A Software-Defined Radio Approach for the Implementation of Ground Station Receivers

Jyh-Ching Juang, Chiu-Teng Tsai, and Jiun-Jih Miau

Abstract As many pico-esats will be released in one launch, the closeness in spatial and spectral separation between different pico-sats may render problems for ground stations in satellite tracking. We implement a ground station receiver with software defined radio (SDR) approach to solve this problem. In the SDR, bandpass sampling is used to down convert RF signal. Single antenna interference cancellation (SAIC) technique with Maximum-Likelihood Sequence Estimator (MLSE) algorithm is used to cancel interference. Doppler shift for transmitter is estimated based on received signals. The SDR-based ground station provides a receiver capable of receiving multi-channel, flexible data rate, flexible modulation type, with co-channel interference (CCI) cancellation capability.

1 Introduction

Recently, many pico-sats and/or small satellites have been developed and planned to be launched to take advantage of short development time, miniature devices, standard launcher interfaces, and piggy-back launch opportunities. Many missions including collaborative earth observation can be realized through the design of pico-sats and their constellation. However, a problem associated with the pico-sat operations is that the communication frequencies, typically in the UHF/VHF band, are very close between two different pico-sats. As many pico-sats will be released in one launch, the closeness in spatial and spectral separation between different pico-sats may render problems for ground stations in satellite tracking, especially in the early orbit phase. Even when there is a contact, it may be difficult for a participating ground station to distinguish the satellite that is being pointed at by the ground

J.-C. Juang
Department of Electrical Engineering, National Cheng Kung University, Tainan, Taiwan
e-mail: juang@mail.ncku.edu.tw

C.-T. Tsai
Department of Electrical Engineering, National Cheng Kung University, Tainan, Taiwan

J.-J. Miau
Department of Aeronautics and Astronautics, National Cheng Kung University, Tainan, Taiwan

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station antenna. The station may have to resolve the desired signal out of a class of near-by interferences. Also, the frequency overlap due to Doppler shift, clock drift and operation error aggravate the tracking problem. Indeed, if the contact with a satellite is interrupted by such errors, the station may have to search the signal again, which is highly time-consuming. Giving the very limited contact time of LEO satellites, the tracking of a cluster of satellites may be extremely challenging.

Traditional ground station receivers are typically implemented by commercial amateur radios. The signal received is down converted to intermediate frequency (IF) by mixers and demodulated by a TNC modem. Then, ground station PC deals with the digital signal to decode the telemetry information. The architecture's weakness is that the channel number is limited to be one or two channels per receiver. And the modulation method and data rate is often fixed. If a user wants to change the capability of a ground station, change of hardware, either through installation of new equipment or tuning of dials/buttons, is necessary. Such a hardware approach may be costly and inflexible to operate. These situations need to be improved in order to have better mission performance. A feasible strategy is to employ a software-defined radio (SDR) approach to implement the ground station receivers. In this paper, a SDR architecture is proposed and developed. The resulting ground station receiver constitutes an antenna, A/D converter and processing software to acquire, process, and decode radio signals. The key for the successful acquisition and tracking of multiple radio signals lies in the use of processing software. In the paper, the processing software is described and its performance against conventional receivers is assessed.

2 Architecture

2.1 Hardware

Figure 1 shows the architecture of the SDR-based receiver. One antenna receives the RF signals. Broadband selective antenna is suitable to receive several satellite bands and reject other bands. An antenna with amateur radio VHF/UHF and ISM 2.4GHz band is considered. Due to weak signal and system noise factor, an LNA is put near to the antenna output port as possible. Then, a filter is designed to suppress noise and prevent aliasing. The A/D converter digitizes the incoming signals into digital samples. This differs from the conventional approach in which mixers and down-converters are used to render IF signal. Conventional ground stations process intermediate frequency (IF) signal and decode by a TNC modem. The SDR-based receiver performs the remaining signal reception and processing tasks using software in a computer.

2.2 Signal Processing Procedure

The RF signal from satellites must be down converted to IF signal. Instead of using mixers, the SDR-based receiver utilizes A/D converter and band pass technique

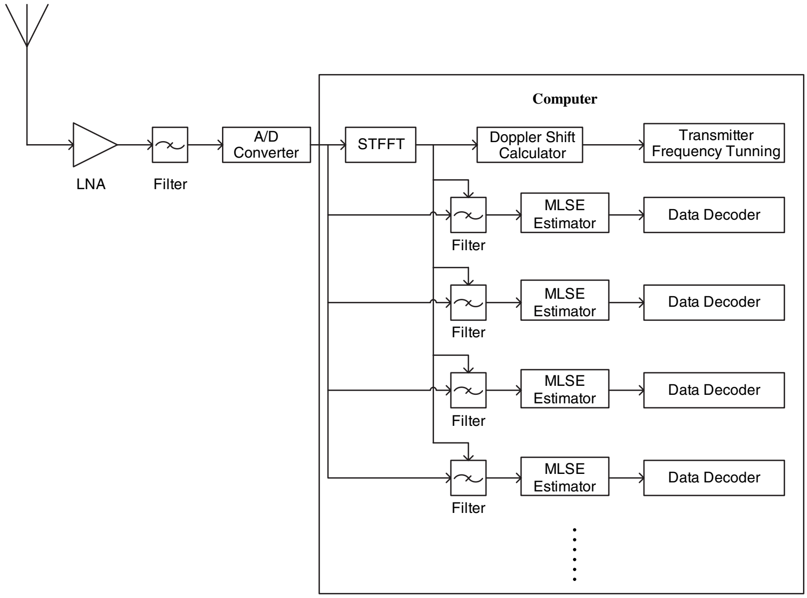

Fig. 1 Architecture of the SDR-based ground station receiver

[1, 6]. The latter allows the use of a low sampling rate device to process high frequency signals. In the approach, the sampling frequency is selected as 20 MHz so as to accommodate different frequency and the associated Doppler variation of different satellites with a communication frequency in the range of 140∼150 MHz and 430∼440 MHz.

The digitized IF samples that are available at the A/D converter output may consist of signals from a cluster of satellites together with noise and interferences. A software processing algorithm is needed to extract the signal from a certain pico-sat. Because the bandwidth is wider in SDR than that in traditional receivers, the noise effect in SDR is also more severe. For a certain signal, other pico-sats' signals and other illegal amateur radio users' signal are regarded as interferences. As a result, the interference issue can not be neglected.

A Short-Time FFT (STFFT) is used to track the variation of the frequency as a function of time. The width of the Short-Time FFT window needs to be well-considered to have a suitable frequency resolution and time resolution. STFFT with wider window has better frequency resolution and worse time resolution; in contrast, STFFT with narrower window has better time resolution and worse frequency resolution. As the Doppler shift due to satellites is not fast, the time resolution is specified as 10 second. The frequency resolution becomes 100 Hz, given the aforementioned sampling frequency. Through the STFFT, the spectrum can be obtained. If the strength of the signal at a certain frequency is greater than the threshold, a signal is detected. Consequently, the frequency information, includes the frequency variation of each working channel, can be utilized to form the digital window and execute the tracking loop. In parallel, several digital filter windows are implemented to suppress the noise. The center frequency of each filter window is the same as every peak's frequency in the spectrum. And the bandwidth of every filter window is 20 kHz, the same as the bandwidth for the narrow frequency modulation communication in amateur radio band.

As a cluster of satellites are in presence, the frequencies of two or more channels may overlap occasionally. In addition, illegal ground-based users may interfere the channel. The co-channel interference (CCI) increases bit error rate (BER) significantly [3, 9]. CCI can be cancelled by the single antenna interference cancellation (SAIC) technique [5, 7] for ground stations with one antenna only, or by implementation multi-input multi-output (MIMO) technique [8] at ground stations with multi antennas. The Maximum-Likelihood Sequence Estimator (MLSE) algorithm [2] is known to be capable of handling CCI in SAIC. The desired signal under interferences can be represented as

$$r[k] = A_1[k]e^{j\theta_1[k]} + A_2[k]e^{j\theta_2[k]} + N[k] \tag{1}$$

where $A_i[k]$ and $\theta_i[k]$ is the amplitude and phase of the i-th signal at time kT_s, respectively. T_s is the sampling period. The Viterbi estimation method [4] is used to determine the maximum likelihood estimate of $(\theta_1[k], \theta_2[k])$. The computation trellis has 64 states, and the trace back depth is 32. Although this method cannot cancel the interference perfectly, the BER has been improved. Figure 2 depicts the successive CCI cancellation architecture.

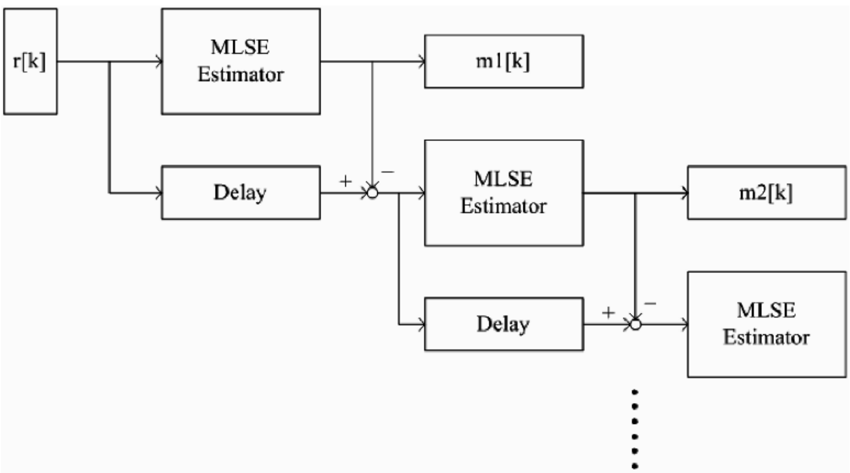

Fig. 2 Successive CCI cancellation architecture

After the interference cancellation stage, the signal output from the MLSE estimator is decoded as digital code, 1 or 0. The data stream from the satellite is then be obtained.

3 Simulation Result

To assess the interference cancellation performance, simulations are performed. The condition of the simulation assumes that the IF is 1 MHz with 1200 bps AFSK signal. Figure 3 shows the simulated BER at IF 1 MHz with 1200 bps AFSK signal, without Doppler shift. Figure 4 further shows the simulated BER at IF 1 MHz with 1200 bps AFSK signal and Doppler shift with variation 20 Hz per second. The Doppler shift condition is selected for usual pico-sat tracking condition.

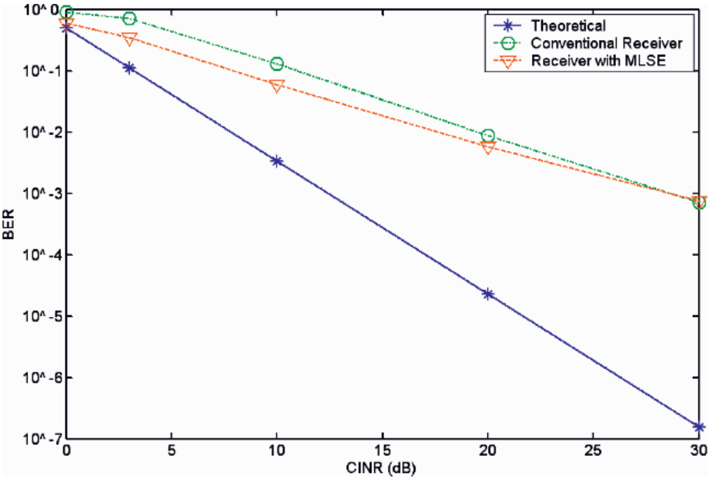

Fig. 3 Simulated BER without Doppler shift

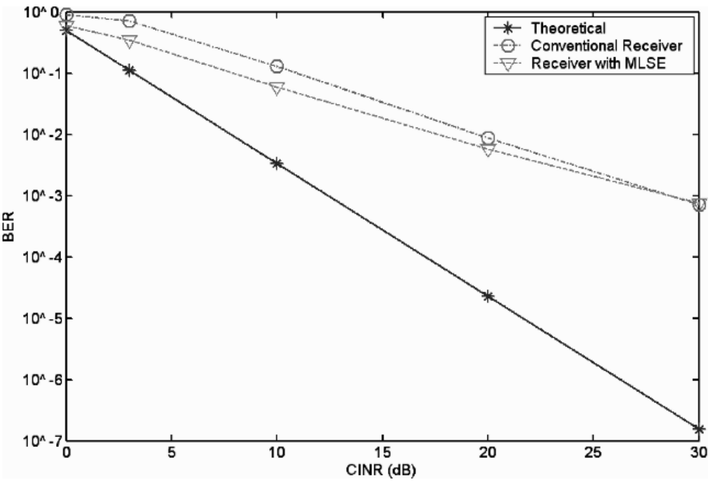

Fig. 4 Simulated BER with Doppler shift

The simulation results entail that the proposed CCI scheme running under as SDR architecture is capable of reducing the effect of interferences on signal reception in the presence or absence of Doppler shifts. The performance enhancement is more significant when the signal to noise and interference ratio is low.

4 Conclusion

The benefits of SDR in terms of programmability and flexibility are widely known. Indeed, SDR-based receivers can change channel number and modulation method by just changing the software. The communication band can be changed by tuning the sampling rate of SDR's A/D converter. SDR can also deal with several different bands at the same time. All these changes can be achieved without hardware modification. The paper has attempted to explore this advantage to build a SDR-based ground station receiver so that a cluster of pico-satellites can be successfully tracked especially in early orbit phase. In particular, an interference cancellation approach is adopted in the SDR to reflect the scenario when the frequency band is occupied with interferences. As a result, users can enjoy a ground station capable of multi channel, multi data rate, flexible architecture, low cost and lower BER.

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