Real-Time DSP-Based Carrier Recovery with Unknown Doppler Shift

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ABSTRACT

In order to make use of the time between scheduled services on NASA's Space Network (SN), a demand assignment, multiple access (DAMA) service has been proposed. In our design for this service, the SN does not know the position of the spacecraft prior to reception of the incoming communication signal and therefore cannot estimate the Doppler shift associated with the carrier. Therefore a modification to the current SN receiver is required for carrier recovery of the incoming signal under unknown Doppler-shift. In this paper, we describe a prototype system (based around the Motorola DSP56303) for real-time carrier recovery with unknown Doppler shift.

1. INTRODUCTION

NASA operates the Tracking and Data Relay Satellite System (TDRSS) (composed of six satellites each known as a TDRS) within the Space Network (SN) to provide telecommunication services between low earth orbiting spacecraft and NASA/customer control and/or data processing facilities. Customer forward data is uplinked from the ground segment to the TDRS and from the TDRS to the customer spacecraft. Customer return data is downlinked from the customer spacecraft via the TDRS to the ground segment and then on to the customer designated data collection location. TDRSS/SN services are typically scheduled days in advance. A Demand Assignment (DA) service has been proposed for customers of TDRSS/SN in response to requests for a simpler, more convenient, and more timely method of scheduling TDRSS support services. With the DA service in place, TDRSS multiple access (MA) services will be able to be scheduled in near real time [1].

The Center for Space Telemetering and Telecommunications at New Mexico State University is currently studying an alternate approach to the NASA/Goddard Space Flight Center design for the DAMA service. Our proposal for small-satellite access of the SN entails the use of a fixed, body-mounted antenna on a spin-stabilized satellite. As the satellite sweeps past a TDRS, data transmission is started and sustained for the pass duration without active antenna pointing by the satellite [2]. Integration of this concept with a DAMA service could provide low-power, low data rate services to a user [3]. Both the prescheduled MA service and DAMA service employ spread spectrum communications. We will assume that the chip rate of the DAMA user is much less than that of the other prescheduled MA users so that the DAMA carrier (spectrum) would be detectable against the white-noise-like spectrum of the MA users [4].

The nature of the DAMA service as implemented with a global beacon as described above, prohibits the SN from knowing the position of the spacecraft a priori and therefore estimating its Doppler-shifted carrier frequency. Theoretical calculations have indicated that this shift may be up to ±64kHz which exceeds the ±3kHz that the ground station receiver (GSR) can currently accommodate [5]. Therefore some method of real-time frequency estimation must be employed as a front-end to the GSR if the proposed system is to have minimal impact to the GSR at the

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White Sands Complex. This paper examines a low-cost, highly flexible DSP-based prototype of such a system which employs classical techniques for frequency estimation.

2. SIMULATION RESULTS

In the proposed service, the DAMA carrier will be located in frequency at the first null in the TDRS spectrum (2287.5MHz + 6MHz) as in Fig. 1 which for illustrative purposes does not show spread spectra. For the DAMA service, we assume binary phase shift keying (BPSK) modulation with a data rate R_b = 1k bits per second and a chip rate, R_c = 10k chips per second. Assuming a main lobe bandwidth of 200kHz in the frequency-shifted DAMA spectrum and up to a ±64kHz Doppler shift, frequency estimation occurs over a 328kHz bandwidth and must be accurate to within ±3kHz (Fig. 2). Fig. 3 illustrates a typical DAMA power spectrum (Doppler-shifted and spread) for the above parameters. We employ a windowed Discrete Fourier Transform (DFT) implemented with the Fast Fourier Transform (FFT) along with peak detection on the magnitude squared of the FFT to determine the carrier frequency. Extensions to this include short-time spectral averaging prior to peak detection.

In order to determine the accuracy of the proposed frequency estimator, simulations were performed using the following design technique/parameters. The frequency of the carrier is 164kHz (typical of a DAMA request after required bandpass filtering and frequency-shifting) and assumes a positive Doppler shift equal to 32kHz (50% of the calculated maximum positive shift). We simulate the presence of MA users and channel noise with additive white Gaussian noise (AWGN) for various signal-to-noise ratios (SNRs). Finally, for the given R_b, R_c, and a sampling rate, f_s = 1MHz, the FFT is performed over a block of N = 4096 samples which provides desired accuracy as described next.

Fig. 4 illustrates histograms of the frequency estimates along with the actual frequency (center dotted line) and the desired estimation range (outer dotted lines) for various SNRs. For each SNR, 10,000 estimates were performed. From these histograms, we can compute the proportion of estimates that lie within the desired estimation range. Fig. 5 illustrates the estimation accuracy for various SNRs. We see that for the given R_c the technique is 81-86% accurate over a –10dB - 10dB SNR range.

3. PROTOTYPE DESCRIPTION

We have developed a DSP-based prototype to implement the above approach for real-time, continuous frequency estimation on a limited bandwidth. The design uses a Motorola DSP56303 signal processor (303), a supplementary ADC/DAC, and a 64K SRAM. The idea in using a general-purpose DSP is two-fold: 1) low-cost digital implementation and 2) flexibility for future enhancements. These future enhancements might include estimates for multiple carriers and priority assignments, computation of averaged frequency estimates, and provision for a locking signal for the GSR. In this prototype, we assume the bandwidth over which to identify the carrier is 24kHz, a sampling rate of f_s = 48kHz, and N = 4096.

The flow diagram of the software for the 303 is shown in Fig. 6. The code makes use of a number of canned routines readily available for this processor. Benchmarks indicate frequency estimates are computed in approximately ten sample periods or 666μs at a clock speed of 80MHz on the 303. Measurements have shown this system to be accurate over the full bandwidth down to a SNR of approximately –4dB.

4. SYSTEM DESIGN

From simulation results, we must base the frequency estimate over a 4096 sample block to achieve desired accuracy.

Assuming f_s = 1MHz, approximately L = 53,273 program instructions must be executed to produce the estimate (see Fig. 6 for instruction count), and the estimate must be formed before the next date vector is acquired, we can compute the necessary processing speed as

$$\begin{aligned}\mu &\geq \frac{f_s}{N} L \\ &= 13 \text{ mips}\end{aligned} \quad . \qquad (1)$$

The necessary processing speed (1) is well within performance limits of the 303 even with additional overhead taken into account. The 303 will deliver its frequency estimate to the GSR either as a locking tone at the estimated frequency (or some fraction of it) or as voltage proportional to the estimated frequency with the intention of driving a voltage controlled oscillator.

5. CONCLUSIONS

In our proposal for the Demand Assignment, Multiple Access service for small satellite access of the Space Network, accurate estimation of the Doppler-shifted, spread spectrum carrier frequency is required since location of the satellite is not known a priori. We have developed a DSP-based hardware/software prototype system to estimate carrier frequencies (using a windowed DFT) to within the resolution required for the Ground Station Receiver. Estimation of this carrier is possible only if the chip rate of the DAMA user is much less than that for the MA user. Using this approach we open up the possibility for additional features which might prove useful for the DAMA service while still minimizing the impact on the GSR.

REFERENCES

[1] TDRSS Online Information Center. http://www530.gsfc.nasa.gov/tdrss/ May 1997.

[2] S. Horan, T. Minnix, and J. Vigil, "Small satellite access of the space network," accepted for publication to *IEEE Transactions on Aerospace and Electronic Systems*, 1996.

[3] S. Horan, "An operational concept for a demand assignment multiple access system for the space network," *Proc. of the 1996 International Telemetering Conference* vol. XXXII.

[4] L. Couch II, *Digital and Analog Communication Systems*. Upper River Saddle, NJ: Prentice-Hall, 1997.

[5] M. Sanchez, "Doppler extraction for a demand assignment multiple access service for NASA's space network," *Proc. of the 1996 International Telemetering Conference* vol. XXXII.

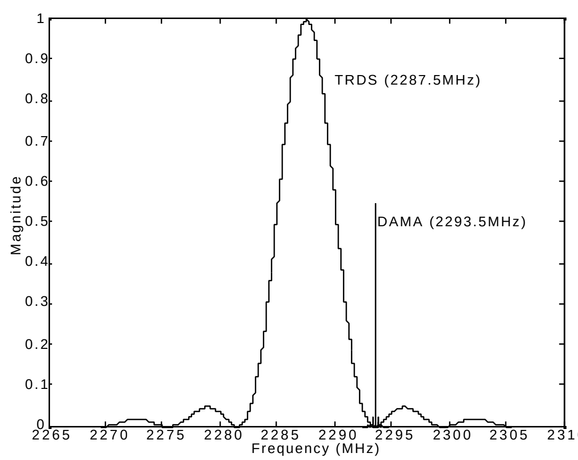

Fig. 1: Proposed spectral location of DAMA request.

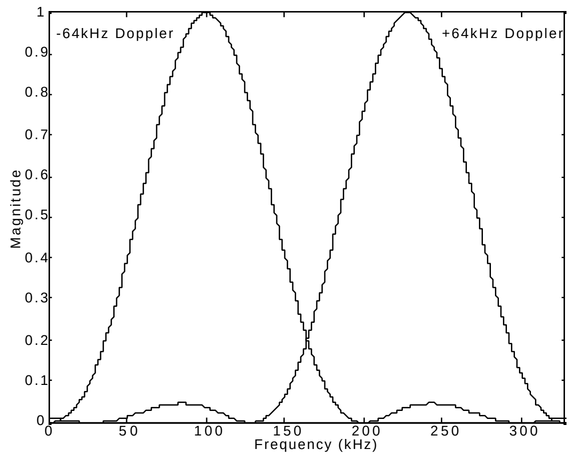

Fig. 2: Doppler-shifted DAMA signal spectrum.

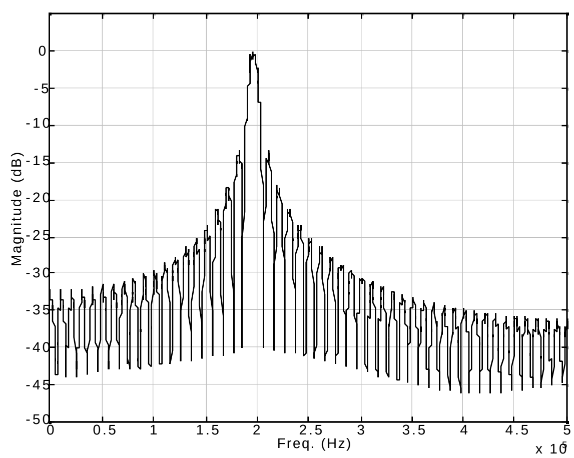

Fig. 3: Average DAMA power spectrum (Doppler-shifted and spread)

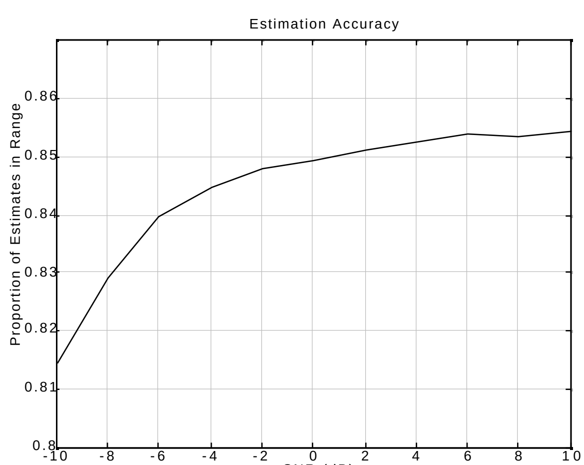

Fig. 5: Estimation accuracy for various SNRs

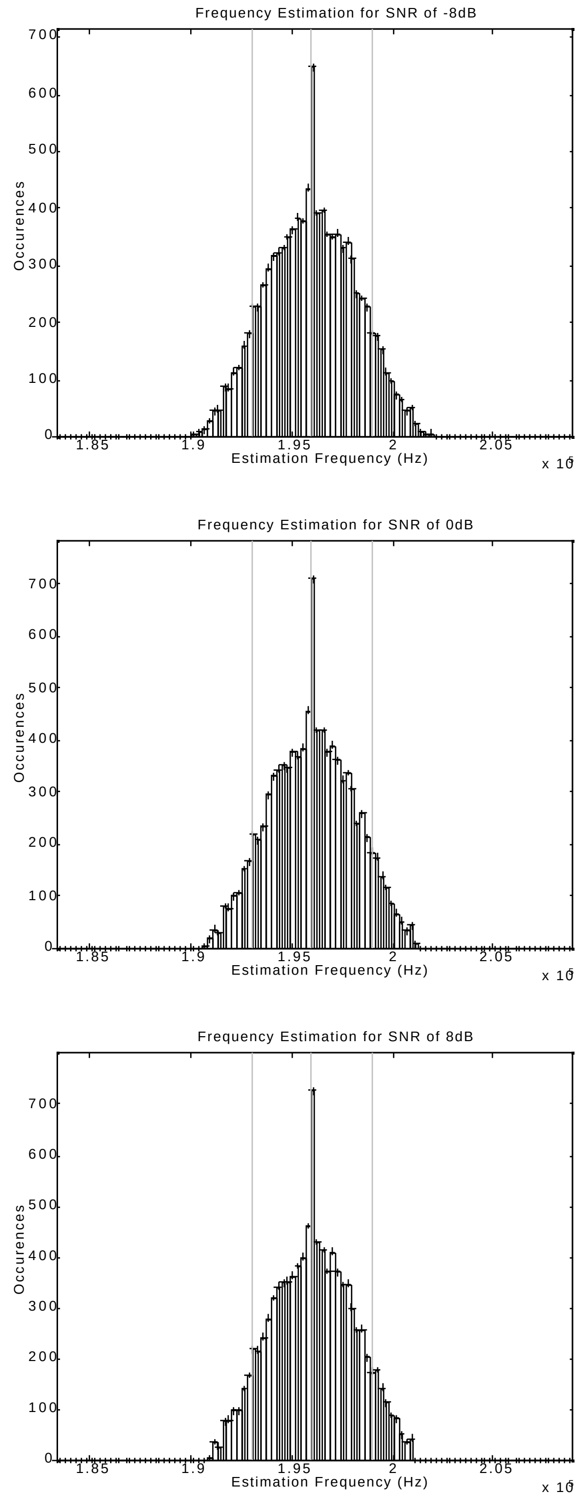

Fig. 4: Estimation histograms for various SNRs

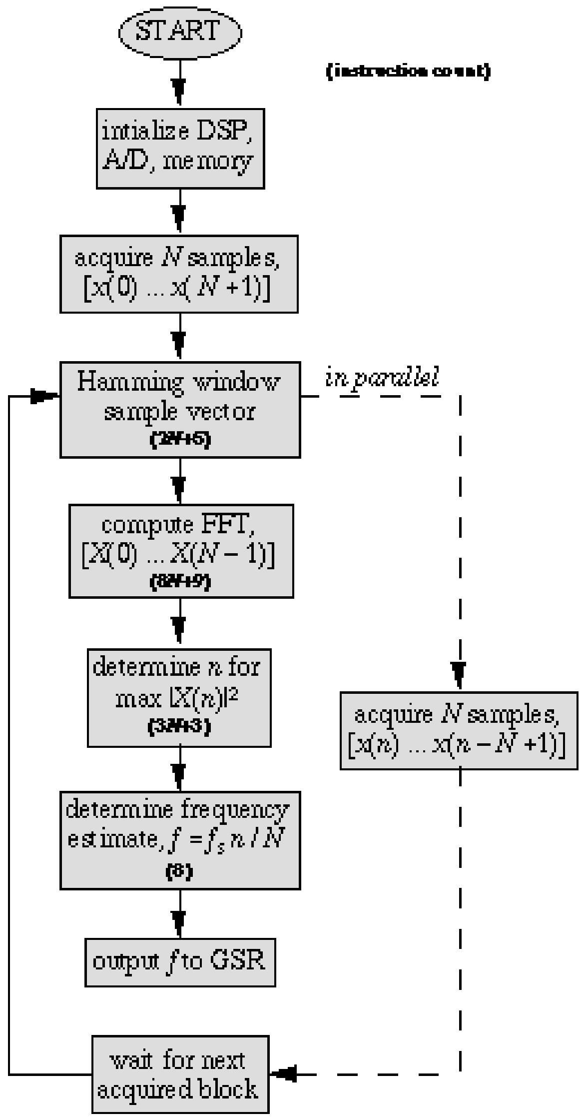

Figure 6: Flow diagram of Motorola DSP56303 software for frequency estimator