GPP-SDR Implementation of a Low Complexity Generic Receiver for Narrowband and Wideband HF

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***Abstract*—HF remains an essential military operational technology for BLOS communications when SATCOM is not available. 2G and 3G HF standards have been developped for 3 kHz narrowband channels. The latest wideband 4G HF standards enable higher data rates by increasing the bandwidth available for transmission. The two main solutions aggregate either contiguous or non-contiguous 3 kHz narrowband channels up to 24/48 kHz. This paper describes a low complexity generic receiver with channel estimation, time and frequency synchronization for 2G, 3G, 4G and HF-XL standards and a performance evaluation in terms of BER or PDR vs SNR on narrowband and wideband HF channel models. The narrowband and wideband HF standards have been implemented on a GPP-based SDR platform with open-source libraries and run in real-time.**

I. Introduction

High Frequency (HF) remains an essential military operational technnology for Beyond Line of Sight (BLOS) communications when SATtelite COMmunication (SATCOM) is not available.

2G and 3G HF standards have been developped for 3 kHz narrowband channels [1], [2]. The latest wideband 4G standards enable higher data rates by increasing the bandwidth available for transmission [3], [4], [5], [6]. The two main solutions aggregate either contiguous or non-contiguous 3 kHz narrowband channels up to 24/48 kHz.

Most of the literature on reception of narrowband and wideband HF standards considers perfect channel estimation, time and frequency synchronization. This paper describes a low complexity generic receiver with channel estimation, time and frequency synchronization for 2G, 3G, 4G and HF-XL standards and a performance evaluation in terms of Bit Error Rate (BER) or Packet Delivery Ratio (PDR) vs Signal to Noise Ratio (SNR) on narrowband and wideband HF channel models. For the narrowband and wideband HF channel models, the Comité Consultatif International des Radiocommunications (CCIR) and International Telecommunication Union (ITU) Recommandations F.520-2 and F.1487 based on the Watterson channel model are valid for bandwidths up to 12 kHz with a straighforward configuration [7], [8], although the authors in [9] show that the Watterson channel model is still valid for wideband HF standards. Another channel model for wideband HF standards it the Vogler and Hoffmeyer channel model valid for bandwidth up to 1 MHz with a more complex configuration [10]. The narrowband and wideband HF standards have been implemented on a General Purpose Processor (GPP)-based Software Defined Radio (SDR) platform with open-source libraries and run in real-time.

Section II gives a brief overview of 2G-Automatic Link Establishement (ALE), 3G-ALE, 4G-ALE/HF and HF-XL standards. Section III gives a description of the low complexity generic receiver used for 3G-ALE, 4G-ALE/HF and HF-XL standards with channel estimation, time and frequency synchronization. Section IV gives a performance comparison of 2G, 3G, 4G and HF-XL standards in terms of BER or PDR vs SNR on narrowband and wideband HF channel models. Section V gives some details on the implementation of narrowband and wideband HF standards on GPP-based SDR platform.

II. Narrowband and Wideband HF Standards

A. 2G-ALE

As described in the Appendix A of [1], [3] and shown in Figure 1, the 2G-ALE transmitted bursts are structured into 24 bits frames (3 bits for preamble and 21 bits for data) which are Golay (24,12) encoded, interleaved, concatenated with one stuff bit, resulting into 49 bits repeated 3 times and modulated by 8-Frequency Shift Keying (FSK) in the range of 750 - 2500 Hz spaced 250 Hz apart with symbol rate R_s=125 symbols/s (375 bps). The duration of a burst t_d is therefore 392 ms with $N_{tot} = FR_st_d$ samples, F being the oversampling factor (F=96 in the implementation).

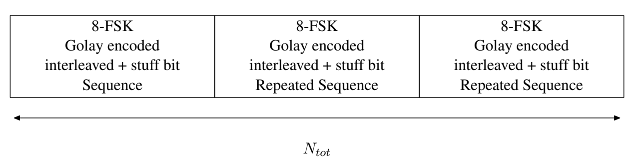

Fig. 1. Structure of the 2G-ALE burst

The receiver uses a half-band filter to remove out-of-band noise followed by a quadrature demodulation, filtering, sampling, majority voting on the three repeated sequences, de-interleaving, and Golay decoding.

B. 3G-ALE

As described in the Appendix C of [1], [2] and shown in Figure 2, the 3G-ALE consists of 6 Burst Waveforms (BW0-5) with 3 kHz bandwidth and structured as concatenated Transmit Level Control/Automatic Gain Contol (TLC/AGC), preamble and data sequences. The data bits (e.g. 26 bits for BW0, 48 bits for BW1, 4n-7 bits with n=32,64,...,512 for BW3, 50 bits for BW5) are CRC-32 encoded for BW3 and encoded either with a convolutional code with rate R=1/2, constraint K=7, generator polynomials (91,121) or R=1/3, K=7, (457,435,367), interleaved, converted into Walsh sequences, repeated, scrambled, modulated by 8-Phase Shift Keying (PSK) and filtered by a Root Raised Cosine (RRC) filter with a roll-off factor of 0.35 with symbol rate R_s=2400 symbols/s. The durations of the bursts t_d are 613.33 ms for BW0, 1306.67 ms for BW1, 373,33+(13.33n) ms for BW3, 1013.33 ms for BW5 with $N_{tot} = FR_st_d$ samples (F=4 in the implementation).

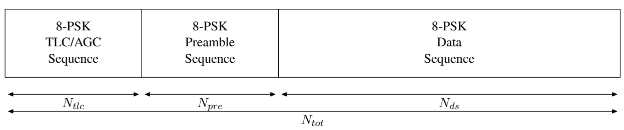

Fig. 2. Structure of the 3G-ALE bursts

C. 4G-ALE/HF

As shown in Figure 3 and described in the Appendix G of [3] and in the Appendix D of [4], 4G-ALE consists of 2 Waveforms Deep-Wideband Automatic Link Establishement (D-WALE) and Fast-Wideband Automatic Link Establishement (F-WALE) with 3 kHz bandwidth. 4G-HF consists of 14 waveforms (WID0-13) with 12 possible bandwidths from 3 kHz to 48 kHz and 4 possible interleaver lengths from ultra short to long. The waveforms are structured as concatenated TLC/AGC, preamble and data sequences. The data bits (e.g. 96 bits for D-WALE and F-WALE) are encoded either by a punctured convolutional code with rate R=1/2, constraint K=7, generator polynomials (91,121) or R=1/2, K=9, (369,491), interleaved, either converted into Walsh sequences and repeated, scrambled, modulated by 8-PSK for WID0 and D-WALE or modulated by M-PSK/M-QAM and structured into alternating frames and miniprobe sequences for WID1-13 and F-WALE, and filtered by a RRC filter with a roll-off factor of 0.35 with symbol rate R_s=2400c symbols/s, with c the number of adjacent channels used for transmission up to 48 kHz, with $N_{tot} = FR_st_d$ samples (F=4 in the implementation).

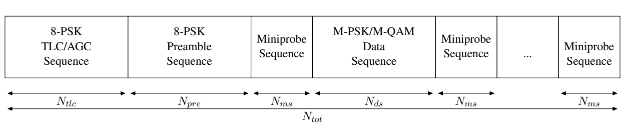

Fig. 3. Structure of the burst 4G-ALE and 4G-HF bursts

D. HF-XL

As described in the Appendix H of [5], the HF-XL consists of 7 waveforms with variable number of channels up to 16 and variable number of frames up to 72. The waveforms are structured as concatenated initialization sequence, preamble, miniprobe and data sequences similarly to Figure 3. The data bits are encoded by a convolutional code with rate R=1/2, constraint K=7, generator polynomials (133,171), interleaved, modulated by M-PSK/M-QAM and structured into alternating frames and miniprobe sequences, and filtered by a RRC filter with a roll-off factor of 0.35 with symbol rate R_s=2400 symbols/s per channel, the number of non-adjacent channels used for transmission up to 16 channels in 64 channels of 3 kHz (total of 192 kHz), leading to a sampling rate FR_s and $N_{tot} = FR_st_d$ samples (F=84 in the implementation).

III. Low complexity generic receiver for 3G-ALE, 4G-ALE/HF and HF-XL with channel estimation, time and frequency synchronization

A low complexity generic receiver for 3G-ALE, 4G-ALE/HF and HF-XL depicted in Figure 4 consists of a time, frequency and phase synchronization component and a hybrid Preamble-based and Decision Directed Least Mean Square DD-LMS channel estimator used to compute a Decision Feedback Equalizer (DFE) structure composed of feedforward and feedback filters.

A. System Model

We consider a time and frequency selective channel with time, frequency, phase offsets and additive white Gaussian noise (AWGN). The received signal $\{y(k)\}$ after low-pass filtering (root raised cosine filter) can be modeled as

$$\begin{aligned} y(k) &= e^{j(2\pi\alpha k+\phi)}\sum_{l=0}^{L-1} h(k,l)x(k-l-\tau)+n(k) \\ &= e^{j(2\pi\alpha k+\phi)}\mathbf{h}^T(k)\mathbf{x}(k-\tau)+n(k) \end{aligned} \tag{1}$$

with τ the time offset, α the carrier frequency offset, ϕ the carrier phase offset, l the multipath index and L the maximum delay spread, $\mathbf{h}(k) = [h(k,0)\dots h(k,L-1)]^T$ the time-varying complex-valued channel attenuations of length L, $\mathbf{x}(k-\tau) = [x(k-\tau)\dots x(k-\tau-L+1)]^T$ the oversampled transmitted vector and n_i the AWGN with variance $N_0/2$ per dimension.

1) Time, frequency and phase synchronization: Time synchronization is performed on the addition of the TLC/AGC sequence and the 8-PSK preamble sequence. A peak search of the correlation function between the received signal and a stored 8-PSK pseudo-random sequence is performed. Assuming $N = N_{tlc}+N_{pre}$, the optimization problem can be written as

$$\hat{\tau} = \underset{k}{argmax} \ \ |r(k)|^2 \tag{2}$$

with

$$r(k) = \frac{1}{N}\sum_{n=0}^{N-1} y(n+k)x^*(n) \quad k\in[0\dots N_{tot}-N] \tag{3}$$

As the correlation function can have several peaks, it is necessary to search for the first significant peak in the correlation function.

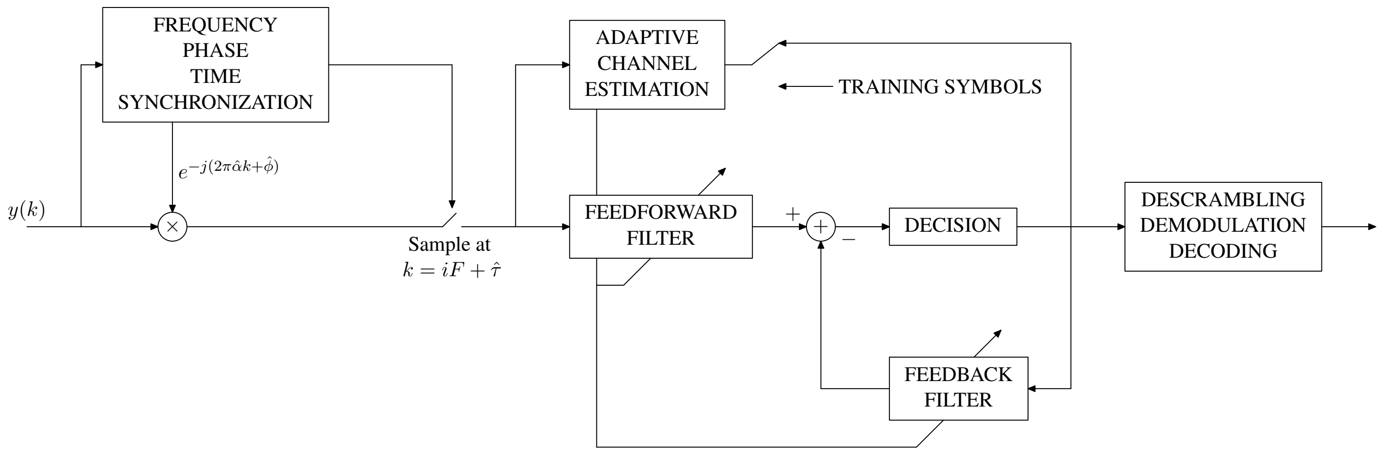

Fig. 4. Block diagram of the generic receiver for 3G-ALE, 4G-ALE/HF and HF-XL with time and frequency synchronization

Carrier frequency and phase synchronization applies the iterative frequency estimation algorithm by interpolation on Fourier coefficients described in [11] to the correlation function between the received signal and a stored 8-PSK pseudo-random sequence signal at the time offset estimate or at the most significant peak of the correlation function. The algorithm is described in Algorithm 1 with $N = N_{tlc} + N_{pre}$ and $z = [z(0) \dots z(N-1)]$ with

$$z(k) = y(k + \hat{\tau})x^*(k) \tag{4}$$

Finally, the data-aided (DA) carrier frequency estimate is given by $\hat{\alpha} = \frac{\hat{\beta}+\hat{\delta}_Q}{N}$, and the DA carrier phase estimate by $\hat{\phi} = arg(X_0)$.

Algorithm 1 Iterative frequency estimation algorithm for DA carrier frequency and phase synchronization

Let $Z = FFT(z)$, $E(k) = |Z(k)|^2$, $k = 0 \dots N-1$
Find $\hat{\beta} = \underset{k}{argmax}\ \ E(k)$
Set $\hat{\delta}_0 = 0$
Loop : for each i from 1 to Q
$\quad X_p = \sum_{n=0}^{N-1} z(n) e^{-j2\pi n \frac{\hat{\beta}+\hat{\delta}_{i-1}+p}{N}}, p = \pm 0.5$
$\quad \hat{\delta}_i = \hat{\delta}_{i-1} + \frac{1}{2} Re\left\{\frac{X_{0.5}+X_{-0.5}}{X_{0.5}-X_{-0.5}}\right\}$
$X_0 = \sum_{n=0}^{N-1} z(n) e^{-j2\pi n \frac{\hat{\beta}+\hat{\delta}_Q}{N}}$

with Q the number of iterations (Q=2 in the implementation). The signal is then corrected and downsampled at instants

$$y(i) = y(k) e^{-j(2\pi\hat{\alpha}k+\hat{\phi})} |_{k=iF+\hat{\tau}} \tag{5}$$

2) Preamble-based and Decision Directed Adaptive Channel Estimation: Assuming a static channel and after synchronization and downsampling, equation (1) can be rewritten as:

$$\mathbf{y} = \mathbf{X}\mathbf{h} + \mathbf{n} \tag{6}$$

with $\mathbf{y} = [y_0 \dots y_{N-1}]^T$, $\mathbf{h}(i) = [h(i,0) \dots h(i, M-1)]^T$, $M = L/F$.

$$\mathbf{X} = \begin{bmatrix} x_0 & 0 & \dots & 0 \\ x_1 & x_0 & \ddots & \vdots \\ \vdots & \ddots & \ddots & 0 \\ x_K & x_{K-1} & \dots & x_0 \\ \vdots & \ddots & \ddots & \vdots \\ x_{N-1} & x_{N-2} & \dots & x_{N-K-1} \end{bmatrix}. \tag{7}$$

We then perform a QR decomposition of matrix $\mathbf{X}$

$$\mathbf{A} = \mathbf{Q}\mathbf{R} \tag{8}$$

with $\mathbf{Q}$ a unitary matrix and $\mathbf{R}$ a lower triangular matrix. The estimated channel is given by

$$\hat{\mathbf{h}} = \mathbf{R}^{-1}\mathbf{Q}^H\mathbf{y} \tag{9}$$

The preamble-based channel estimation is used as an initialization vector in a time-varying multipath channel, for which we apply the complex LMS algorithm [12] as an adaptive channel estimation to track its time variations

$$\mathbf{h}(i+1) = \mathbf{h}(i) + \beta e(i)\mathbf{x}^*(i) \tag{10}$$

with

$$e(i) = y(i) - \mathbf{h}(i)\mathbf{x}(i) \tag{11}$$

the error function and $\mathbf{x}(i)$ the training symbols or the decision symbols provided by the Decision Feedback Equalizer (DFE).

3) Minimum Mean Square Error Decision Feeback Equalizer: The DFE feedfoward and feedback filters are defined by the following equations [13]

$$\mathbf{f}_{ff,i} = (\mathbf{H}_i\mathbf{V}\mathbf{H}_i^H + \frac{1}{SNR}\mathbf{I}_{N_1+1})^{-1}\mathbf{h}_{i,N_1+1} \tag{12}$$

with N_1 the number of precursor taps and

$$\mathbf{H}_i = \begin{bmatrix} h_{0,i} & \dots & h_{M-1,i} & 0 & \dots & 0 \\ 0 & h_{0,i} & \dots & h_{M-1,i} & \ddots & \vdots \\ \vdots & \ddots & \ddots & \ddots & \ddots & 0 \\ 0 & \dots & 0 & h_{0,i} & \dots & h_{M-1,i} \end{bmatrix}. \tag{13}$$

a $(N_1+1)\times(N_1+L)$ channel convolution matrix with $\mathbf{h}_{i,N_1+1}$ the N_1+1 column of $\mathbf{H}$, $\mathbf{V}$ a $(N_1+L)\times(N_1+L)$ diagonal matrix in which the N_1+1 first elements are 1 and the remaining $M-1$ diagonal elements are 0.

$$\mathbf{f}_{fb,i} = -\mathbf{H}_{fb,i}^H \mathbf{f}_{ff,i} \tag{14}$$

$$\mathbf{H}_{fb,i} = \begin{bmatrix} 0 & \dots & \dots & \dots & \dots & 0 \\ \vdots & \ddots & \ddots & \ddots & \ddots & \vdots \\ 0 & \ddots & \ddots & \ddots & \ddots & \vdots \\ h_{M-1,i} & 0 & \ddots & \ddots & \ddots & \vdots \\ \vdots & \ddots & \ddots & \ddots & \ddots & \vdots \\ h_{1,i} & \dots & h_{M-1,i} & 0 & \dots & 0 \end{bmatrix}. \tag{15}$$

The estimated symbols are given by

$$\tilde{x}(i) = \mathbf{f}_{ff,i}^H \mathbf{y} + \mathbf{f}_{fb,i}^H \hat{\mathbf{x}}_i \tag{16}$$

with $\mathbf{f}_{ff,i} = [f_{N_1,i} \dots f_{0,i}]^T$ the feedforward filter, $\mathbf{f}_{fb,i} = [f_{-1,i} \dots f_{-N_2,i}]^T$ the feedback filter with N_2 the number of postcursor taps, $\mathbf{y}_i = [y_{i+N_1} \dots y_i]^T$ and $\hat{\mathbf{x}}_i = [\hat{x}_{i-1} \dots \hat{x}_{i-N_2}]^T$ is a vector of N_2 previous hard-decided symbols from the equalizer.

IV. Channel models for narrowband and wideband HF

The CCIR and ITU Recommandations F.520-2 and F.1487 are based on the Watterson channel model which is valid for bandwidths up to 12 kHz with a straighforward configuration (delay, doppler) [7], [8], although the authors in [9] also show that the Watterson channel model is still valid for higher bandwidths and wideband HF standards. Each tap of the Watterson channel model can be implementated using the algorithm [14] and described in Algorithm 2. Initialization parameters of the implementation are I=64, doppler spread f_m=0.1 Hz for 'Good' and 1 Hz for 'Poor' channels, downsampled rate f_{ds}=96 Hz, sampling rate f_s depending on the narrowband and wideband HF standards, and N_{tot} the number of channel samples as described in previous paragraphs.

Another channel model for wideband HF standards is the Vogler and Hoffmeyer channel model valid for bandwidth up to 1 MHz with a more complex configuration [10]. An implementation of the channel model with configuration files is given in [15].

Algorithm 2 Implementation of the Watterson Channel Model based on Young's Method

Initialize I, f_m(Hz), f_{ds}(Hz), f_s(Hz), N_{tot}

Set variables $\sigma = f_m/2$, $\Delta f = \dfrac{2f_m}{I-1}$, $J = \lfloor f_{ds}/\Delta f \rfloor$

Generate Complex Gaussian Random Sequence $\mathbf{g} \sim \mathcal{CN}(0,\,1)$ with g_i and $i = 0 \dots I-1$

Generate frequency vector $f_i = -f_m + i\Delta f$ with $i = 0 \dots I-1$

Generate Gaussian Spectrum $s_i = \dfrac{1}{\sqrt{2\pi\sigma^2}} e^{\frac{f_i^2}{2\sigma^2}}$ with $i = 0 \dots I-1$

Multiply Gaussian Spectrum with Random Sequence $r_i = g_i s_i$ with $i = 0 \dots I-1$

Zero Pad $\mathbf{z} = [\mathbf{0}_{\lfloor (J-I)/2 \rfloor} \mathbf{r} \mathbf{0}_{\lfloor (J-I)/2 \rfloor}]$

Take Shifted IFFT $\mathbf{h}_{ds} = IFFT([z(J/2 \dots J-1) z(0 \dots J/2-1)])$

Upsample by repetition or interpolation $\mathbf{h}_{us} = [\underbrace{h_0 h_0 \dots h_0}_{f_s/f_{ds}} \dots \underbrace{h_{J-1} h_{J-1} \dots h_{J-1}}_{f_s/f_{ds}}]$

Get Channel Samples $\mathbf{h}_{tus} = [h_0 \dots h_{N_{tot}}]$

Normalize $\mathbf{h} = \dfrac{\mathbf{h}_{tus}}{\|\mathbf{h}_{tus}\|}$

V. Simulation Results

Simulations are conducted to evaluate the performance of the low-complexity generic receiver with 10^4 Monte Carlo simulations.

Figure 5 shows the BER and PDR performance vs SNR of 2G/3G/4G-ALE with the low-complexity generic receiver on AWGN and random channels. In case of random channels, random time, frequency and phase offsets are drawn for each trial with a constant amplitude. It can be observed that there is no loss of performance on random channels in comparison with AWGN owing to the time, frequency and phase synchronization algorithms.

Figure 6 shows the BER and PDR performance vs SNR of 2G/3G/4G-ALE with the low-complexity generic receiver on CCIR 'Good' and 'Poor' channels with time and frequency offsets. In this case, random multipath channels as well as random time, frequency and phase offsets are drawn for each trial. It can be observed that the best performance is obtained with 4G-ALE F-WALE on CCIR 'Poor' channels. Long bursts have higher probability to have propagation errors due to the DD-LMS DFE compared to short bursts.

Table I summarizes the performance of 2G/3G/4G-ALE with the low-complexity generic receiver with time and frequency offsets (TFO) in comparison with standard requirements. Except for the 2G-ALE which has a different receiver, the performance of the proposed receiver is good in case of Gaussian and CCIR 'Good' channels with time and frequency offsets in comparison with standard requirements. A performance degradation can be observed for 3G-ALE and 4G-ALE D-WALE on CCIR 'Poor' channels due to the

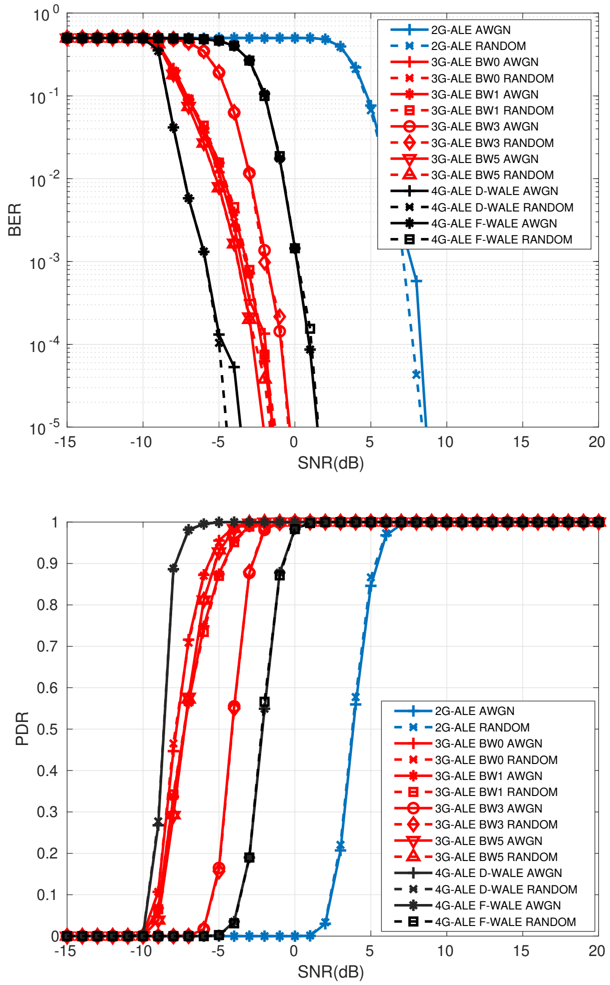

Fig. 5. BER and PDR performance of 2G/3G/4G-ALE on AWGN and random channels

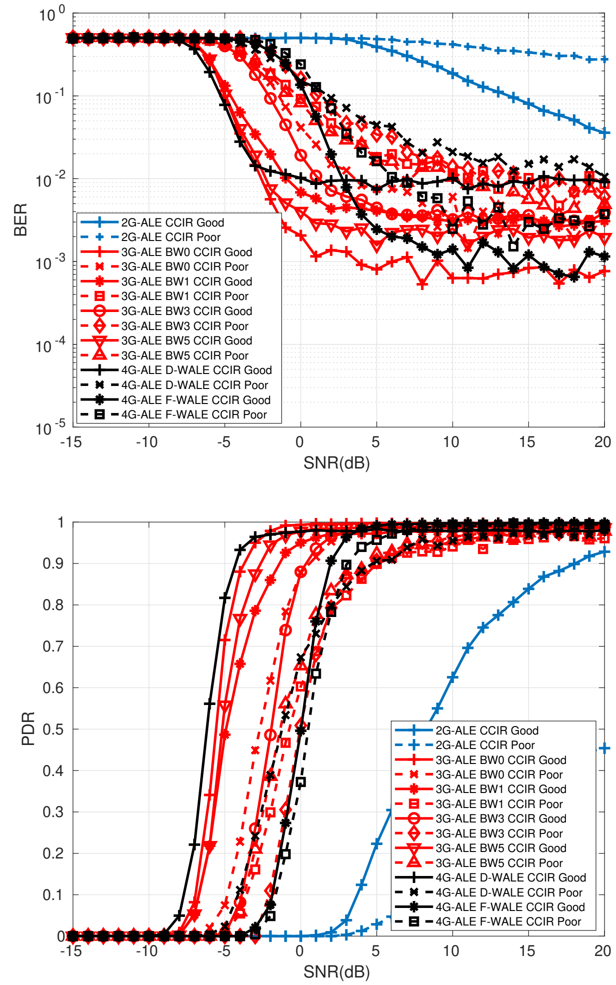

Fig. 6. BER and PDR performance of 2G/3G/4G-ALE on CCIR 'Good' and 'Poor' channels

combination of estimation errors in the receiver introduced by filtering, up/down-conversion, channel estimation, time and frequency synchronization, and propagation errors from the LMS-DD DFE. However, the 4G-ALE F-WALE has a very good performance on CCIR 'Poor' channels and is the best choice for ALE.

TABLE I
REQUIRED SNR FOR A PACKET DELIVERY RATIO OF 95% BETWEEN STANDARD REQUIREMENTS AND IMPLEMENTATION

Standard/Channel	Gaussian/ with TFO	CCIR Good/ with TFO	CCIR Poor/ with TFO
2G-ALE	0/5.5	8.5/8.5(52%)	11/11(21%)
3G-ALE BW0	-7/-5	1/-3	3/1.5
3G-ALE BW1	-7/-4	1/0	3/7
3G-ALE BW3	-/-2.5	-/1.5	-/7
3G-ALE BW5	-7/-5	1/-2	3/7
4G-ALE D-WALE	-6/-7.5	2/-3.5	4/7
4G-ALE F-WALE	2/-0.5	10/2.5	10/4

Figure 7 shows the BER and PDR performance vs SNR of 4G-HF with the low-complexity generic receiver on AWGN and random channels with 1 superframe preamble and Short 'S' interleaver. It can also be observed that there is no loss of performance on random channels in comparison with AWGN owing to the time, frequency and phase synchronization algorithms.

Figure 8 shows the BER and PDR performance vs SNR of 4G-HF with the low-complexity generic receiver on CCIR 'Poor' channels with time and frequency offsets with 1 superframe preamble and Short 'S' interleaver. It can be observed that for DD-LMS DFE BPSK and QPSK waveforms offers the best performance (WID0-6, WID13) while there is a degradation in performance from 8-PSK to 256-QAM.

Table II summarizes the performance of 4G-HF with the low-complexity generic receiver with TFO, 1 superframe preamble, and Short 'S' interleaver in comparison with standard requirements with 20 superframes preamble and Long 'L' interleaver. Due to the error floor in CCIR Poor channels, the 10^{-5} BER standard requirements are compared with 95%

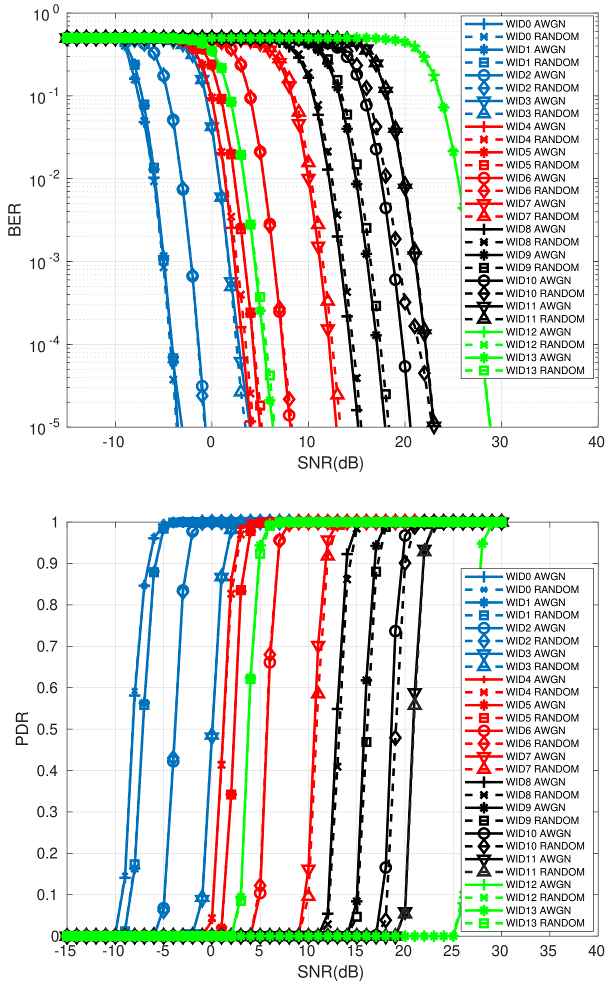

Fig. 7. BER and PDR performance of 4G-HF on AWGN and random channels

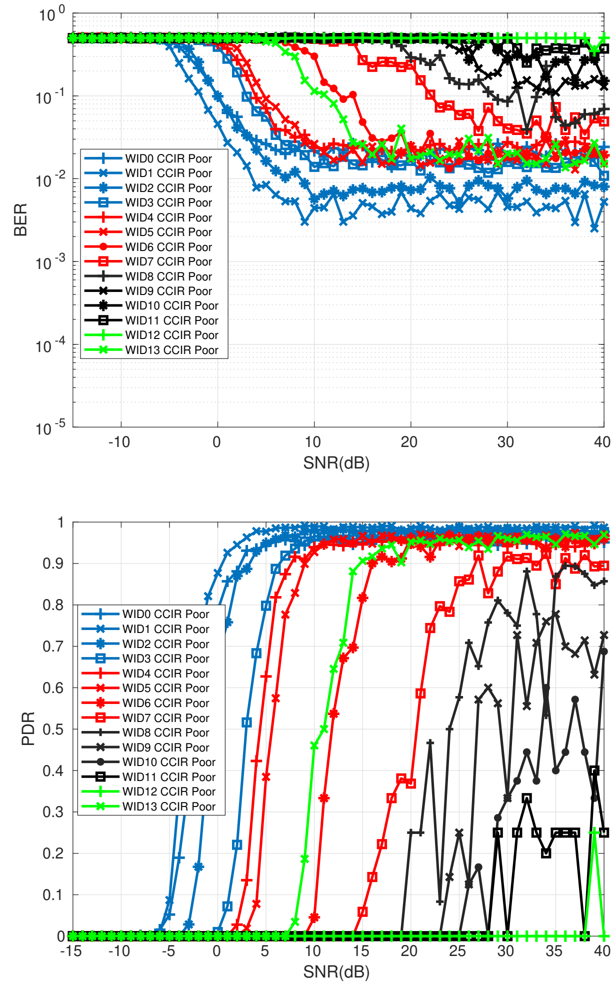

Fig. 8. BER and PDR performance of 4G-HF on CCIR 'Poor' channels

PDR for the implementation. It can be observed that BPSK and QPSK waveforms (WID0-6, WID13) are the best choices to cope with 'Poor' channels with time and frequency offsets using the proposed receiver.

Figure 9 shows the BER and PDR performance vs SNR of HF-XL with the low-complexity generic receiver on AWGN and random channels with 1 frame interleaver (Ultra Short). It can also be observed that there is no loss of performance on random channels in comparison with AWGN owing to the time, frequency and phase synchronization algorithms.

Figure 10 shows the BER and PDR performance vs SNR of HF-XL with the low-complexity generic receiver on CCIR 'Poor' single and multiple (16) channels with 1 frame interleaver (Ultra Short). It can be observed that for DD-LMS DFE BPSK and QPSK waveforms offers the best performance while there is a degradation in performance from 8-PSK to 64-QAM.

Table III summarizes the performance of HF-XL with the low-complexity generic receiver with TFO and 1 frame interleaver (Ultra Short) in comparison with standard requirements with 72 frames interleaver (Very Long). Due to the error floor in CCIR Poor channels, the 10^{-5} BER standard requirements are compared with 95% PDR for the implementation. It can also be observed that BPSK and QPSK waveforms are the best

TABLE II
COMPARISON OF REQUIRED SNR BETWEEN 4G-HF STANDARD REQUIREMENTS AND IMPLEMENTATION

Waveform/Channel	Gaussian(10^{-5})/ with TFO(10^{-5})	CCIR Poor(10^{-5})/ with TFO(95%)
0	-6/-3.5	-1/5
1	-3/-3.5	3/2.5
2	0/-0.5	5/5
3	3/3.5	7/9
4	5/4.5	10/11
5	6/5	11/11
6	9/8	14/18(90%)
7	13/13	19/23(80%)
8	16/15	23/27(65%)
9	19/18	27/31(72%)
10	21/20.5	31/35(40%)
11	24/23	-/40(25%)
12	30/28.5	-/40(0%)
13	6/6	11/15

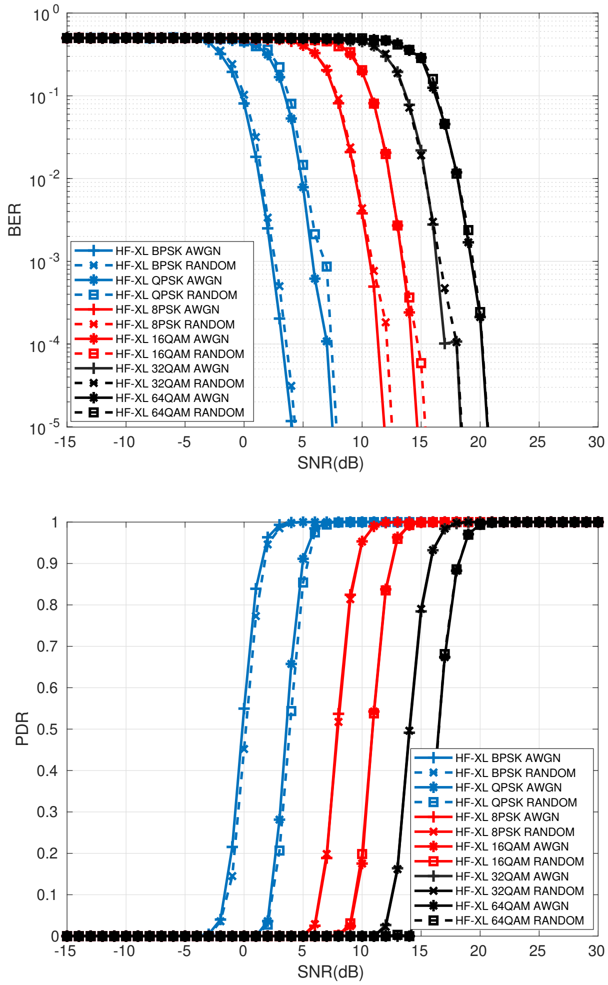

Fig. 9. BER and PDR performance of HF-XL on AWGN and random channels

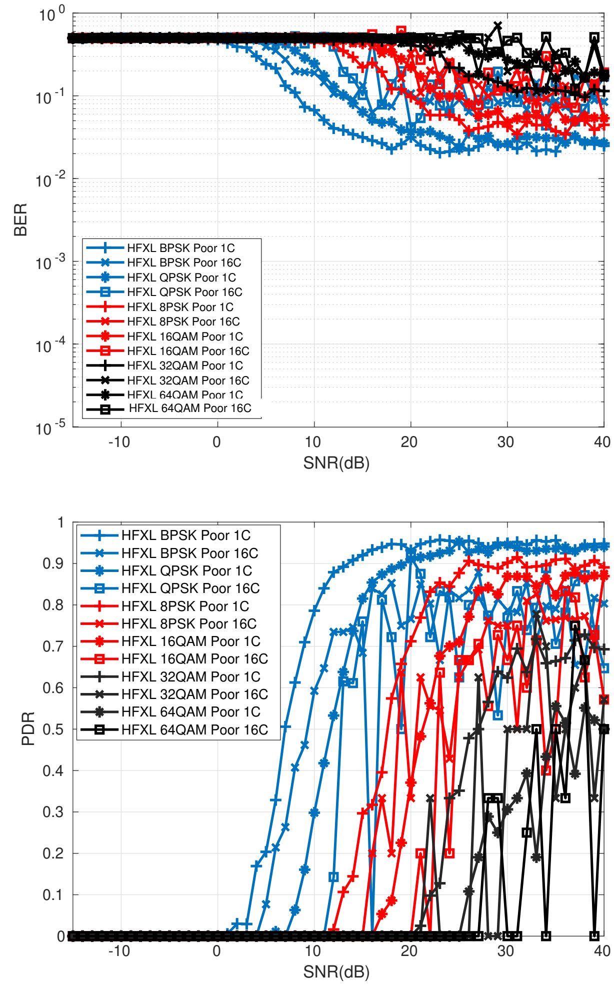

Fig. 10. BER and PDR performance of HF-XL on CCIR ’Poor’ single and multiple (16) channels

choices to cope with ’Poor’ channels with time and frequency offsets using the proposed receiver.

TABLE III
COMPARISON OF REQUIRED SNR BETWEEN HF-XL STANDARD REQUIREMENTS AND IMPLEMENTATION

Waveform/ Channel	Gaussian(10^{-5})/ with TFO(10^{-5})	Single-Channel CCIR Poor(10^{-5})/ with TFO(95%)	Multi-Channel CCIR Poor(10^{-5})/ with TFO(95%)
64-QAM	22/20.5	29/33(50%)	31/35(50%)
32-QAM	19/18.5	28/32(63%)	27/31(50%)
16-QAM	16/14.5	24/28(84%)	24/28(56%)
8-PSK	14/11.5	21/25(88%)	21/25(66%)
QPSK	9/7.5	15/19(90%)	18/22(72%)
BPSK	6/4	12/16(93%)	14/18(85%)

VI. IMPLEMENTATION ON GPP-BASED SDR

The low-complexity generic receiver minimizes and simplifies the receiver, which is important in military portable equipment. The different narrowband and wideband HF standards have been successfully implemented in C++ using open-source libraries (Qt, UHD, IT++, GStreamer) and are able to run in real-time on a laptop running Linux connected with USRP B205-mini software defined radios and Ham It Up for up/down-conversion to HF frequencies. A spectrum representations of 2G, 3G, 4G and HF-XL standards in the HF software with USRP B205-mini software defined radios is given in Figure 11.

The software has also been combined with an open-source implementation of STANAG 5066 [16], [17] for email transfer and a modified version for generic IP transfer. A software representations of the 2G-ALE with Open5066 for mail transfer is given in Figure 12.

The HF software and USRP B205-mini allow to perform the necessary handshakes and wideband sensing procedures of 4G-ALE as shown in Figure 13.

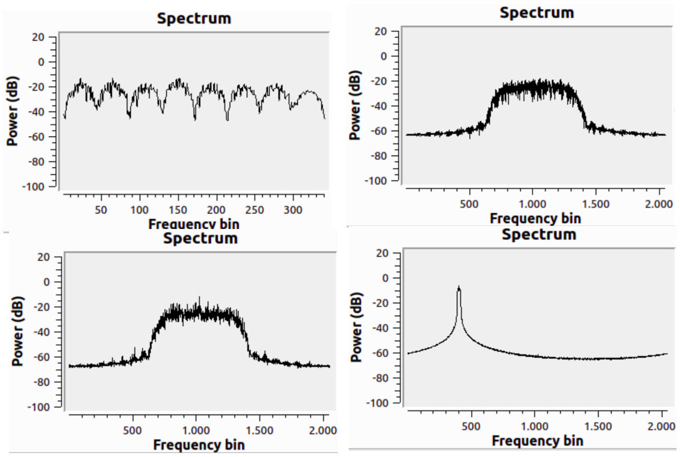

Fig. 11. Spectrum representations of 2G, 3G, 4G and HF-XL standards in the wideband HF software with USRP B205-mini software defined radios

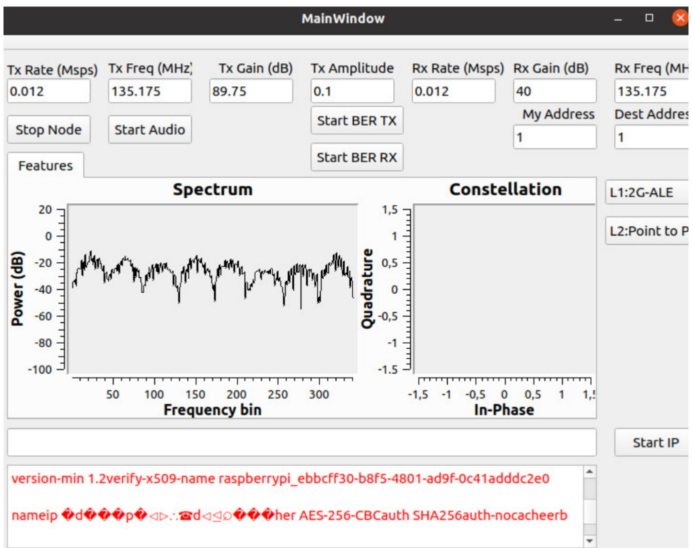

Fig. 12. Combination of the 2G-ALE with Open5066 for mail transfer

A. Possible improvements

Possible improvements of the implementation are turbo-equalization, iterative time-frequency-phase synchronization, and iterative channel estimation although it would require more computation time that could hinder the real-time capability of the GPP-based software.

Possible improvements to Open5066 and more generally to STANAG 5066 and 5070 are the channel access sub-layer and ARQ for frequency and rate adaptation of wideband HF waveforms.

Another possible improvement for 4G-ALE is to make it interoperable with HF-XL waveforms on 192 kHz bandwidth.

This implementation could also be tested with other implementations for interoperability and to improve the implementation, fix bugs etc. (e.g. Harris radios from Belgian Army, CWIX with other nations).

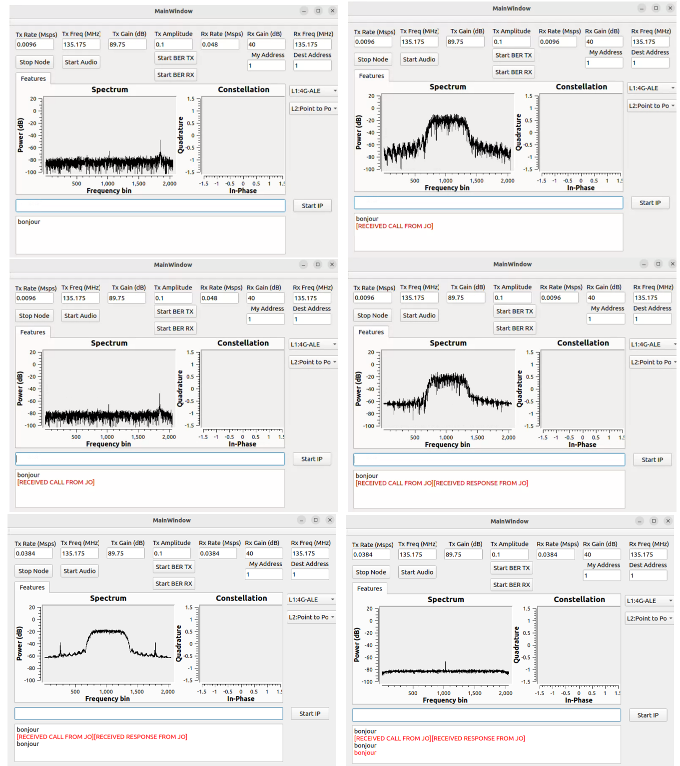

Fig. 13. 4G-ALE procedure

VII. Conclusion

This paper has described a low complexity generic receiver with channel estimation, time and frequency synchronization for 2G, 3G, 4G and HF-XL standards and a performance evaluation in terms of BER or PDR vs SNR on narrowband and wideband HF channel models. It is shown that time and frequency synchronization as well as channel estimation/tracking affect the performance of the receiver in case of multipath channels.

The implementation runs in real-time on a Linux laptop connected with USRP B205-mini software defined radios and Ham It Up for up/down-conversion to HF frequencies. The HF software and USRP B205-mini allow to perform the necessary handshakes and wideband sensing procedures of 4G-ALE. The software has also been combined with an open-source implementation of STANAG 5066 for email transfer and a modified version for generic IP transfer. Future improvements of the implementation have also been proposed.

Acknowledgements

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