring long-range communication, narrowband networking waveform (NBNW) tends to be a dominant choice [2].

Modern strategic VHF communication frameworks require increased data rates regardless of small channel bandwidth of 25 KHz. As the demand for high data rates increased, the requirements of functioning well across a variety of modes,

ranges and waveform standards also increased. Software Defined Radio (SDR) addresses these challenges by taking into account dynamic spectrum management [3].

To support heterogeneous requirements of future wireless networks, the increased demand for higher data rates and higher quality has motivated to design a flexible waveform that supports multiple bandwidths/multiple data rates. To achieve this multiband, our focus on implementation in this paper is to design a narrowband SDR waveform based on the Continuous phase modulation (CPM) scheme. In recent years, the demand for bandwidth efficient good signaling schemes having constant envelope property has increased for digital transmission over band-limited radio stations. For this reason, continuous phase modulation (CPM) could be a great choice for applications over satellite and terrestrial radio systems due to its narrow power spectrum and attractive power/bandwidth performance. Continuous phase modulation (CPM) is a nonlinear modulation scheme where the phase responds linearly to the input data. CPM has an advantage of a constant envelope that makes it robust to amplitude distortion results in efficient utilization of power in the transmit amplifiers so the power amplifier can work in saturation. A complete overview of CPM can be found in [4]. In [5], M-ary Full response CPM schemes have been investigated; a gain in terms of E_b/N_0 is acquired without expanding bandwidth by increasing the number of levels M from 2 to 4, contrasted with MSK. Bigger enhancements are possible with partial response systems [6] where the instantaneous frequency depends on more than one information symbol.

The patent [6] explains the M-ary partial response system with regard to their minimum Euclidean distance, error likelihood, and spectral properties. An optimum receiver supported the Viterbi algorithm is proposed. To have an RC framework with pulse length L the modulation index h should be chosen larger as L is increased which offer decrease values of the upper bounds on the minimum Euclidean distance. It has been analyzed in [7] that in the NATO NBWF, to increase the data rate the symbol duration (T) itself gets reduced and the symbol rate (R) increases by keeping the amount of information (M) constant. This expansion of bandwidth is compensated with the reduction of modulation index h . However, for high throughput modes, this spectral growth cannot be compensated

by a reduction in h , as it possesses two and three 25 KHz channels, which do not meet the necessity, as the military range is a scarce resource. Therefore, to increase the data rate the modulation order M should be increased at the expense of demodulator complexity. The design of a multi- h continuous phase modulation (CPM) waveform has been patented in [8] to increase the throughput three times the information rate already accessible on UHF military satellite communication (MILSATCOM) channels. It allows way better spectral/power efficiency by expanding M with lower indices, provided an equivalent high gain as accomplished in 4-ary modulation previously. 2.6 dB of gain is accomplished without expanding bandwidth by shifting to partial response with the expense of receiver complexity. CPFSK-OFDM systems have been implemented in [9] by using software defined radio (SDR) and analyzed them in the awgn channel. Better Ber performance is achieved by using modulation index 0.75 for CPFSK.

The focus of this paper is to design a multiband waveform based on narrowband CPM software defined radio (SDR) waveform to support the increasing demand for high throughput for better future wireless networks. To this end, Section II introduces the system model for CPM. Section III presents the throughput analysis of the proposed narrowband networking waveform. Section IV describes a proposed waveform consisting of several CPM modes providing high throughput with better quality. Section V presents the BER curve that demonstrates the performance analysis for CPM modes and their comparison.

II. GENERAL SYSTEM DESCRIPTION

A. Transmitter side of CPM narrowband SDR waveform

For CPM systems, the complex baseband representation of the transmitted signal is

$$s(t, I) = \sqrt{\frac{2E_s}{T_s}} e^{j\varphi(t, I)} \quad (1)$$

where the information carrying and time-varying phase of the n th symbol is given by

$$\varphi(t, I) = 2\pi h \sum_{i=-\infty}^n I_i q(t - iT_s) \quad (2)$$

with $nT_s < t \leq T_s$ is the symbol interval.

The parameter I denote a long sequence of uncorrelated M -ary data symbols, denoted by $I = I_i$ take on values $I = \{\pm 1, \pm 3, \dots, \pm (M-1)\}$ if M is even. E_s denotes the average energy per information symbol, T_s represents one symbol period. The variable h is referred to as modulation index $h = r/p$ where (r and p are relatively prime integers), $q(t)$ is the phase-smoothing response, and its derivative is the frequency pulse $g(t)$ assumed of duration LT and area $1/2$ and the

amplitude of the baseband pulse $g(t)$ is chosen to give the maximum phase change $h\pi$ radians over each symbol interval. Defining the baseband phase response (phase pulse)

$$q(t) = \int_{-\infty}^t g(\tau) d\tau; \quad -\infty < t < \infty \quad (3)$$

A causal CPM system is obtained if the frequency pulse $g(t)$ satisfies

$$\begin{cases} g(t) = 0; & LT < t < 0 \\ g(t) \neq 0; & 0 \leq t \leq LT \end{cases} \quad (4)$$

If $g(t) = 0$ for all $t > LT$ the signal is called full response CPM signal and if $g(t) \neq 0$ for all $t > LT$ entire the signal is called partial response CPM [6]. We have assumed both full response [5] as well as partial response schemes [6]. Typical types of instantaneous frequency pulses are rectangular (LREC) and raised-cosine (LRC). The pulse $g(t)$ is assumed Gaussian by a time-bandwidth product of 0.3 [4].

B. The receiver side of CPM narrowband SDR waveform

The complex envelope of the received signal thus reads

$$r(t) = s(t, I) + n(t) \quad (5)$$

Where $s(t, I)$ the M -ary symbol is related to the information symbol I . In addition, the branch metric calculation block calculates the correlation between the generation of template signals waveform $t(I_i, \theta)$ and the received signals $r(t)$ as shown in figure 1. $v_n(I_i, \theta)$ represents the n th-received symbol to be the symbol I_i that reaches the trellis with the associated signal phase θ .

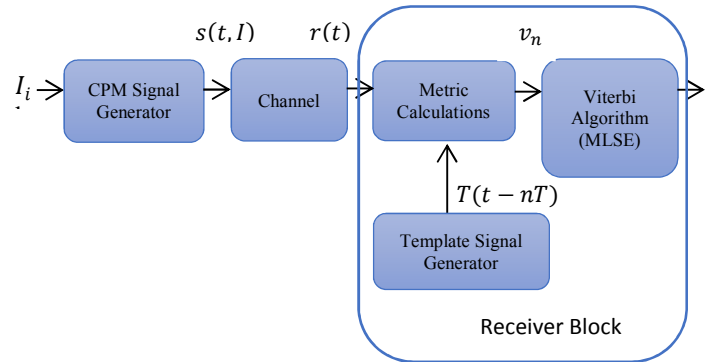


Figure 1: MLSE receiver block diagram.

The criterion of maximum likelihood (ML) results in the decision of a received signal $r(t)$ based on conditional probabilities $p(s(t, I)|r(t))$. A detector that minimizes the likelihood of wrong decisions must observe the received signal throughout the entire time axis and select the infinitely long I_i sequence that minimizes the likelihood of error. This is referred to as maximum likelihood sequence estimation (MLSE) [10].

III. THROUGHPUT CALCULATION

The numerical system for the computation of achieving a throughput of the proposed narrowband waveform is currently proposed [11]. The available RF bandwidth for the narrowband waveform is assumed 25 kHz, 50 kHz, 75 kHz, and 100 kHz. Utilizing this accessible bandwidth B_{RF} , we compute the maximum allowed sampling rate (f_s) (chips/sec). Note that the CPM block generates the data at the rate f_s , which is shown as:

$$f_s = \frac{2B_{RF}}{B_{norm}N_s} \quad (6)$$

Where B_{RF} is the RF bandwidth, N_s is the up-sampling factor and B_{norm} denote the normalized bandwidth which is calculated from transmitted data using its normalized, two-sided Power Spectral Density (PSD). Given the f_s , the overall throughput for the k^{th} user is given as:

$$R_k = f_s \log_2(M) \quad (7)$$

where M is the alphabet size and R_k is the throughput of the k^{th} user.

As an example, consider, $B_{RF}=25$ KHz, $M=2$, $N_s=4$, $B_{norm}=0.7$. The throughput of the k^{th} user comes out to be 17.6 kbps.

IV. PROPOSED MULTIBAND WAVEFORM

The CPM waveform is described by many modes that are possible for different values of M , h , and L but we have chosen the mode based on the better BER performance. For all modes, the pulse shaping is done with a Gaussian pulse of bandwidth time product 0.3.

Table I suggests a parametric depiction of ten proposed CPM modes, giving user data rates/throughput(R) extending from 17.4 kbps to 88.1 kbps in 25 kHz channel bandwidth. In the first column of Table I, the ten unique modes are demonstrated with their user data rates (R) in the last column. Furthermore, L denotes the symbol duration, which specifies that all modes use the partial response as well as full response modulation, and has chosen to be 1, 2, and 3. The parameter M indicates the number of different symbols to be transmitted, which is 4-ary and 8-ary for all the different modes; h is representing the modulation index (max. phase change in a symbol duration) i.e. $\{1/2, 1/4, 1/8, 1/16\}$.

To summarize, the increase in the data rate (R) is achieved with an increase of the symbol rate or the sampling rate (f_s) where the symbol rate (f_s) is somehow reciprocal to the normalized bandwidth (B_{norm}). According to the proposed multiband waveform concept, by increasing RF bandwidth from 25 KHz to 100 KHz channel, will increase the symbol rate (f_s), which in turn increases the data rate (R) [7]. Therefore, by shifting towards multiple bandwidths of 25 KHz, 50 KHz, 75

KHz and 100 KHz, utilizing the same normalized bandwidth and ber performance the throughput increases from 17.4 Kbps to 69.6 Kbps for mode 1 as shown in table II, same goes for all other modes. It can be observed that for fixed bandwidth all modes have a distinctive normalized bandwidth occupation. The lower the normalized bandwidth it needs, the higher will the user data rate or throughput (R).

TABLE I: Proposed Narrowband CPM Waveform Transmission Modes for $B_{RF} = 25$ KHz.

Mode	M	h	L	Normalized Bandwidth (B_{norm})	Sampling Rate (KHz)	Data Rate (kbps)	E_b/N_0 to reach BER of 10 ⁻³
Mode 1	8	1/2	2	1.078	5.8	17.4	4.2 dB
Mode 2	8	1/4	2	0.6207	10.1	30.2	7.8 dB
Mode 3	4	1/2	3	1.0817	11.5	23.1	5.5 dB
Mode 4	8	1/8	3	0.3724	16.8	50.3	14.4 dB
Mode 5	4	1/4	2	0.6606	18.9	37.9	9.5 dB
Mode 6	4	1/8	1	0.5526	22.6	45.2	13.7 dB
Mode 7	8	1/16	2	0.273	22.9	68.7	19.7 dB
Mode 8	4	1/8	2	0.4349	28.7	57.5	15.4 dB
Mode 9	4	1/16	1	0.3151	39.7	79.3	19.5 dB
Mode 10	4	1/16	2	0.2837	44.1	88.1	21.3 dB

TABLE II: Proposed Multimode Multiband CPM transmission Modes of operation for $B_{RF} = 25$ KHz, $B_{RF} = 50$ KHz., $B_{RF} = 75$ KHz and $B_{RF} = 100$ KHz.

Mode	M	h	L	Data Rate (Kbps)			
				$B_{RF} = 25$ KHz	$B_{RF} = 50$ KHz	$B_{RF} = 75$ KHz	$B_{RF} = 100$ KHz
Mode 1	8	1/2	2	17.4	34.8	52.2	69.6
Mode 2	8	1/4	2	30.2	60.4	90.6	120.8
Mode 3	4	1/2	3	23.1	46.2	69.3	92.4
Mode 4	8	1/8	3	50.3	100.8	151.0	201.4
Mode 5	4	1/4	2	37.9	75.7	113.5	151.3
Mode 6	4	1/8	1	45.2	90.5	135.7	180.9
Mode 7	8	1/16	2	68.7	137.4	206.0	274.7
Mode 8	4	1/8	2	57.5	95.0	172.4	229.9
Mode 9	4	1/16	1	79.3	158.7	238.0	317.3
Mode 10	4	1/16	2	88.1	176.2	264.3	352.4

V. BER PERFORMANCE EVALUATION

Based on the system model presented in section II, the BER performance of the proposed Narrowband CPM waveform in the AWGN channel has been evaluated. The simulations have been carried out using MATLAB. Figure 2 shows the corresponding bit error rate (BER) curves for the proposed ten modes presented in table I. It can be seen that for modes 1, 2, 4, and 7 the use of small modulation indexes consume less bandwidth and increased throughput but does not buy the BER performance. Comparing modes 6 and 8 the bandwidth utilized

by the partial response, i.e. $L > 1$ is much less than a full response waveform i.e. $L=1$ using the same indices with an increase in throughput but approximately 1.65 dB loss in performance as shown in figure 3.

For modes, 7 and mode 10 increasing the alphabet size consume more bandwidth but provides better ber performance. However, it must be noted that mode 10 is providing the highest throughput rate of 176.2 kbps while shifting towards multiple bandwidths of 25 KHz to 50 KHz with smallest modulation index, small alphabet size, least consumption of normalized bandwidth, but the price that has to pay is the BER performance.

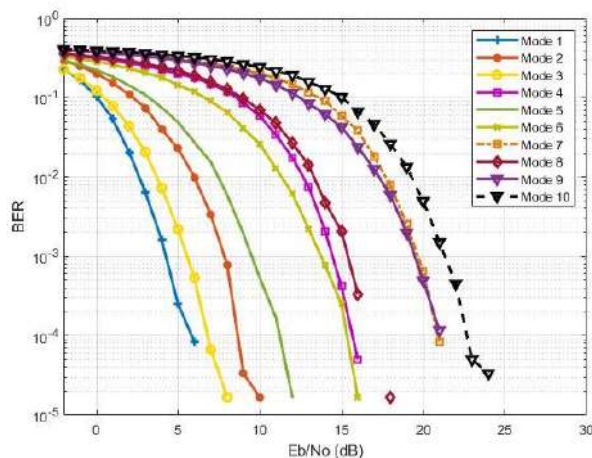


Figure 2: BER Performance of 10 Proposed Modes of CPM Narrowband waveform.

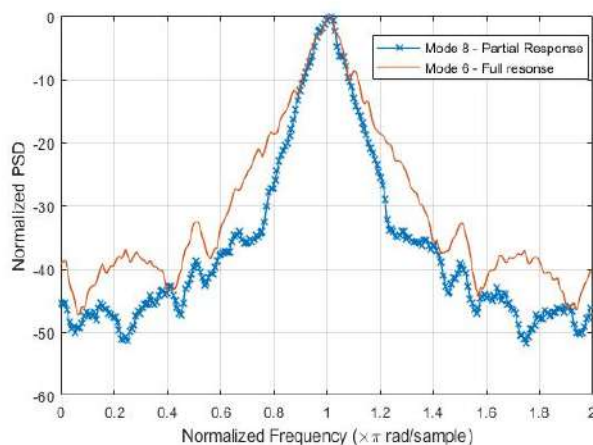


Figure 3: Power Spectrum of CPM signal with different L .

VI. CONCLUSIONS AND FUTURE WORK

A family of waveforms for narrowband continuous phase modulation for software defined radio (SDR) has been presented that supports multiple bandwidth /multiple data rates

where range and throughputs are significantly improved to support heterogeneous requirements of future wireless networks compared to legacy systems. The results indicate that proposed waveforms for appropriate choices of M , h and L have shown to meet user data rates up to 88.1 kbps in 25 kHz bandwidth and have been doubled by shifting toward multiple bandwidths up-to 100 KHz however; it requires high E_b/N_0 for high throughput modes. Though, the AWGN performance is not a sufficient benchmark, the future work is to implement the following proposed multiband CPM transmission modes in SUI Channels.

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