GPP-SDR Implementation of a Low Complexity Generic Receiver for UHF SATCOM

Vincent Le Nir, Mathias Becquaert

***Abstract*—SATellite COMmunications (SATCOM) technology is essential for current and future military operations. This paper describes a low complexity generic receiver with time and frequency synchronization for the Ultra High Frequency (UHF) SATCOM standard and a performance evaluation in terms of Bit Error Rate (BER) vs Signal to Noise Ratio (SNR) on random channels. The UHF SATCOM standard has been implemented on a General Purpose Processor (GPP)-based Software Defined Radio (SDR) platform with open-source libraries and runs in real-time.**

***Index Terms*—SATCOM, Synchronization, Frequency Estimation, Phase Estimation**

I. Introduction

SATellite Communications (SATCOM) technology is essential for current and future military operations. The SATCOM technology can use large bandwidths for high throughput, directional antennas for low probability of detection, fast frequency hopping for anti-jamming, and low earth orbit sattelites for low latency.

Different SATCOM standards have been developed for the Ultra High Frequency (UHF), Super High Frequency (SHF), or Extremely High Frequency (EHF) bands. The UHF SATCOM standard (STANAG 4531) has been developped for 5 kHz and 25 kHz channels and operates in different weather conditions, foliage, mobility and other obstacles for teletype, low speed data, or voice [1].

Authors in [2] and references herein present receiver implementations for Shaped Binary Phase Shift Keying / Shaped Offset Quatrature Shift Keying SBPSK/SOQPSK Continuous Phase Modulation (CPM) signals for the UHF SATCOM standard. This paper describes a low complexity generic receiver with time and frequency synchronization and a performance evaluation in terms of Bit Error Rate (BER) vs Signal to Noise Ratio (SNR) on random channels. The low-complexity generic receiver minimizes and simplifies the receiver, which is important in military portable equipment. The UHF SATCOM standard has been implemented on a General Purpose Processor (GPP)-based Software Defined Radio (SDR) platform with open-source libraries and runs in real-time.

Section II gives a brief overview of the UHF SATCOM standard. Section III gives a description of the low complexity generic receiver used for the UHF SATCOM standard with time and frequency synchronization. Section IV gives a performance comparison of the UHF SATCOM standard in terms of BER vs SNR on random channels. Section V gives some details on the implementation of the UHF SATCOM standard on a GPP-based SDR platform.

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II. The UHF SATCOM Standard

As described in [1] and shown in Figure 1, the burst of length N_{tot} consists of a continuous wave (CW) signal of length N_{cw}, a (S)BPSK/(S)OQPSK/FSK pseudo-random sequence signal of length N_{prs} and a (S)BPSK/(S)OQPSK/FSK data sequence signal of length N_{ds}. The data bits are differentially encoded and can be encoded by a convolutional code with rate R=1/2, constraint K=7, generator polynomials (91,121), punctured in case of R=3/4, and modulated by (S)BPSK/(S)OQPSK/FSK depending on the modulation option.

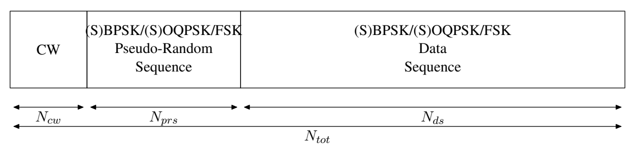

Fig. 1. Structure of the UHF SATCOM burst

III. Low complexity generic receiver for UHF SATCOM with channel estimation, time and frequency synchronization

A low complexity generic receiver for UHF SATCOM similar to the receiver depicted in [3] consists of joint coarse carrier frequency, phase and time synchronization, fine time synchronization, and Non Data Aided (NDA) fine carrier frequency and phase synchronization before (S)BPSK/(S)OQPSK/FSK demodulation, depuncturing, convolutional and differential decoding. Compared to [3] in which the NDA fine carrier frequency and phase synchronization is applied to the NATO Narrow Band Waveform (STANAG 5630 Ed. 1) bursts with partial response CPM, this paper applies the NDA fine carrier frequency and phase synchronization to the UHF SATCOM bursts with (S)BPSK/(S)OQPSK/FSK.

A. System Model

We consider a single-tap channel with time, frequency, phase offsets and additive white Gaussian noise (AWGN). The received signal $\{y(k)\}$ can be modeled as

$$y(k) \quad = Ae^{j(2\pi\alpha k+\phi)}x(k-\tau)+n(k) \qquad (1)$$

with A the complex-valued channel attenuation, τ the time offset, α the carrier frequency offset, ϕ the carrier phase offset, $x(k-\tau)$ the oversampled transmitted signal and $n(k)$ the AWGN with variance $N_0/2$ per dimension.

B. Joint coarse carrier frequency, phase and time synchronization

Joint coarse carrier frequency, phase and time synchronization is performed on the CW signal. The synchronization algorithm is an extension of the iterative frequency estimation algorithm by interpolation on Fourier coefficients described in [4] to take into account carrier phase and time synchronization. Let N_{cw} the number of samples of the CW signal, N_{tot} the total number of samples of the burst, $\hat{\alpha}$ the estimated carrier frequency offset with $\hat{\beta}$ the integer part of the estimated carrier frequency offset and $\hat{\delta}$ the non-integer part of the estimated frequency offset. The extended algorithm is described in Algorithm 1 with $N = N_{cw}$.

Algorithm 1 Joint coarse carrier frequency, phase and time synchronization algorithm

Loop : for all k, $y_k = [y(k) \dots y(k+N)]$

  Let $Y_k = FFT(y_k)$, $E_k(i) = |Y_k(i)|^2$, $i = 0 \dots N-1$

  Find $\hat{\beta} = \underset{i}{argmax}\ \ E_k(i)$

  Set $\hat{\delta}_0 = 0$

  Loop : for each i from 1 to Q

    $X_p = \sum_{n=0}^{N-1} y(n) e^{-j2\pi n \frac{\hat{\beta}+\hat{\delta}_{i-1}+p}{N}}, p = \pm 0.5$

    $\hat{\delta}_i = \hat{\delta}_{i-1} + \frac{1}{2} Re\left\{\frac{X_{0.5}+X_{-0.5}}{X_{0.5}-X_{-0.5}}\right\}$

  $X_{0,k} = \sum_{n=0}^{N-1} y(n) e^{-j2\pi n \frac{\hat{\beta}+\hat{\delta}_Q}{N}}$

  $\hat{\alpha}_k = \frac{\hat{\beta}+\hat{\delta}_Q}{N}$

Coarse time offset estimate : $\hat{\tau} = \underset{k}{argmax} |X_{0,k}|^2$

Coarse carrier frequency offset estimate : $\hat{\alpha} = \alpha_{\hat{\tau}}$

Coarse carrier phase offset estimate : $\hat{\phi} = arg(X_{0,\hat{\tau}})$

with Q a fixed number of iterations (Q=2 in the implementation). This algorithm searches for the time offset whose estimated iterative frequency offset has the maximum power. The carrier frequency offset estimate is the carrier frequency offset at the time offset estimate. The carrier phase offset estimate is the carrier phase offset of the CW signal at the time and frequency offset estimates.

C. Fine time synchronization

Fine time synchronization is performed on the addition of the CW signal and the (S)BPSK/(S)OQPSK/FSK pseudo-random sequence signal. A peak search of the correlation function between the received signal and a stored CW signal plus (S)BPSK/(S)OQPSK/FSK pseudo-random sequence signal around the estimated coarse time offset is performed. Assuming $N = N_{cw} + N_{prs}$, the optimization problem can be written as

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

with

$$r(k) = \frac{1}{N}\sum_{n=0}^{N-1} y(n+k)x^*(n) \quad k \in [\hat{\tau} - \frac{N_{cw}}{2} \dots \hat{\tau} + \frac{N_{cw}}{2}] \tag{3}$$

D. Non data aided fine carrier frequency and phase synchronization

NDA fine carrier frequency and phase synchronization is performed on the full (S)BPSK/(S)OQPSK/FSK signal.

We assume that the received signal is low-pass filtered to eliminate out-of-band noise and sampled at symbol rate $1/T$. As the received signal has a maximum of four constellation points, we propose to take the fourth power of the transformed signal $z(k) = \tilde{y}(i)^4$, and to apply the iterative frequency estimation algorithm [4] on the resulting signal. The algorithm is described in Algorithm 2 with $N = N_{prs} + N_{ds}$ and $z = [z(0) \dots z(N-1)]$.

Algorithm 2 Iterative frequency estimation algorithm NDA fine 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

  $X_p = \sum_{n=0}^{N-1} z(n) e^{-j2\pi n \frac{\hat{\beta}+\hat{\delta}_{i-1}+p}{N}}, p = \pm 0.5$

  $\hat{\delta}_i = \hat{\delta}_{i-1} + \frac{1}{2} Re\left\{\frac{X_{0.5}+X_{-0.5}}{X_{0.5}-X_{-0.5}}\right\}$

$X_0 = \sum_{n=0}^{N-1} z(n) e^{-j2\pi n \frac{\hat{\beta}+\hat{\delta}_Q}{N}}$

Finally, the NDA carrier frequency estimate is given by $\hat{\alpha} = \frac{\hat{\beta}+\hat{\delta}_Q}{N}\frac{1}{4}$, and the NDA carrier phase estimate by $\hat{\phi} = arg(X_0)\frac{1}{4}$.

IV. Simulation results

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

Figures 2 and 3 show the BER performance vs SNR of 5 kHz and 25 kHz UHF SATCOM modulation options with the low-complexity generic receiver on random channels (random time, frequency and phase offsets are drawn for each trial with a constant amplitude). It can be observed that low data rate modulation options can operate a lower SNR than high data rate modulation options, corresponding to a range -7 dB/16dB SNR for 5 kHz and 8/17dB for 25 kHz. The use of a convolutional code allows to have a steeper BER slope at the expense of a higher SNR trigger point.

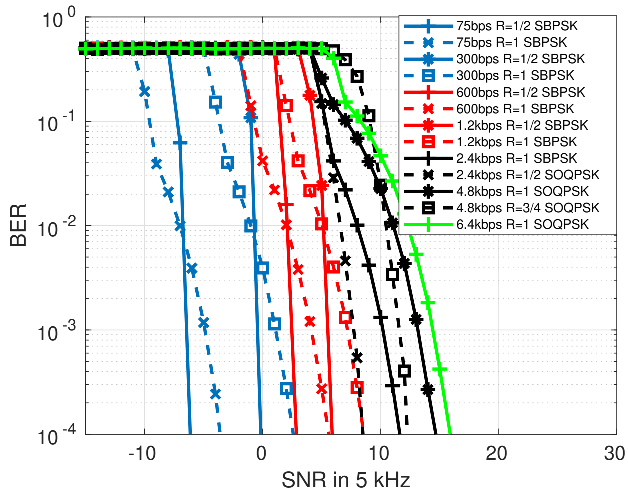

Fig. 2. BER performance of 5 kHz UHF SATCOM on random channels

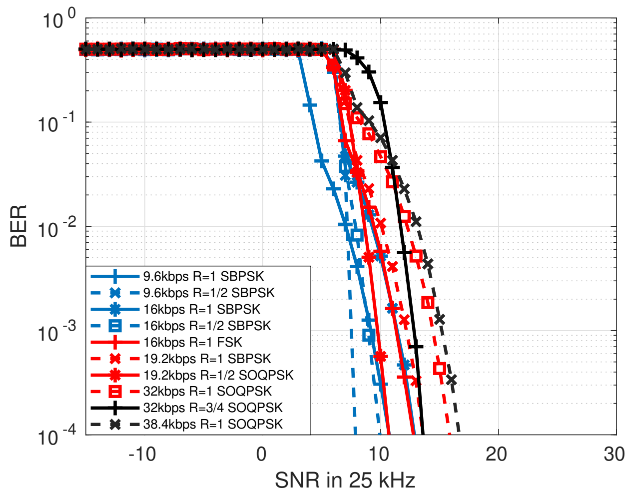

Fig. 3. BER performance of 25 kHz UHF SATCOM on random channels

V. Implementation on GPP-based SDR

The low-complexity generic receiver minimizes and simplifies the receiver, which is important in military portable equipment. The different UHF SATCOM modulation options 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. A spectrum representation of the UHF SATCOM standard in the SATCOM software with USRP B205-mini software defined radios is given in Figure 4.

VI. Conclusion

This paper has described a low complexity generic receiver with time and frequency synchronization for the UHF SATCOM standard and a performance evaluation in terms of BER vs SNR on random channels. It can be observed that low data rate modulation options can operate a lower SNR than high data rate modulation options and that the use of a convolutional code allows to have a steeper BER slope at the expense of a higher SNR trigger point. The implementation runs in real-time on a Linux laptop connected with USRP B205-mini software defined radios.

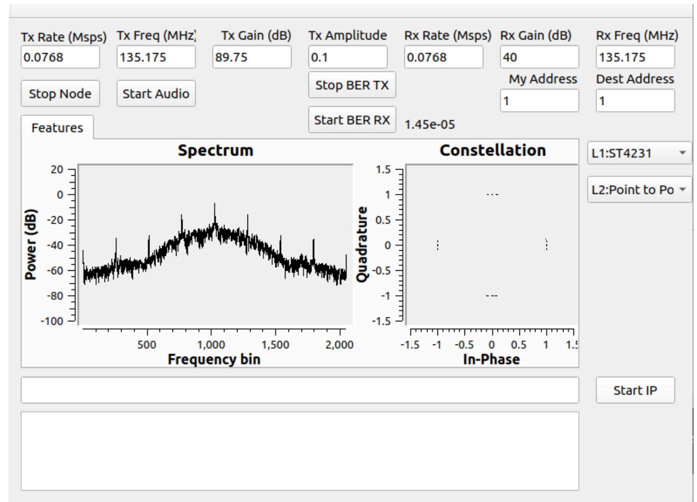

Fig. 4. Spectrum representation of the UHF SATCOM standard in the SATCOM software with USRP B205-mini software defined radios

References

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