Astropulse: A Search for Microsecond Transient Radio Signals Using Distributed Computing
1. Introduction

2. Telescope and Hardware

2.1. Sky Coverage

Arecibo Observatory (figure 1) scans approximately \( \frac{1}{3} \) of the sky, between declinations of \(-1.33\) and \(38.03\) degrees (figure 2). Because of this, Astropulse cannot see the galactic center (around \(-29\) dec) but can see 452 out of the 1826 pulsars in the ATNF pulsar database\(^1\), including the Crab.

2.2. ALFA Receiver

The ALFA receiver (figure 3) has 7 dual-polarization beams on the sky arranged in a hexagonal pattern, each with a 3.5′ beamwidth. The central beam has a gain of 11 K / Jy, and the other beams have 8.5 K / Jy. The system temperature is 30 K.

2.3. Downconverter

Multiple experiments use the signal from the ALFA receiver, so we split the signal using an IF splitter. The splitter outputs are labelled 0A, 1A ... 6A, 6B (figure 4). The letter corresponds to polarization, and the number corresponds to one of the seven ALFA feeds (or beams.) These 14 signals are attenuated by 6 to 13 decibels, and then enter our multibeam quadrature baseband downconverter. Our downconverter has 16 inputs, so at this point two dead (grounded) signals are introduced.

The downconverter translates the signal down by some frequency $\nu_0$, so that our 2.5 MHz bandwidth will be centered at 0 MHz. We would like a mathematical operation that sends $\cos \nu t$ to $\cos (\nu - \nu_0)t$, but no such operation exists. (To see this, note that if we translate $f(t) = \cos 2\nu_0 t$ “down” by $\nu_0$, we should get $\cos \nu_0 t$. If we translate $g(t) = \cos -2\nu_0 t$, then according to our rule, we are supposed to get a different result,

\footnote{http://www.naic.edu/alfa/gen_info/info_obs.shtml}
cos \(-3\nu_0 t\). But the cosine is an even function, so \(f(t) = g(t)\), and the two results should have been the same. Note that physical processes which shift frequencies of real functions, such as Doppler shifts, do not modify frequencies by adding or subtracting a constant amount, though they might multiply by a constant.

Instead, we consider our signal to be complex, and multiply by \(e^{-i\nu_0 t}\). This means that we make a copy of the signal, multiply the first copy by \(\cos \nu t\) and call it the “real part”, and multiply the second copy by \(-\sin \nu_0 t\) and call it the “imaginary part”. The multiplication is performed by an NEC UPC2766GR chip. The effect of the downconversion on \(\cos \nu t\) is:

\[
\begin{align*}
(\cos \nu t) \cdot e^{-i\nu_0 t} &= \frac{1}{2} (e^{i\nu_0 t} + e^{-i\nu_0 t}) \cdot e^{-i\nu_0 t} \\
&= \frac{1}{2} (e^{i(\nu-\nu_0)t} + e^{-i(\nu+\nu_0)t})
\end{align*}
\]

So, assuming \(\nu \approx \nu_0\), the second term can be removed by a low pass filter (linear technology LT C1560-1), and we’re left with a single complex Fourier component at the desired frequency. At this point, we have 32 real signals (or 16 complex signals), of which 4 (or 2) correspond to dead RF inputs. The original real-valued signal had two components.
(sine and cosine) at each frequency from $\nu_0 - B/2$ to $\nu_0 + B/2$, where $B$ is the bandwidth. Our complex signals also have two components (real and imaginary) at each frequency from $-B/2$ to $B/2$.

### 2.4. DDA Cards

These 32 real channels are directed through ribbon cables to the Digital Data Acquisition (DDA) cards on a Dell PC. RF inputs 1 through 8 go to DDA card number 1, and RF inputs 9 through 16 go to DDA card number 0. Each EDT card reads 16 bits of data at a time; one real and one imaginary bit for each of 8 complex channels.

### 2.5. Data Recorder

The 32 channels are directed to a Dell PC running our datarecorder2 program. In addition to reading this data, we read telescope coordinates from the Arecibo telescope’s data broadcast network, SCRAMnet. The coordinates consist of the Right Ascension (RA) andDeclination (Dec) to which the telescope is currently pointing, as well as the time for which that RA and Dec are valid from SCRAMnet. As output, the datarecorder2 program creates both quicklook files and ordinary data files. A quicklook file contains only one EDT card, whereas an ordinary data file may interleave data blocks from both EDT cards.

An ordinary data file is composed of “blocks” written to disk, each of which has a 4096-byte header followed by a $2^{20}$-byte data segment. The blocks are in groups of 128 blocks, each group coming from a single EDT card. Within each data block, each word of data corresponds to one time sample. A word is composed of the 16 EDT bits, numbered
The data recorder is running intel, therefore it is a little-endian machine. So bits 0-7 reside in the first byte of a word, and bits 8-15 reside in the second byte. The data files are stored on a hot swappable SATA drive, which fills up in 5 to 7 hours of continuous use. Since we are taking data 1/3 of the time, we must swap out the SATA drive about once per day.

### 2.6. Arrival at Berkeley

The staff at the Arecibo Observatory swap the drives out when they are full. When enough drives have been collected, they ship the drives to us at Space Science Lab, UC Berkeley. We copy the files to static hard drives located at Berkeley, wipe the SATA drives, and send them back to Arecibo. We use 20 SATA drives in all, each of which holds 500 or 715 GB. We also send a copy of each file to NERSC, the National Energy Research Scientific Computing Center. This ensures that we can retrieve the data at any time.

In all, we have taken over 100 TB of data from ALFA multibeam. We need a large (6 TB) disk array at Berkeley to buffer the data before it is sent to volunteers. The volunteers’ PCs then process the data and send the results back to Berkeley. For a discussion of data processing after this point, see Section ?? on BOINC, and Section ?? on the algorithm for the volunteers’ client program.
3. Algorithm: Client

4. Backend

5. Testing and Verification

6. Results and interpretation

7. Stardust@home

8. Suggestions for further research